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ORIGINAL ARTICLE

Identification of abnormalities in the lumbar nerve tract using diffusion-weighted magnetic resonance neurography

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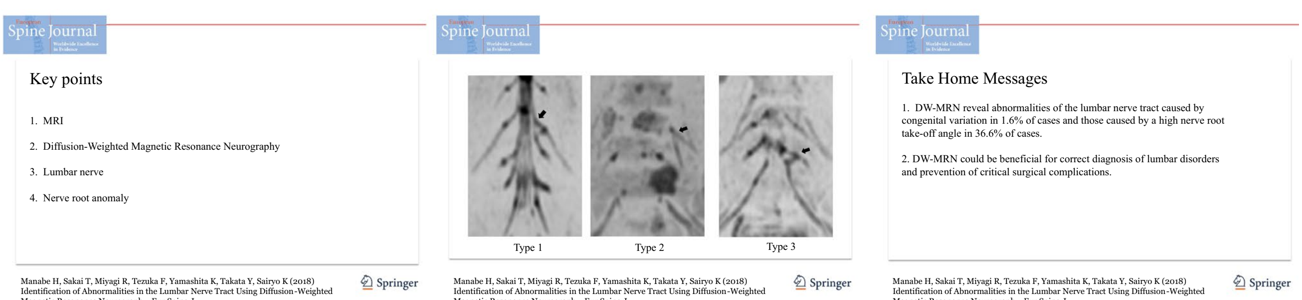
Abstract

Introduction Abnormalities of the lumbar nerve tract caused by congenital variations or high nerve root take-off angles are difficult to visualize. Diffusion-weighted magnetic resonance neurography (DW-MRN) has recently been introduced for imaging of the lumbosacral region. The aims of this study were to identify lumbar nerve tract abnormalities caused by congenital variation or a high nerve root take-off angle using DW-MRN and to assess the diagnostic value of this imaging modality.
Methods A total of 573 magnetic resonance images from 575 patients (261 men, 314 women; mean age 58.5 years) with low back/leg pain were retrospectively analyzed. We classified congenital variations in the lumbar nerve roots using the Neidre and MacNab criteria and investigated nerve roots with a take-off angle of 60° or more.
Results and discussion Congenital variations were identified in 8 patients (9 nerve roots, 1.6%). The most commonly identified variation was in the sacral nerve root ($n=5$) followed by the L4 ($n=3$) and L5 ($n=1$) nerve roots. All variations identified were on the left side. There were 3 cases of type 1a variation, 1 of type 1b, 1 of type 2, and 4 of type 3. In total, 210 (36.6%) of the magnetic resonance images showed high nerve root take-off angles at the intervertebral foramen that was caused by disk herniation, spondylolisthesis, or osteophytes with degeneration. Patients with high nerve root take-off angles were significantly older than those without ($P<0.05$).

Graphical abstract These slides can be retrieved under Electronic Supplementary Material.



Keywords MRI · Diffusion-weighted magnetic resonance neurography · Lumbar nerve · Nerve root anomaly

Introduction

Low back pain (LBP) and/or leg pain (LP) is common complaints worldwide and may negatively affect activities of daily living [1]. Plain radiographs, computed tomography (CT) scans, and magnetic resonance (MR) images with or

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without enhancement are often used to diagnose these symptoms. However, conventional radiologic imaging does not always yield convincing findings. Detection of peripheral nerve lesions in particular is not straightforward. Moreover, correct diagnosis of intraforaminal and/or extraforaminal stenosis in the lumbosacral region is well known to be difficult.

In addition to intraforaminal and/or extraforaminal lesions, abnormalities of the lumbar nerve tract caused by congenital variations or high nerve root take-off angles are difficult to visualize using conventional radiologic tools. If surgery is performed without recognition of the existence of lumbar nerve tract abnormalities, critical problems such as nerve root injury could occur and lead to failed back surgery syndrome [2]. There have been several reports of unfavorable outcomes in patients with abnormalities of the lumbar nerve tract [3, 4]. Therefore, preoperative appreciation of the running of the nerve roots would help to avoid postoperative problems.

Diffusion-weighted magnetic resonance (MR) neurography (DW-MRN) has recently been introduced and applied in the lumbosacral region [5, 6]. DW-MRN is a non-invasive examination that does not need radiation exposure or contrast medium and can visualize the path and morphology of a nerve root, especially in the hidden zone [7]. Signals from a minute vascular plexus that could not be excluded by normal MR neurography can be excluded by using strong background signal suppression.

The purpose of this study was to identify abnormalities in the lumbar nerve tract caused by congenital variations or high nerve root take-off angles using DW-MRN and to assess the value of this imaging modality as a diagnostic tool.

Materials and methods

MR imaging (MRI) scans for 575 consecutive patients (261 men, 314 women; mean age 59.8 years) who visited Suiho Daiichi Hospital with a complaint of LBP and/or LP between January 2014 and March 2015 were retrospectively examined. All examinations were performed using a 1.5-T MRI system (Intera; Philips Healthcare, Best, The Netherlands) with the following scanning parameters: motion-probing gradient with a single plane (A-P), *B*-value of 800 s/mm^2, TR/TE/TI values of 5000/80/180 ms, flip angle of 90°, slice thickness/gap of 5/1 mm, field of view of 300 mm, matrix of 256 × 256, and scan time of 2 min and 50 s. The Achieva 3.2 system (Philips Healthcare) was used for image analysis. DW-MRN was routinely examined.

Structural defects that could affect the running tract, such as compression fractures and degenerative changes, were evaluated using conventional MRI. Two senior orthopedic surgeons (H·M, R·M) evaluated and interpreted the coronal DW-MRN images to identify abnormalities of the lumbar nerve tract caused by congenital variation or a high nerve root take-off angle. This study was conducted with the approval by the ethical review board of Tokushima University Hospital.

Congenital variations of the nerve root

The running tracts of the lumbar nerve roots were evaluated using DW-MRN and congenital variations were classified using the Neidre and MacNab criteria (Fig. 1) [8]. Type 1 is a conjoined type where two nerve roots arise from a common dural sheath (type 1a) or from two closely adjacent dural sheaths (type 1b). In Type 2, two different nerve roots exit through one foramen. In type 2a the foramen is

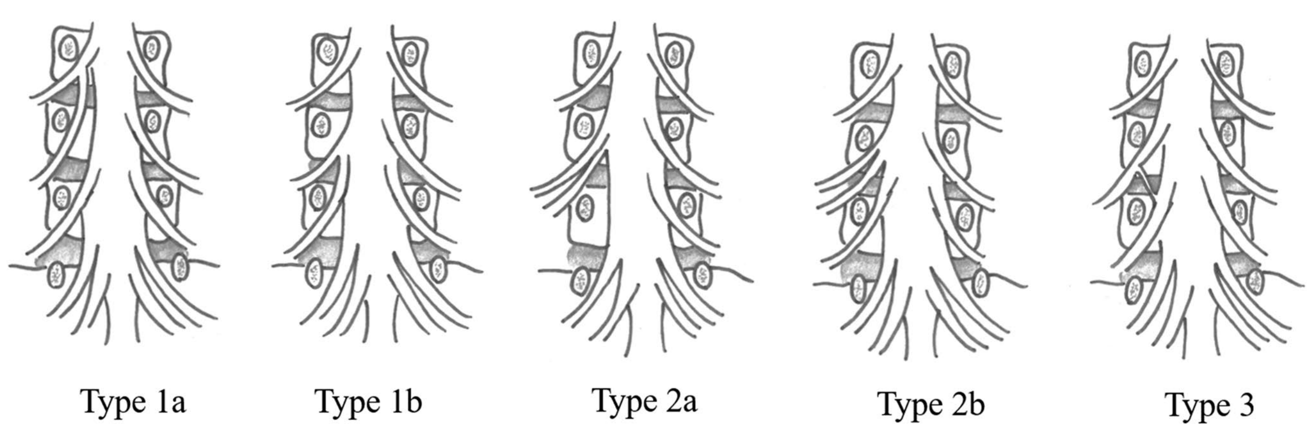

Fig. 1 Neidre and MacNab criteria for congenital variations in the lumbar nerve roots. Type 1, a conjoined type where two nerve roots arise from a common dural sheath; type 2, two different nerve roots exit through the one foramen; and type 3, two adjacent nerve roots are connected by an anastomosis

unoccupied by nerve roots, and in type 2b the entire foramen is occupied by nerve roots. Type 3 is a tract in which two adjacent nerve roots are connected by an anastomosis. In this study, we defined the most caudal mobile lumbar vertebra as L5.

High take-off nerve root angles

In this study, we defined a take-off angle of 60° or more as "high take-off nerve root angle" in accordance with previous studies (Fig. 2) [6, 9].

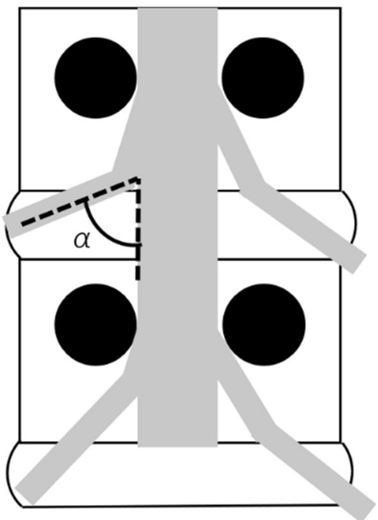

Fig. 2 Designation of a high take-off nerve root angle. α indicates the angle formed between the dura and the nerve root tract in the intervertebral foramina

Statistical analysis

The statistical analyses were performed using Statistical Package for Social Sciences version 21 software (IBM Corp., Armonk, NY). The t test was adjusted for comparison between the positive and negative transverse change groups. A P value < 0.05 was considered statistically significant. Intraobserver and interobserver agreement was estimated using the κ statistic.

Results

Two of the 575 MRI scans were excluded because of metal artifacts and low signal intensity, leaving 573 MRI scans (for 573 patients) available for inclusion in the study.

Congenital variation in the nerve root

Congenital variations were identified in 9 (1.6%) nerve roots in 8 patients. One patient had two congenital variations. The most commonly identified variation was in the sacral nerve root ($n = 5$) followed by the L4 ($n = 3$) and L5 ($n = 1$) nerve roots. All variations were identified to be on the left side. Using the Neidre and MacNab criteria, there were 3 cases of type 1a congenital variation, 1 of type 1b, 1 of type 2, and 4 of type 3 (Fig. 3; Table 1).

High nerve root take-off angles

High nerve root take-off angles at the intervertebral foramina caused by disk herniation, spondylolisthesis, or osteophytes

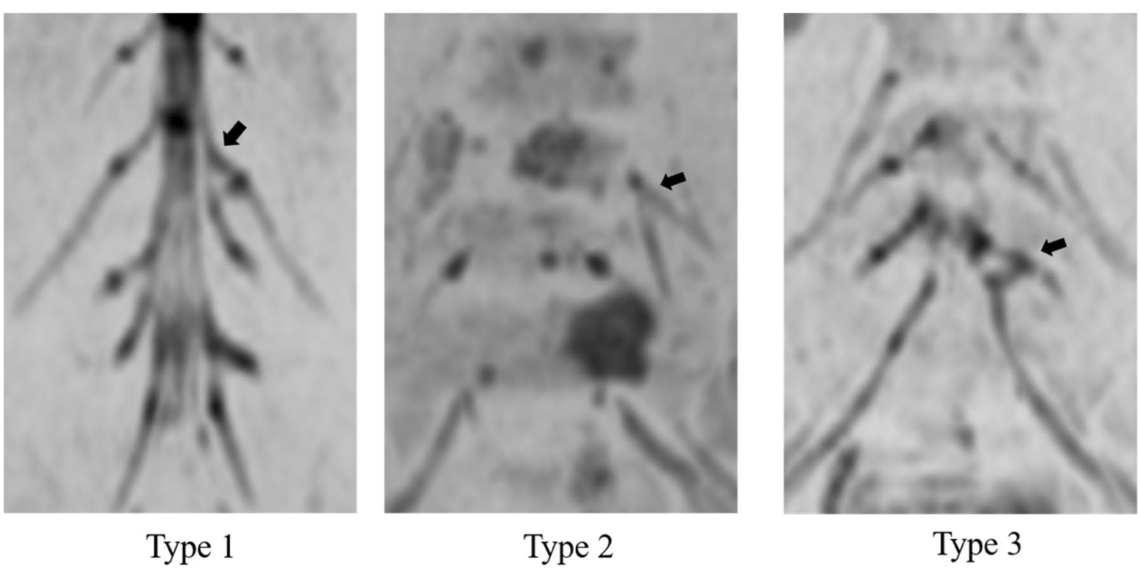

Fig. 3 Panels showing the nerve root anomalies in our cases based on the Neidre and MacNab classification system. The arrow indicates bifurcations with a nerve root abnormality

Table 1 Characteristics of cases with anomaly nerve root

	Age	Sex	Level	Side	Type (Neidre and MacNab criteria)
Case 1	69	M	L4	Left	1a
			S1	Left	1a
Case 2	75	F	L5	Left	1a
Case 3	61	F	S1	Left	1b
Case 4	76	M	L4	Left	2b
Case 5	61	M	L4	Left	3
Case 6	81	F	S1	Left	3
Case 7	49	F	S1	Left	3
Case 8	73	F	S1	Left	3

Table 2 Summary of all cases by presence of transverse change

	Sex (men:female)	Age
Transverse charge (+)	105:105	61.0 (31–93) y.o.*
Transverse charge (−)	154:209	56.1 (18–93) y.o.*

with degeneration were identified in 210 (36.6%) of the 573 MRI scans (Fig. 4). The mean age of patients with a high nerve root take-off angle was 61.0 (range 31–93) years and that of those without was 56.1 (range 18–93) years; the difference was statistically significant ($P < 0.05$; Table 2).

Intraobserver and interobserver repeatability

Intraobserver and interobserver repeatability showed substantial agreement for transverse change; the κ coefficient for intratester reliability was 0.782 and that for interobserver reliability was 0.604.

Discussion

Takahara et al. [10] were the first to report that whole-body diffusion-weighted imaging (DWI) with background body signal suppression could be used to screen the whole body for malignancy. DWI is a non-invasive imaging technique that evolved from the conventional MRI sequence. It can provide valuable information on microstructural organization by observing the random movement of water molecules with the motion search gradient spreading in several directions [11, 12], whereby diffusibility can be thought of as an intrinsic tissue property. Thus, DWI may be useful for detecting imaging abnormalities, e.g., in the solid organs within the abdomen and in the nervous and musculoskeletal systems [5, 13]. In the lumbar spine, a correct understanding of the exact pathway of the nerve roots makes it possible to devise a detailed preoperative plan more easily. Eguchi et al. [5] reported that edema and Wallerian degeneration of compressed nerve roots caused by disk herniation can be analyzed by quantification of the mean apparent diffusion coefficient.

Congenital variations of the nerve root, also known as nerve root anomalies, were first reported in 1949 by Zagnoni [14]. Although asymptomatic in many cases, a nerve root with a congenital variation may be more easily damaged by

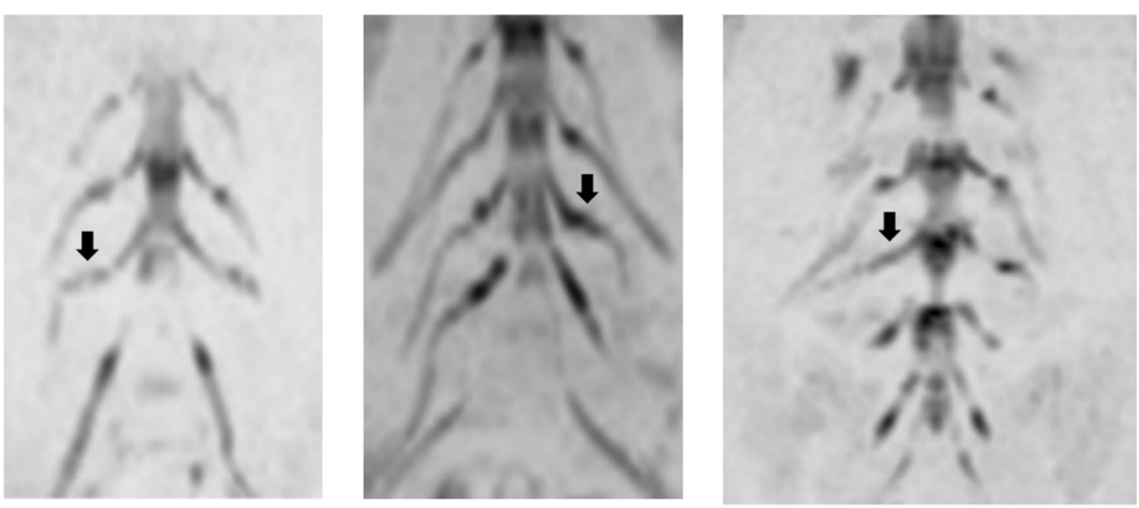

Fig. 4 Coronal diffusion-weighted magnetic resonance neurography image showing the transverse running of the nerve root. Arrows indicate high nerve root take-off angles

intraoperative manipulation than a normal nerve root because of its more limited mobility [15]. Congenital variation is very difficult to identify preoperatively and is considered to be a cause of failed back surgery syndrome. There is wide variation in the prevalence of congenital variations in these nerve roots. A cadaveric study reported a high prevalence of 14% [16], whereas that identified during surgery was reported to be as low as 0.49–1.3% [17, 18]. Studies using various imaging modalities, including myelography, computed tomography, and MRI, reported prevalence rates in the range of 0.25–2.2% [19, 20]. In the present study, the prevalence was 1.6%, which is similar to the rates in previous imaging-based reports. Using the Neidre and MacNab classification system for lumbosacral anomalies, the most common anomaly was type 1, defined as a conjoined nerve root consisting of two nerve roots within a common sheath. In the present study, the number of MRI scans showing a type 3 anomaly was the same as that showing a type 1 anomaly. In previous studies, the anomalies were usually unilateral and showed a male predilection [21, 22], typically with involvement of the L5 and S1 nerve roots [19, 23]. In our study, there were no sex-related differences; however, all cases identified were unilateral and on the left side.

Intervertebral foraminal stenosis is reported to account for 8–11% of all lumbar degenerative diseases and is not a rare pathologic entity [24]. Inaccurate diagnosis of intervertebral foraminal stenosis is also a risk factor for failed back surgery syndrome. Burton, et al. reported that foraminal stenosis accounts for about 60% of the causes of failed back syndrome [25]. Although conventional MRI and/or CT myelography is frequently used for diagnosis of foraminal stenosis in the lumbar spine, foraminal stenosis is often difficult to diagnose. DW-MRN has the advantage of being superior to conventional MRI for suppressing microvessels by DWI and combining fat suppression images, to allow visual assessment of the nerve roots. In addition, it is easy to diagnose multiple-level abnormalities of the lumbar nerve tract caused by congenital variation or high nerve root take-off angles simultaneously on coronal DW-MRN images.

In this study, DW-MRN clearly revealed abnormalities of the lumbar nerve tract that can be helpful in surgical planning. We acknowledge that our study had several limitations. First, it was MRI-based and did not consider clinical symptoms/findings or other radiologic findings. Second, the DWI was unable to identify the junction of the root and dura clearly because of a low signal to noise ratio. However, we consider that DW-MRN would be beneficial for both diagnosis and surgical planning.

Conclusion

In this study, DW-MRN reveal abnormalities of the lumbar nerve tract caused by congenital variation in 1.6% of cases and those caused by a high nerve root take-off angle in 36.6% of cases. DW-MRN could be beneficial for correct diagnosis of lumbar disorders and prevention of critical surgical complications.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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