ORIGINAL ARTICLE

# A Novel Technique Using Magnetic Resonance Imaging in the Supine and Prone Positions for Diagnosing Lumbar Adhesive Arachnoiditis: A Preliminary Study

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■ **Abstract**

*Background:* Lumbar adhesive arachnoiditis is a debilitating neuropathic condition and is difficult to diagnose owing to lack of definitive diagnostic criteria. By focusing on the intrathecal mobility of nerve roots, we assessed whether useful diagnostic criteria could be established using MRI.

*Methods:* Seventeen patients with a high risk for lumbar adhesive arachnoiditis and 18 no-risk patients with chronic low back pain and/or leg pain participated in this study. The patients underwent MRI in both the supine and prone positions. Eleven axial T2-weighted images between the L2 and L5/S levels were obtained, and the proportion of the low-intensity area in the dorsal half to the total low-intensity area in the dural sac was calculated for each axial view.

*Results:* At some lumbar levels, the low-intensity area in the dorsal half of the dural sac was relatively larger in patients with a high risk for lumbar adhesive arachnoiditis than in the no-risk patients. In the no-risk group, the proportion of the low-intensity area in the dorsal half in the supine position was significantly higher than that in the prone position at all lumbar levels. However, in the high-risk group, at some levels, the proportions were not significantly different in the dorsal half of the dural sac between the supine and prone positions.

*Conclusion:* In patients with a known risk for lumbar adhesive arachnoiditis, nerve roots lose their potential to migrate in the dural sac in the gravitational force direction on MRI. ■

**Key Words:** lumbar adhesive arachnoiditis, magnetic resonance imaging, chronic low back pain

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## INTRODUCTION

Lumbar adhesive arachnoiditis is a debilitating neuropathic condition. It had been diagnosed as tumors of the spinal cord or spinal meningitis, but it was first recognized as a separate disease entity in 1909, and some case-series reports have been published.[1–3] Many

types of injuries to intrathecal neural structures (eg, those induced by chemicals from oil-based contrast media used for myelography and local anesthetics used for spinal or epidural anesthesia; infections; blood in the CSF; and trauma resulting from needle tips, catheter insertion, and dural tears during spinal surgeries) can cause the condition.[4] Pathological changes associated with lumbar adhesive arachnoiditis include inflammatory cell infiltration and fibrous tissue outgrowth into the subarachnoid space; these changes result in a fibrous tangle, entrapping the lumbar and sacral nerve roots, and cauda equina, followed by neuropathic pain.[3–6]

The clinical presentation of lumbar adhesive arachnoiditis is complex. It usually presents as lumbar and leg pain and is sometimes accompanied by intermittent claudication, hypesthesia, and neurological deficits, such as incomplete motor paralysis, abnormal lower limb reflexes, and/or bladder and rectal dysfunction. These clinical features can result in an erroneous diagnosis of lumbar spinal stenosis, lumbar disc lesion, or compressive spinal cord lesion. In clinical practice, most physicians are probably unaware of lumbar adhesive arachnoiditis. Generally, laboratory and neurophysiological tests do not facilitate diagnosis.[7] Radiology is sometimes useful, and some radiological findings are characteristic of the condition.[7] Computed axial tomography myelography can reveal a homogeneous contrast pattern without root shadows; subarachnoid filling defects; or prominent, thick, and clumped nerve roots with narrowing and shortening of the thecal sac.[8] MRI can reveal the following changes: empty sac appearance, soft tissue replacing the subarachnoid space, conglomerations of nerve roots centrally in the dural sac, and adhesions peripherally tethering the nerve roots.[9,10] However, the precise relationship between the complex clinical symptomatology and pathological imaging findings has not yet been defined and validated. Therefore, clinical diagnosis of the condition remains challenging. The incidence of lumbar adhesive arachnoiditis is unclear owing to the lack of definitive diagnostic criteria; however, it is considered a relatively rare condition.

Nerve roots are usually located in the posterior half of the dural sac in the supine position[11]; however, in patients with lumbar adhesive arachnoiditis, they are located in the anterior half.[8] Generally, nerve roots have the potential to move in the gravitational force direction in the dural sac.[11] Because lumbar adhesive arachnoiditis is characterized by the dense deposition of collagen and the adherence of nerve roots to each other and the dural sac, we hypothesized that the condition is associated with a loss of nerve root mobility in the dural sac. Because arachnoiditis adhesions generally occur on the dorsal segments in most cases,[12] comparing the locations of nerve roots in the dural sac in the supine and prone positions could help evaluate nerve root mobility. By focusing on the intrathecal mobility of the nerve roots and cauda equina, we assessed whether useful diagnostic criteria for lumbar adhesive arachnoiditis could be established using MRI.

## METHODS

### Participants

Thirty-five patients who presented with the chief complaints of lumbar and leg pain were included in this study. All participants were outpatients at the Department of Anesthesiology and Pain Relief Center, The University of Tokyo Hospital. Table 1 presents the demographic and clinical characteristics of the patients.

No definitive diagnostic criteria were established for lumbar adhesive arachnoiditis. Instead, we divided the patients into the following 2 groups: (1) high-risk group and (2) no-risk group. The groups included patients with and without past histories of known risk factors for lumbar adhesive arachnoiditis (eg, lumbar spinal surgery, exposure to an intrathecal oil-based contrast agent, etc.), respectively.[4] The high-risk group comprised 17 patients with risk factors for the condition; 15 of those 17 patients had undergone lumbar spine surgery at least once, and the remaining 2 patients had intrathecally received an oil-based contrast agent. The no-risk group comprised the remaining 18 patients who had none of the above-mentioned risk factors but presented with lumbar spinal canal stenosis with lumbar and/or leg pain. We additionally investigated whether the patients in each group had MRI presentations, which

**Table 1. Demographic and Clinical Characteristics of the Patients**

| | High-risk Group ($n$ = 17) | No-risk Group ($n$ = 18) | $P$ Value |
|---|---|---|---|
| Male: Female | 7:10 | 5:13 | 0.40 |
| Age, mean years | 72 | 72 | 0.95 |
| BMI, mean kg/m$^2$ | 23.4 | 22.4 | 0.21 |
| NRS, mean score | 5.9 | 6.2 | 0.67 |
| CRP, mean mg/dL | 0.07 | 0.13 | 0.45 |

BMI, body mass index; CRP, serum C-reactive protein; NRS, 11-point numerical rating scale to assess pain.
$P$ values were obtained using the chi-squared test and Mann–Whitney test as appropriate.

are proposed, but not still validated, to be associated with susceptibility for lumbar adhesive arachnoiditis, with the aim of complementing the diagnosis of adhesive arachnoiditis. We used the following 3 typical axial MRI views in the supine position: (1) conglomerations of the adherent roots residing centrally with the thecal sac, (2) roots that are peripherally adherent to the meninges and conferring an empty sac appearance, and (3) a soft-tissue mass replacing the subarachnoid space.[10] The presence of these features was assessed in all the MR images of the participants, and we counted the numbers of participants in each group who had at least 1 of the 3 MRI presentations.

The Ethical Review Board of the Faculty of Medicine, the University of Tokyo, approved this study. This study was registered in our institute [ID: 3905-(5)]. The purpose and protocol of the study were explained to all patents, and informed consent was obtained from the patients prior to study initiation.

### MRI and Evaluation of the Intrathecal Mobility of the Nerve Roots and Cauda Equina

The patients underwent MRI in both the supine and prone positions, and axial views of T2-weighted images of the lumbar vertebrae and sacral bone were obtained. The intrathecal mobility of the nerve roots at the upper, middle, and lower vertebral levels from the 2nd to 5th lumbar vertebrae (L2 to L5) as well as the intervertebral levels between L2 and the sacral bone were assessed. Thus, the mobility was assessed at a total of 11 levels from L2 to the intervertebral level between L5 and the sacral bone (L5/S).

At each level, by referencing the inner bone edge of the lumbar spinal canal, the outline of the high-intensity area (ie, the dural sac = lumbar subarachnoid space) was manually mapped using the Data picker software that sets coordinate axes in image data and measures length and areas.[13] Based on the midpoint of the anteroposterior body–midline of the dural sac, the ventral and posterior halves of the dural sac were defined. Using Data picker, the low-intensity areas (ie, nerve roots and cauda equina) in the ventral and dorsal halves of the dural sac were separately measured (Figure 1). The proportion of the low-intensity area in the dorsal half to the total low-intensity area in the ventral and dorsal halves was then calculated at the 11 levels from L2 to L5/S. In addition, narrow grade[14] and sedimentation sign,[15–17] both of which have been reported as objective evaluations of lumbar spinal canal stenosis, were assessed in all patients in the supine position. The details of the narrow grade have been described in a previous study.[14] Briefly, the grading was as follows: Grade A, CSF is clearly visible inside the dural sac but its distribution appears inhomogeneous with sparse nerve roots and cauda equina; Grade B, the nerve roots and cauda equina occupy the entire dural sac but can still be individualized (some CSF is still present, giving the sac a grainy appearance); Grade C, the nerve roots and cauda equina cannot be individualized and the dural sac produces a homogeneous gray signal with no visible CSF signal (epidural fat is posteriorly present); and Grade D, no epidural fat is posteriorly present in addition to the nerve roots and cauda equina being nonrecognizable. The sedimentation sign was considered negative if the nerve roots and cauda equina rested dorsally in the dural sac and positive if the nerve roots and cauda equina conglomerated centrally in the dural sac rather than sedimented or rested posteriorly in the sac owing to gravity.[15–17] Because there was not

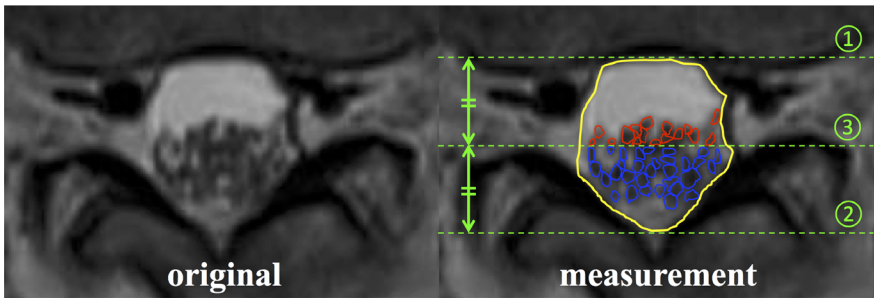


**Figure 1.** Measurements of the low-intensity areas in the ventral and dorsal halves in the lumbar dural sac. Focusing on lumbar MRI (T2-weighted images, axial view), we outlined the dural sac (yellow line) and defined the midpoint of its anteroposterior diameter (green dotted line). We measured the low-intensity areas in the ventral (red line) and dorsal (blue line) halves of the dural sac. We then calculated the proportion of the low-intensity area in the dorsal half of the dural sac to the total low-intensity area in the ventral and dorsal halves of the dural sac.

sufficient intrathecal space to move the nerve roots and cauda equina according to posture changes in patients with narrow grades B to D, we examined the sedimentation sign for respective lumbar axial images specified as narrow grade A. We compared the narrow grade and sedimentation sign with the proportion of nerve roots on the dorsal side of note; lumbar levels wherein the nerve roots and cauda equina were absent in the spinal canal were excluded.

Some MRI findings (ie, clumped nerve roots, empty sac appearance [roots peripherally adherent to the meninges], and deformities of the dural sac) have been proposed as the typical presentations of lumbar adhesive arachnoiditis.[7,8,10] However, these signs variedly emerge in patients with lumbar adhesive arachnoiditis; therefore, they are not established and validated as useful diagnostic symptoms. In particular, we assessed the mobility of the nerve roots and cauda equina in this study.

### Statistical Analysis

To evaluate the intrathecal mobility of the nerve roots and cauda equina within each patient group, the proportions between the supine and prone positions were compared using the Wilcoxon signed-rank test. The Mann–Whitney test was used to compare the proportions in both positions between the 2 groups. The chi-squared test was used to evaluate the severity of the spinal canal stenosis findings (ie, the narrow grade and sedimentation sign between the 2 groups). Spearman's rank correlation test was used to analyze the relationship between the proportions of the dorsal nerve root areas with the narrow grade or sedimentation sign within each patient group. In addition, the chi-squared test was used to evaluate the presence or absence of the classical MRI findings indicative of lumbar adhesive arachnoiditis. $P < 0.05$ was considered statistically significant.

## RESULTS

There were no significant differences in terms of the demographic characteristics between the 2 patient groups (see Table 1). Table 2 presents the intergroup findings between the supine and prone positions for each patient group, as well as the intragroup differences between these positions. At least 1 of the typical presentations of lumbar adhesive arachnoiditis (clumped nerve roots, empty sac appearance, or deformities of the dural sac) was observed in 8 of the 17 patients in the high-risk group but none in the no-risk group. In the no-risk group, the proportion of the low-intensity area in the dorsal half of the dural sac in the supine position was significantly higher than that in the prone position at all lumbar levels, indicating that intrathecal mobility of the nerve roots and cauda equine occurs in the gravitational force direction (see Table 2 and Figure 2). At the majority of lumbar levels in the high-risk group, there were significant differences between the 2 positions. There was also a significant difference at all levels in the high-risk group compared with that in the no-risk patient group. However, the proportion of the low-intensity area in the dorsal half of the dural sac in the prone position was comparable with that in the supine position at the L5 middle and L5/S levels (Figure 3).

**Table 2. Lumbar MRI Findings in Patients With and Without Known Risk Factors for Lumbar Adhesive Arachnoiditis**

| Level | Position | High-risk Group | No-risk Group | *P* Value† |
|---|---|---|---|---|
| L2 middle | Supine | 70.5 [52.6,84.7]**, ‡ | 72.8 [46.9,88.3]**, ‡ | 0.99 |
| | Prone | 22.7 [0.0,33.1]‡ | 0.9 [0.0,13.6]‡ | 0.12 |
| L3 middle | Supine | 81.6 [54.3,92.4]**, ‡ | 76.1 [59.4,91.8]**, ‡ | 0.81 |
| | Prone | 38.1 [2.3,50.4]‡ | 11.2 [0.0,32.5]‡ | 0.10 |
| L3/4 | Supine | 66.4 [44.3,79.6]**, ‡ | 70.1 [47.8,84.1]**, ‡ | 0.32 |
| | Prone | 22.7 [12.7,44.3]‡ | 11.1 [0.0,39.0]‡ | 0.06 |
| L4 upper | Supine | 70.9 [54.4,86.4]**, ‡ | 65.0 [47.3,83.4]**, ‡ | 0.56 |
| | Prone | 34.8 [18.7,51.8]‡ | 16.8 [2.4,32.8]‡ | **0.02** |
| L4 middle | Supine | 71.9 [54.1,79.3]**, ‡ | 71.0 [54.9,78.7]**, ‡ | 0.68 |
| | Prone | 44.4 [26.2,64.8]‡ | 14.0 [7.0,29.9]‡ | **0.01** |
| L4 lower | Supine | 67.7 [56.8,77.9]**, ‡ | 59.1 [50.5,72.4]**, ‡ | 0.49 |
| | Prone | 37.7 [23.4,60.4]‡ | 17.7 [11.3,42.8]‡ | 0.05 |
| L4/5 | Supine | 51.2 [42.7,69.7]*, ‡ | 49.8 [36.6,57.2]**, ‡ | 0.40 |
| | Prone | 30.5 [21.8,47.8]‡ | 23.0 [16.4,28.5]‡ | 0.08 |
| L5 upper | Supine | 50.6 [40.4,71.8]**, ‡ | 51.7 [46.7,64.6]**, ‡ | 0.99 |
| | Prone | 33.3 [22.0,44.4]‡ | 26.6 [15.6,43.2]‡ | 0.33 |
| L5 middle | Supine | 54.8 [43.3,70.1]‡ | 41.5 [32.4,51.2]**, ‡ | 0.07 |
| | Prone | 45.1 [30.0,58.5]‡ | 16.9 [2.0,28.7]‡ | **0.03** |
| L5 lower | Supine | 58.7 [37.1,70.3]**, ‡ | 45.9 [30.8,52.1]**, ‡ | 0.13 |
| | Prone | 30.7 [8.9,56.7]‡ | 23.5 [7.0,32.1]‡ | 0.28 |
| L5/S | Supine | 36.7 [32.9,47.7]‡ | 35.9 [23.8,47.4]**, ‡ | 0.69 |
| | Prone | 27.9 [6.6,49.7]‡ | 7.8 [0.0,29.1]‡ | **0.03** |

The values indicate the proportion of the low-intensity area in the dorsal half of the dural sac to the total low-intensity area in the dural sac. Data are presented as medians, with 25th and 75th percentiles, respectively, presented in brackets.
*P* values were obtained from the †Mann–Whitney test between 2 patient groups or the ‡Wilcoxon signed-rank test for intergroup comparisons (*$P < 0.05$, **$P < 0.01$).
Bold values is shown when there is a significant difference between the two groups in the same body position.

Comparing the 2 patient groups, in the supine position, no differences were observed in the proportions in the dorsal half of the dural sac at all lumbar levels (see Table 2). At the L4 upper, L4 middle, L5 middle, and L5/S levels in the prone position, compared with the no-risk group, the high-risk group displayed a larger proportion of low-intensity areas in the dorsal half of the dural sac (see Figure 3).

Regarding conventional imaging indices of lumbar spinal canal stenosis, no significant differences were

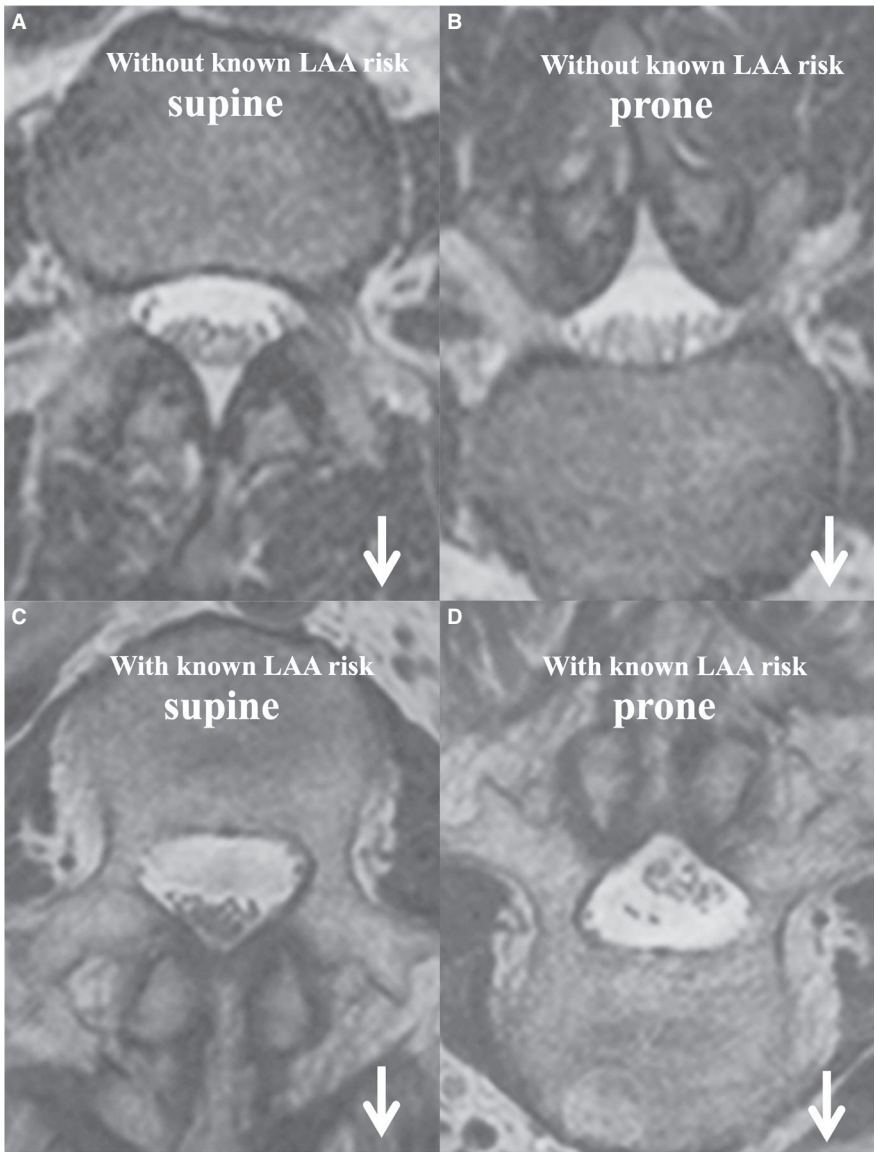


**Figure 2.** Demonstration of axial T2-weighted magnetic resonance images of the L4 middle level in the supine and prone positions in patients with or without known risk factors for lumbar adhesive arachnoiditis. The upper panels (A and B) are images from a single patient without known risk factors for the condition. The lower panels (C and D) depict the results for a single patient with a known risk factor (ie, lumbar spinal surgery) for the condition. Arrows indicate the gravitational force direction. MRI evaluations with postural changes can help visualize the intrathecal mobility of the lumbar nerve roots and cauda equina. LAA, lumbar adhesive arachnoiditis.

observed in the narrow grade between the high- and no-risk groups; further, there were no significant differences in the sedimentation sign at all lumbar levels except for L5 upper (Table 3). In the no-risk group, some lumbar levels exhibited a significant correlation of the narrow grade with the rootlet proportion of the dorsal half of the dural sac in the supine position. This correlation was not significant in the prone position. In the high-risk group, no relationship was observed between the narrow grade and rootlet proportion under the supine and prone positions. In addition, some significant relationships were observed between the rootlet proportion and the sedimentation sign in the supine position in both groups. However, in the prone position, no significant relationship was observed between the sedimentation sign and proportion of fine roots in either group.

Table 4 shows the number of the patients positive or negative for the typical MRI findings in each group. Of the typical findings, a patient was considered to have positive findings if at least 1 finding was observed. However, if none of the 3 findings were observed, a patient was considered to have negative findings. The high-risk group was more strongly suspected with lumbar adhesive arachnoiditis ($P = 0.0037$).

## DISCUSSION

Here, by focusing on the intrathecal mobility of the nerve roots and cauda equina, we assessed whether

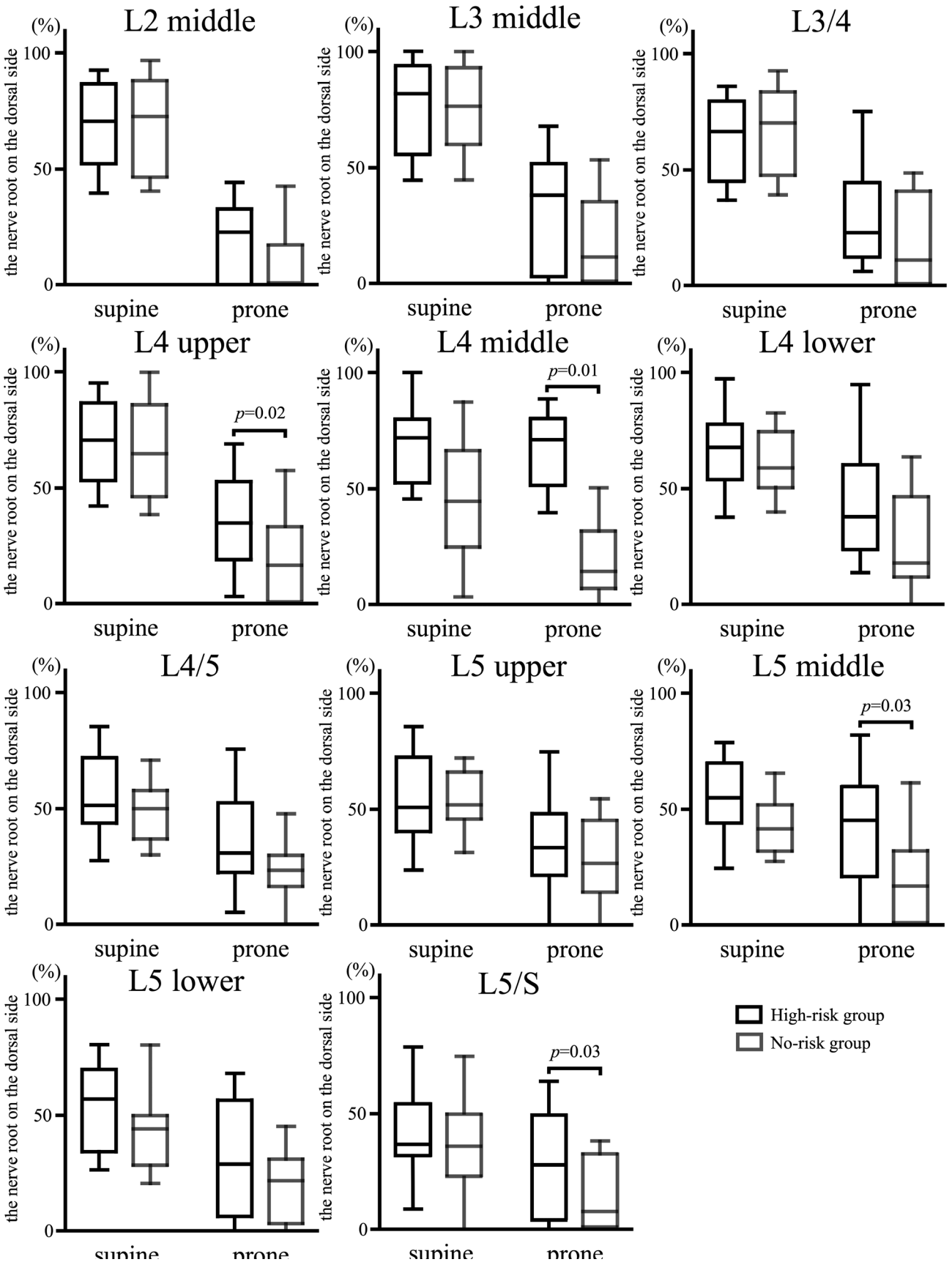
L2 middle
L3 middle
L3/4
L4 upper
L4 middle
L4 lower
L4/5
L5 upper
L5 middle
L5 lower
L5/S
(%)
100
50
0
the nerve root on the dorsal side
supine
prone
p=0.02
p=0.01
p=0.03
High-risk group
No-risk group

**Figure 3.** Box plots showing the proportion of the nerve roots and cauda equina remaining on the dorsal side at the specific lumbar levels. Box plots show the median with the first and third quartiles of the ratio of the low-intensity area in the dorsal half of the dural sac to the total low-intensity area in the ventral and dorsal halves of the dural sac in patients with (black boxes; high-risk group, $n$ = 17) and without known risk of lumbar adhesive arachnoiditis (gray boxes; no-risk group, $n$ = 18). The bars indicate the 10th and 90th percentiles. $P$ values indicating significant differences between the 2 groups are shown.

**Table 3. Proportion of Patients With Each Narrow Grade and Sedimentation Sign at Each Vertebral Level**

| | | Narrow Grade | | | | | | | Sedimentation Sign | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Level | Group | A | B | C | D | *P* Value* | Supine | Prone | + | – | *P* Value* | Supine | Prone |
| L2 middle | High-risk | 14 | 3 | 0 | 0 | 0.06 | $P = 0.02^{\dagger}$ | $P = 0.59$ | 6 | 8 | 0.69 | $P = 0.35$ | $P = 0.49$ |
| | | | | | | | **$r = -0.57$** | $r = 0.16$ | | | | $r = -0.29$ | $r = 0.22$ |
| | No-risk | 18 | 0 | 0 | 0 | | — | — | 9 | 9 | | $P < 0.01^{\dagger}$ | $P = 0.78$ |
| | | | | | | | | | | | | **$r = -0.87$** | $r = 0.07$ |
| L3 middle | High-risk | 14 | 3 | 0 | 0 | 0.26 | $P = 0.44$ | $P = 0.58$ | 6 | 8 | 0.57 | $P = 0.04^{\dagger}$ | $P = 0.47$ |
| | | | | | | | $r = -0.21$ | $r = 0.16$ | | | | **$r = -0.57$** | $r = -0.22$ |
| | No-risk | 17 | 1 | 0 | 0 | | $P = 0.22$ | $P = 0.92$ | 9 | 8 | | $P < 0.01^{\dagger}$ | $P = 0.88$ |
| | | | | | | | $r = -0.30$ | $r = 0.02$ | | | | **$r = -0.87$** | $r = 0.50$ |
| L3/4 | High-risk | 13 | 3 | 1 | 0 | 0.86 | $P < 0.01^{\dagger}$ | $P = 0.60$ | 4 | 9 | 0.23 | $P = 0.01^{\dagger}$ | $P = 0.44$ |
| | | | | | | | **$r = -0.66$** | $r = 0.14$ | | | | **$r = -0.72$** | $r = -0.25$ |
| | No-risk | 13 | 3 | 2 | 0 | | $P < 0.01^{\dagger}$ | $P = 0.01^{\dagger}$ | 7 | 6 | | $P < 0.01^{\dagger}$ | $P = 0.71$ |
| | | | | | | | **$r = 0.71$** | **$r = 0.60$** | | | | **$r = -0.86$** | $r = -0.10$ |
| L4 upper | High-risk | 15 | 1 | 1 | 0 | 0.15 | $P = 0.04^{\dagger}$ | $P = 0.86$ | 7 | 8 | 0.66 | $P < 0.01^{\dagger}$ | $P = 0.46$ |
| | | | | | | | **$r = -0.49$** | $r = 0.05$ | | | | **$r = -0.74$** | $r = -0.22$ |
| | No-risk | 13 | 5 | 0 | 0 | | $P < 0.01^{\dagger}$ | $P < 0.01^{\dagger}$ | 5 | 8 | | $P = 0.01^{\dagger}$ | $P = 0.64$ |
| | | | | | | | **$r = -0.75$** | **$r = 0.69$** | | | | **$r = -0.76$** | $r = 0.15$ |
| L4 middle | High-risk | 15 | 2 | 0 | 0 | 0.41 | $P = 0.08$ | $P = 0.94$ | 7 | 8 | 0.84 | $P = 0.01^{\dagger}$ | $P = 0.61$ |
| | | | | | | | $r = -0.45$ | $r = -0.04$ | | | | **$r = -0.71$** | $r = -0.16$ |
| | No-risk | 14 | 4 | 0 | 0 | | $P = 0.01^{\dagger}$ | $P = 0.54$ | 6 | 8 | | $P = 0.06$ | $P = 0.08$ |
| | | | | | | | **$r = -0.59$** | $r = 0.16$ | | | | $r = -0.54$ | $r = 0.50$ |
| L4 lower | High-risk | 15 | 4 | 0 | 0 | 0.41 | $P = 0.13$ | $P = 0.82$ | 9 | 6 | 0.88 | $P = 0.01^{\dagger}$ | $P = 0.27$ |
| | | | | | | | $r = -0.41$ | $r = -0.07$ | | | | **$r = -0.66$** | $r = -0.32$ |
| | No-risk | 14 | 4 | 0 | 0 | | $P < 0.01^{\dagger}$ | $P = 0.05$ | 8 | 6 | | $P < 0.01^{\dagger}$ | $P = 0.10$ |
| | | | | | | | **$r = -0.67$** | $r = 0.46$ | | | | **$r = -0.82$** | $r = 0.47$ |
| L4/5 | High-risk | 15 | 2 | 0 | 0 | 0.19 | $P = 0.06$ | $P = 0.60$ | 12 | 3 | 0.12 | $P = 0.04^{\dagger}$ | $P = 0.54$ |
| | | | | | | | $r = -0.49$ | $r = -0.16$ | | | | **$r = -0.54$** | $r = -0.19$ |
| | No-risk | 11 | 3 | 3 | 1 | | $P < 0.01^{\dagger}$ | $P = 0.85$ | 11 | 0 | | — | — |
| | | | | | | | **$r = -0.66$** | $r = 0.06$ | | | | | |
| L5 upper | High-risk | 14 | 3 | 0 | 0 | 0.76 | $P = 0.03^{\dagger}$ | $P = 0.61$ | 8 | 6 | 0.03 | $P = 0.01^{\dagger}$ | $P = 0.95$ |
| | | | | | | | **$r = -0.54$** | $r = -0.16$ | | | | **$r = -0.72$** | $r = -0.04$ |
| | No-risk | 14 | 3 | 0 | 1 | | $P = 0.03^{\dagger}$ | $P = 0.59$ | 13 | 1 | | $P = 0.29$ | $P = 0.71$ |
| | | | | | | | **$r = -0.52$** | $r = 0.16$ | | | | $r = -0.38$ | $r = -0.17$ |
| L5 middle | High-risk | 14 | 3 | 0 | 0 | 0.29 | $P = 0.12$ | $P = 0.44$ | 10 | 4 | 0.19 | $P = 0.07$ | $P > 0.99$ |
| | | | | | | | $r = -0.41$ | $r = -0.21$ | | | | $r = -0.51$ | $r = 0$ |
| | No-risk | 12 | 6 | 0 | 0 | | $P = 0.14$ | $P < 0.01^{\dagger}$ | 11 | 1 | | $P = 0.17$ | $P > 0.99$ |
| | | | | | | | $r = -0.36$ | **$r = 0.74$** | | | | $r = -0.48$ | $r = 0.05$ |
| L5 lower | High-risk | 13 | 4 | 0 | 0 | 0.21 | $P = 0.25$ | $P = 0.64$ | 12 | 1 | 0.90 | $P = 0.46$ | $P = 0.31$ |
| | | | | | | | $r = -0.31$ | $r = -0.13$ | | | | $r = -0.31$ | $r = -0.39$ |
| | No-risk | 11 | 4 | 3 | 0 | | $P < 0.01^{\dagger}$ | $P = 0.67$ | 10 | 1 | | $P = 0.17$ | $P = 0.83$ |
| | | | | | | | **$r = -0.66$** | $r = 0.11$ | | | | $r = -0.48$ | $r = 0.13$ |
| L5/S | High-risk | 12 | 3 | 0 | 0 | 0.31 | $P = 0.92$ | $P = 0.67$ | 11 | 1 | 0.83 | $P = 0.33$ | $P = 0.50$ |
| | | | | | | | $r = 0.05$ | $r = 0.13$ | | | | $r = -0.39$ | $r = -0.31$ |
| | No-risk | 16 | 1 | 1 | 0 | | $P = 0.73$ | $P = 0.92$ | 15 | 1 | | — | — |
| | | | | | | | $r = -0.09$ | $r = 0.03$ | | | | | |

Data are presented as the number of patients with each narrow grade and sedimentation sign in each group.
*$P$ values were obtained from the chi-squared test between 2 patient groups.
†$P$ values and correlation coefficients ($r$) for the supine and prone positions were obtained from Spearman's rank test and $r$ between the narrow grade or sedimentation sign and the proportion of dorsal nerve roots for the respective groups; $P < 0.05$ ($r$ with significant differences are shown in bold).

lumbar adhesive arachnoiditis could be diagnosed using MRI in the supine and prone positions. MRI with T2-weighted imaging axial views revealed that in the prone position, the nerve roots and cauda equina were primarily located in the ventral half of the subarachnoid space in patients without known risk factors for lumbar adhesive arachnoiditis; however, in the supine position, they were located primarily in the dorsal half. Our results indicated that the nerve roots and cauda equina move in the gravitational force direction. In the high-risk

**Table 4. Typical Presentations of Adhesive Arachnoiditis on Lumbar MRI in Both Patient Groups**

| | High-risk Group | | | No-risk Group | | |
|---|---|---|---|---|---|---|
| Typical Findings | Conglomeration | Empty Sac Appearance | Mass Replacing Subarachnoid Space | Conglomeration | Empty Sac Appearance | Mass Replacing Subarachnoid Space |
| Positive | 6† | 12* 4† | 4† | 4† | 4* 0† | 1† |
| Negative | | 5* | | | 14* | |
| Total | | 17 | | | 18 | |

*$P$ = 0.0037; $P$ values were obtained from the chi-squared test between the 2 patient groups.
†The total number in the last row does not correspond to the total number of patients because 1 patient may have more than 1 finding.

group, in the supine position, the nerve roots and cauda equina were located in the dorsal half of the subarachnoid space, which was comparable with the patients in the no-risk group. However, in the prone position, they were still located in the dorsal half at lumbar levels below L4. Our findings indicate that the intrathecal mobility of nerve roots and the cauda equina is reduced in patients at a high risk for lumbar adhesive arachnoiditis. The no-risk group exhibited lumbar spinal canal stenosis and certainly displayed some relationships among the rootlet proportion in the posterior half of the dural sac and these indices in the supine position. However, most of these relationships were not observed in the prone position. Although the majority of our high-risk participants had previously undergone lumbar spine surgery, conventional indices were not sufficiently sensitive to discriminate patients at high risk from those at no risk. Further, these indices did not indicate the intrathecal immobility of the nerve roots and cauda equina according to postural changes. Our findings indicate that conventional MRI, which is usually conducted only in the supine position, cannot detect this immobility of the nerve roots and cauda equina in patients with lumbar adhesive arachnoiditis.

Lumbar adhesive arachnoiditis presents with complex clinical features. Laboratory and neurophysiological tests are not very useful for diagnosing lumbar adhesive arachnoiditis.[7] Some MRI presentations, such as thick and clumped nerve roots, appearance of an empty sac, and/or central conglomeration of nerve roots in the dural sac, have been proposed but not validated.[10,18] We therefore aimed to explore novel imaging findings to diagnose lumbar adhesive arachnoiditis in this study. From the perspective of lumbar spinal canal stenosis, characteristic imaging findings, such as severe narrow grade and sedimentation signs, have been proposed. In addition, these findings are not sensitive enough for the discrimination of lumbar spinal canal stenosis from lumbar adhesive arachnoiditis. For example, the sedimentation sign can be reversed by lumbar spine surgery, indicating that this sign only reflects morphological deflection and possibly the reversible mobility of the nerve roots and cauda equina in the dural sac.[15] In fact, our high-risk patients did not exhibit these imaging findings. These signs have been proposed for diagnosing lumbar spinal canal stenosis but not lumbar adhesive arachnoiditis. In the present study, the signs were not sensitive enough for diagnosing lumbar adhesive arachnoiditis because most high-risk patients had a normal narrow grade. Based only on clinical symptomatology, the condition could be erroneously diagnosed as a spinal disease (eg, lumbar spinal canal stenosis, spinal cord lesion, etc.). Further, sometimes the condition could also be diagnosed as psychological distress, pain, and sensory and/or motor deficits, which are widely observed in arachnoiditis in the lower part of the body without a spatial correlation to individual peripheral nerve territories.

In this study, we successfully visualized the immobility of the nerve roots and cauda equina, against the effect of gravity, in the dural sac in patients with a high risk for lumbar adhesive arachnoiditis. Our findings support the pathology of the condition wherein fibrous tissue outgrowth results in a fibrous tangle that traps the nerve roots and cauda equina in the dural sac. Moreover, our findings indicate that the condition is definitely a neuropathic disease. The definitive diagnosis of neuropathic pain currently requires observational confirmation of a lesion or disease of the somatosensory nervous system.[19] As mentioned previously, there is no validated test to confirm the diagnosis; therefore, most physicians are probably still unaware of the condition. Comparing the lumbar MRI findings of the nerve roots and cauda equina in the supine and prone positions and visualizing the immobility of these structures would help in screening and diagnosing the condition. However, considering the small sample size of our study, conclusions must be drawn cautiously. Future studies involving

more patients with and without lumbar and/or leg pain as well as with and without known risk factors for lumbar adhesive arachnoiditis are warranted to ensure the validity of our present MRI technique for diagnosing lumbar adhesive arachnoiditis.

Although the classical examples of the 3 types of MRI presentations[10,18] are yet to be validated as diagnostic markers for lumbar adhesive arachnoiditis, our present findings support the presumption that these imaging observations may be indicative of the typical presentations of lumbar adhesive arachnoiditis. After establishment of the inter- and intra-rater reliabilities of these presentations, they may certainly become useful for the diagnosis of lumbar adhesive arachnoiditis. However, presently, some patients belonging to the high-risk group did not show any of these presentations; however, they clearly presented with immobility of the nerve roots and cauda equina, against the effect of gravity, in the prone position. Therefore, our present MRI paradigm might be more useful than these classic presentations for diagnosing lumbar adhesive arachnoiditis, though a direct comparison of the 2 is required.

### Limitations

Although, lumbar adhesive arachnoiditis generally presents with complex clinical features, no definitive signs and symptoms have been established. In addition, no diagnostic criteria using imaging findings of the condition have been confirmed. We included patients with the chief complaints of lumbar and leg pain and divided them into 2 groups based on the presence or absence of known risk factors for lumbar adhesive arachnoiditis. The study did not include patients who were definitively diagnosed with lumbar adhesive arachnoiditis using a neurosurgical maneuver. Although the visualization of impaired mobility of the nerve roots and cauda equina consequently reached significance at some lumbar levels, the number of patients was small. Therefore, this study should be considered a preliminary study, and future studies including more patients with definitive diagnoses are needed to confirm the present findings.

## CONCLUSION

We observed that the mobility of the nerve roots and cauda equina in the dural sac is impaired at the lumbar level in patients with a high risk for lumbar adhesive arachnoiditis. Further, comparing the findings of MRI performed in the supine and prone positions could facilitate the early detection of lumbar adhesive arachnoiditis. Because accurate diagnosis is a crucial part of the integrated approach to pain management, once lumbar adhesive arachnoiditis is diagnosed using this approach, effective treatment might be instituted.

## CONFLICTS OF INTEREST

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## REFERENCES

1. Aldrete JA. *Arachnoiditis: The Silent Epidemic*. Denver, CO: Future Medical Publishers; 2000.

2. Horsley V. A clinical lecture on chronic spinal meningitis: its differential diagnosis and surgical treatment. *Br Med J*. 1909;1:513–517.

3. Reynolds F. Damage to the conus medullaris following spinal anaesthesia. *Anaesthesia*. 2001;56:238–247.

4. Long DM. Chronic adhesive spinal arachnoiditis. *Neurosurg Quart*. 1992;2:296–319.

5. Quiles M, Marchisello PJ, Tsairis P. Lumbar adhesive arachnoiditis. Etiologic and pathologic aspects. *Spine (Phila Pa 1976)*. 1978;3:45–50.

6. Burton CV. Lumbosacral arachnoiditis. *Spine (Phila Pa 1976)*. 1978;3:24–30.

7. Rice I, Wee MY, Thomson K. Obstetric epidurals and chronic adhesive arachnoiditis. *Br J Anaesth*. 2004;92:109–120.

8. Aldrete JA. Chronic adhesive arachnoiditis. *Br J Anaesth*. 2004;93:301; author reply 01-3.

9. Delamarter RB, Ross JS, Masaryk TJ, Modic MT, Bohlman HH. Diagnosis of lumbar arachnoiditis by magnetic resonance imaging. *Spine (Phila Pa 1976)*. 1978;15:304–310.

10. Ross JS, Masaryk TJ, Modic MT, et al. MR imaging of lumbar arachnoiditis. *Am J Roentgenol*. 1987;149:1025–1032.

11. Takiguchi T, Yamaguchi S, Hashizume Y, Kitajima T. Movement of the cauda equina during the lateral decubitus position with fully flexed leg. *Anesthesiology*. 2004;101:1250.

12. Lombardi G, Passerini A, Migliavacca F. Spinal arachnoiditis. *Br J Radiol*. 1962;35:314–320.

13. Blue Moon Factory, Yamanashi, Japan. Data Picker (R). http://hp.vector.co.jp/authors/VA019223/ (accessed August 6, 2019)

14. Schizas C, Theumann N, Burn A, et al. Qualitative grading of severity of lumbar spinal stenosis based on the morphology of the dural sac on magnetic resonance images. *Spine (Phila Pa 1976)*. 2010;35:1919–1924.

15. Barz C, Melloh M, Staub LP, Lord SJ, Merk HR, Barz T. Reversibility of nerve root sedimentation sign in lumbar spinal stenosis patients after decompression surgery. *Eur Spine J*. 2017;26:2573–2580.

16. Barz T, Staub LP, Melloh M, et al. Clinical validity of the nerve root sedimentation sign in patients with suspected lumbar spinal stenosis. *Spine J*. 2014;14:667–674.

17. Barz T, Melloh M, Staub LP, et al. Nerve root sedimentation sign: evaluation of a new radiological sign in lumbar spinal stenosis. *Spine (Phila Pa 1976)*. 2010;35:892–897.

18. Aldrete JA. Nerve root "irritation" or inflammation diagnosed by magnetic resonance imaging. *Anesthesiology*. 2003;98:1294; author reply 94.

19. Treede RD, Jensen TS, Campbell JN, et al. Neuropathic pain: redefinition and a grading system for clinical and research purposes. *Neurology*. 2008;70:1630–1635.