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Significance of Gd-DTPA–Enhanced Magnetic Resonance Imaging for Lumbar Disc Herniation: The Relationship Between Nerve Root Enhancement and Clinical Manifestations

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Summary: Gd-DTPA–enhanced magnetic resonance (MR) imaging can depict not only the morphology but also the pathological changes of a nerve root compressed by herniated disc. Enhanced MR imaging was performed on 115 patients treated surgically for lumbar disc herniation. Nerve root enhancement was seen in 39.1% of the patients preoperatively and in 58.7% postoperatively. Preoperative root enhancement reflects the radicular pain intensity rather than the degree of neurological deficits, whereas postoperative enhancement did not correlate with the radicular symptoms. Nerve root enhancement represents an intraneural edema in the affected nerve root. Enhanced MR imaging is a potential method for the identification of an affected nerve root in patients with a discrepancy between the level of disc herniation and neurological manifestations. **Key Words:** Gd-DTPA—Magnetic resonance imaging—Disc herniation—Lumbar spine.

Magnetic resonance (MR) imaging is useful for evaluating many spinal disorders because of its high soft tissue contrast sensitivity and multiplanar imaging capability, in addition to its noninvasive nature (1,16). Using a combination of imaging planes and pulse sequence parameters, the anatomy of the spine can be clearly depicted, with the exception of bony elements. MR imaging not only shows the morphology of the spinal cord but also reveals intramedullary lesions due to acute or chronic spinal cord compression (19). On the other hand, pathological changes in nerve roots due to compression have been to date undetectable with nonenhanced MR imaging. Therefore, if a patient has a discrepancy between the level of disc herniation and neurological manifestations, additional invasive examinations such as selective radiculography or discography are often required, which can identify the affected nerve root. Contrast material–enhanced MR imaging is generally performed for the purpose of differentiating recurrent or residual disc herniation from postoperative scar tissue (6,14). On such occasions, nerve root enhancement has often been observed. Accordingly, we have carried out enhanced MR imaging on the patient with lumbar disc herniation in order to investigate the capability of this modality to depict the pathological changes in a radicular lesion. This study was designed to assess the mechanism and clinical significance of nerve root enhancement.

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MATERIALS AND METHODS

The subjects were 115 patients (84 males and 31 females) who underwent herniotomy via the posterior

approach for lumbar disc herniation. All were treated between October 1990 and March 1992 in our hospital, and contrast-enhanced MR imaging was performed in every case. In addition, 46 consecutive patients out of the 115 patients underwent enhanced MR imaging after surgery. Their ages ranged from 12 to 79 years, with a mean of 43 years and 8 months. Affected levels were L2/3 in three patients, L3/4 in eight, L4/5 in 58, and L5/S1 in 40. Six patients displayed numeric abnormalities in the lumbar spine and experienced disc herniation in L5/6. In all patients, radicular pain was not relieved by conservative treatments such as analgesics, epidural block, pelvic traction, and/or other physical therapies in the weeks leading up to surgery. The clinical criteria for the decision to perform an operation are the presence of prolonged radicular symptoms (pain and/or paralysis) being resistant to conservative treatment, or the presence of bowel–bladder dysfunction. Furthermore, herniated mass in the level corresponding to the radicular symptom needs to be detected on the diagnostic imaging.

Examinations were performed on a 1.5-T MR imager (Magnetom, Siemens) with the use of a 12 × 23 cm surface coil receiver. All patients were examined with the following imaging sequences before and within 10 min after the intravenous administration of 0.1 mmol/kg of gadolinium-diethylenetriaminepentaacetic acid/dimeglumine (Gd-DTPA) (Magnevist, Berlex Laboratories): sagittal T1-weighted spin-echo (SE) images (4-mm slice thickness, 1-mm gap, 600/15 [TR/TE], two excitations, 240–250 mm field of view [FOV] and 256 × 256 matrix size) and axial T1-weighted SE images (5-mm slice thickness, 1.5-mm gap, 600/15 [TR/TE], two excitations, 200–210 mm FOV and 200–256 × 256 matrix size). MR images were obtained in the week prior to surgery and, on average, 1 week after surgery.

The findings of the affected nerve root on enhanced MR imaging were evaluated on multiple axial images. The nerve root enhancement is represented by a high signal intensity in the nerve root. Quantitative analysis of the amount of enhancement was not performed. The root enhancement was defined when an affected nerve root was enhanced in two or more consecutive slices in the proximal portion of the root to the herniation. The slice(s) including the herniated disc and the distal portion of the root to the herniation were excluded from evaluation in this series. The reason for the exclusion was the difficulty in differentiating the root enhancement from the rim enhancement of the herniated disc (3,6) and also from the dorsal root ganglion enhancement, which can be seen normally (2).

TABLE 1. *Scale of radicular pain intensity*

Pain intensity	Point
No radicular pain	3
Occasional slight pain	2
Frequent slight or occasional severe pain	1
Frequent or continuous severe pain	0

Radicular pain intensity was evaluated using the scale proposed by the Japanese Orthopaedic Association (JOA) (7).

Correlations between the root enhancement and several clinical factors were analyzed. The investigated clinical factors were radicular pain intensity, duration of radicular pain before examination (MR imaging), limitation of straight leg raising (SLR), and neurological deficits. Radicular pain intensity was evaluated using the scale proposed by the Japanese Orthopaedic Association (7) (Table 1). SLR test was performed with the patient in the supine position and with the knees in full extension. The examiner slowly raised the patient's lower extremity until the patient reported radiating leg pain distal to the knee level. The subjects of this analysis were 100 patients with L4/5, L5/6, and L5/S1 disc herniation, except for far-lateral herniation in L4/5, because straight leg raising stretches the sciatic nerve and applies tension to the corresponding nerve roots (20). Limitation of SLR was divided into the following two grades: (a) mild limitation, more than 45°; (b) severe limitation, 45° or less. For convenience, the patients without SLR symptoms were included in the mild limitation group. Muscle strength was assessed by means of manual muscle testing, graded as follows: (a) grade 0, no contraction; (b) grade 1, trace contraction; (c) grade 2, the muscle can move a joint through a full range of motion (ROM) but not against gravity; (d) grade 3, the muscle can move a joint through a full ROM against gravity but not against additional resistance; (e) grade 4, the muscle can move a joint through a full ROM against some resistance; and (f) grade 5, normal strength and full ROM. The strength of the muscle was assigned to one of two categories: (a) weak (grades 1–3) and (b) strong (grades 4 and 5). Sensory function was evaluated by pin prick test. The severity of sensory disturbance was defined as follows: (a) severe, less than 50% of intact sensation (e.g., sensation of abdominal skin) and (b) mild, 50% or more. The relations between the enhancement and the location of

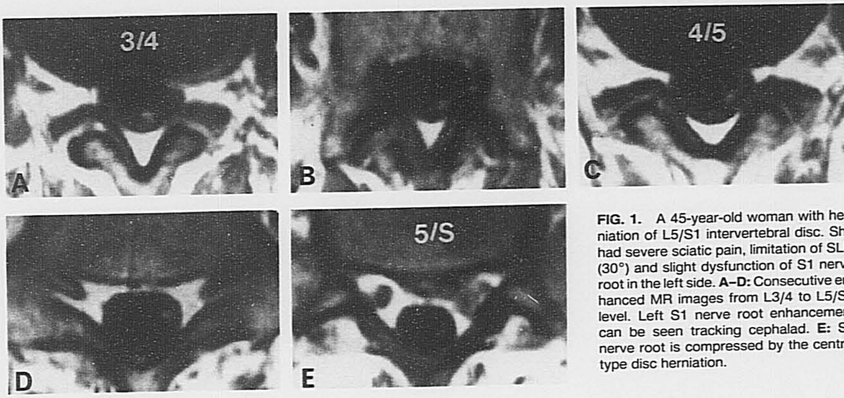

FIG. 1. A 45-year-old woman with herniation of L5/S1 intervertebral disc. She had severe sciatic pain, limitation of SLR (30°) and slight dysfunction of S1 nerve root in the left side. **A–D:** Consecutive enhanced MR images from L3/4 to L5/S1 level. Left S1 nerve root enhancement can be seen tracking cephalad. **E:** S1 nerve root is compressed by the central type disc herniation.

the herniation (on sagittal and horizontal planes), as well as the patients' ages, were analyzed.

The Student *t* test and the Chi-Square test with continuity correction were used for statistical analysis. The chosen level of significance was $p < 0.05$.

RESULTS

All patients who had undergone herniotomy experienced significant relief of radicular pain and improvement of neurological functions postoperatively. The mean radicular pain score was 0.7 points preoperatively and 2.5 points postoperatively.

The enhancement of the affected nerve root was observed in 45 (39.1%) of 115 patients before surgery (Figs. 1 and 2) and in 27 (58.7%) of the 46 patients who underwent postoperative enhanced MR imaging (Fig. 3). The incidence of the root enhancement was higher postoperatively than preoperatively ($p < 0.05$).

In the 46 patients who had undergone the enhanced MR imaging both before and after surgery, 24 showed preoperative enhancement. In 18 (75.0%) of these 24 patients, the decompressed nerve root remained enhanced, despite clinical improvement. On the other hand, in nine (40.9%) of the 22 patients without preoperative enhancement, the nerve root was newly enhanced postoperatively (Fig. 3). Relief of radicular pain and significant neurological recovery were gained in all these nine patients.

A small enhanced signal along a nonaffected nerve root was seen tracking cephalad toward the upper lumbar level in seven (6.1%) of all 115 patients. The same finding was observed both before and after surgery (Figs. 2 and 4).

Preoperative Clinical Manifestations

In 100 patients with sciatic pain due to lower lumbar disc herniations (L4/5 or below), 50 patients had severe limitation of SLR (<45°), whereas only two of the remaining 50 patients displayed no SLR symptoms, and 48 had mild limitation (≥45°). In a neurological aspect, there were 11 patients whose weakest muscle strength was grade 3 or less and 20 patients who sustained severe sensory loss (<50% of intact sensation). From the onset of radicular pain, 50 patients who had undergone MR imaging within 4 weeks had a lower pain score (0.6 ± 0.5 points) than the remaining 65 patients who underwent the same examination 4 or more weeks later (0.8 ± 0.5 points; $p < 0.05$).

Preoperative Nerve Root Enhancement

Preoperatively, patients with the nerve root enhancement had lower radicular pain scores (0.6 ± 0.5 points) than those without the enhancement (0.8 ± 0.4 points; $p < 0.05$) (Table 2).

As can be seen in Tables 3–5, the following relations were analyzed: (a) between the duration of radicular pain and the enhancement; (b) between the limitation of SLR and the enhancement; and (c) between neurological deficits such as motor weakness and sen-

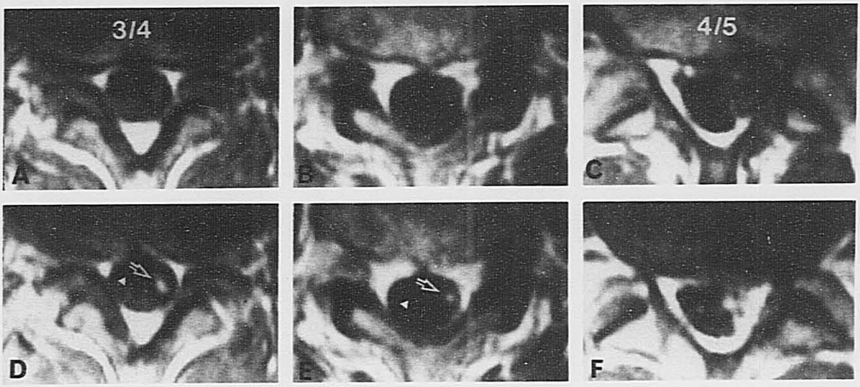

FIG. 2. A 48-year-old man with herniation of L4/5 intervertebral disc in the left side. He had severe sciatic pain projecting into the lateral aspect of the leg, limitation of SLR (40°), and moderate dysfunction of L5 nerve root in the left side. **A–C:** Nonenhanced T1-weighted images. **D–F:** Enhanced MR images depict the affected left L5 nerve root with enhancement (arrow). A small enhanced signal observed in the opposite side is thought to be that of a radicular vein (arrow head).

sory disturbance and the enhancement. Patients with a shorter duration of radicular pain showed the enhancement at a higher rate compared with those of a longer duration. SLR was found to be closely related to the presence of nerve root enhancement. This was observed in 48.0% of the severe limitation group as opposed to 26.0% in the mild or no limitation group. Motor weakness and sensory disturbance did not correlate with the root enhancement.

The relations between the enhancement and the location of herniation and patients' ages are shown in Table 6. The sagittal and horizontal locations of herniated disc, and the patient's age did not influence the root enhancement.

Postoperative Nerve Root Enhancement

The postoperative radicular pain score was 2.5 ± 0.5 in patients with the enhancement and 2.4 ± 0.8 in those without the enhancement. No significant relation existed between the enhancement and the postoperative radicular pain score (Table 2).

DISCUSSION

Computed tomography (CT) is useful in delineating bone detail, and direct axial scans of the spine provide soft tissue discrimination of the disc, nerve roots, and dural sac. However, sagittal, coronal, or oblique views cannot be directly acquired. MR imaging, on the other hand, has multiplanar imaging capability. Using a combination of imaging planes and pulse sequence parameters, the anatomy of the vertebrae, intervertebral discs, spinal nerves, and dural sac can be clearly depicted. MR imaging also provides a great deal of information on the soft tissues in the spine because of its contrast sensitivity. For example, the outer anulus-posterior longitudinal ligament complex can usually be seen as an area of decreased signal in contrast to the inner anulus-nucleus pulposus, which helps in characterizing the type of herniation (1). Therefore, MR imaging is the valuable modality for evaluating lumbar disc herniation. In addition, MR imaging supplements morphological assessment with signal intensity changes that may reflect biochemical substrate changes in the underlying pathological process. Thus, MR imaging represents a potential tool for both morphological and biochemical analysis (1). Although nonenhanced MR imaging can depict intramedullary lesions due to acute or chronic spinal cord compression, radicular lesions due to nerve root compression have, as yet, been undetected. When an affected nerve root proves difficult to be identified, additional examinations such as selective radiculography or discography are often required.

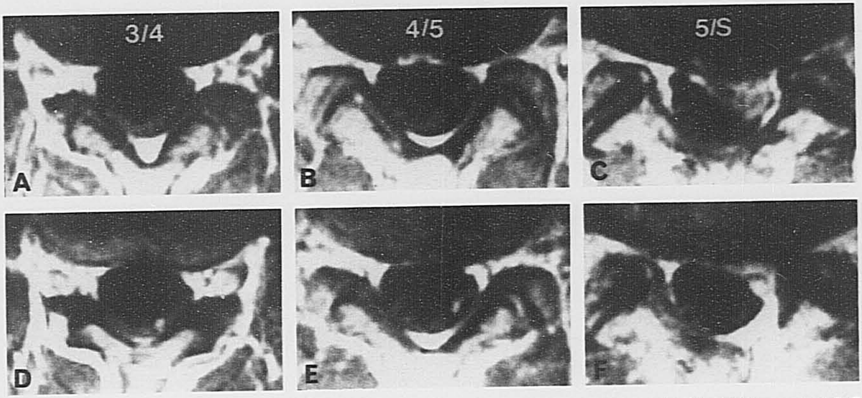

FIG. 3. A 31-year-old man with herniation of L5/S1 intervertebral disc in the left side showed radiculopathy of the left S1 nerve root. **A–C:** Preoperative enhanced MR images do not demonstrate nerve root enhancement. **D–F:** An enhanced S1 nerve root is seen in postoperative enhanced MR images in spite of relief from radicular pain and neurological recovery.

Contrast on MR imaging among different tissues is affected by an exogenously administered paramagnetic contrast agent. Gd-DTPA is the only contrast agent available for clinical use. Gd-DTPA was chosen because of its high relaxation properties, which are attributable to its seven unpaired electrons. T1 relaxation is enhanced; that is, T1 time is shortened by the presence of paramagnetic substances with unpaired electrons (5). This agent often improves the contrast differentiation between pathological and normal pro-

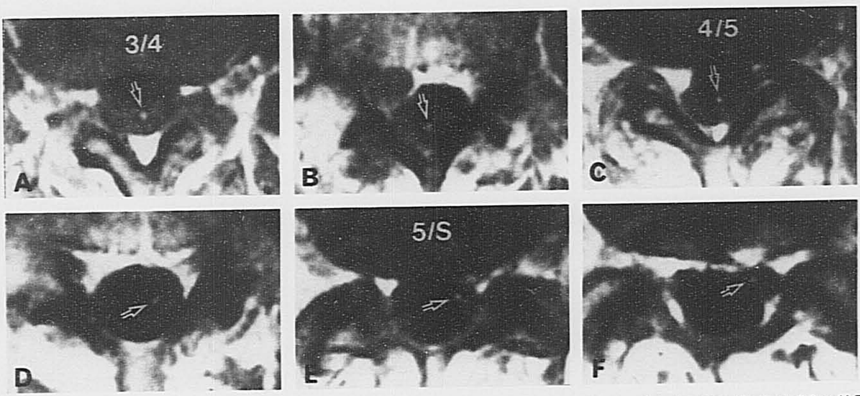

FIG. 4. A 58-year-old man with herniation of L4/5 intervertebral disc. He suffered from anterior leg pain in the right side due to L4 and L5 radiculopathy. **A–F:** Consecutive enhanced MR images from L3/4 to L5/S1 level do not demonstrate the enhancement of the affected nerve roots but show small enhanced signals along a nonaffected S1 nerve root on the opposite side (arrow). This small image is thought to be a radicular vein. **B:** The herniated disc in L4 pedicle level.

TABLE 2. *Correlation between nerve root enhancement (NRE) and radicular pain score*[a]

	With NRE	Without NRE	p Value[b]
Preoperative (points)	45 (0.6 ± 0.5)	70 (0.8 ± 0.4)	0.019[c]
Postoperative (points)	27 (2.5 ± 0.5)	19 (2.4 ± 0.8)	0.604[d]

[a] n (mean ± SD).
[b] Unpaired *t* test.
[c] Significant difference.
[d] Not significant.
Radicular pain intensity was evaluated using the scale proposed by the Japanese Orthopaedic Association (JOA) (7).

TABLE 4. *Correlation between nerve root enhancement (NRE) and straight leg raising test*

		With NRE (n = 37)	Without NRE (n = 63)	p Value[a]
SLR test (n = 100[b])	>45°	13	37	0.038[c]
	≤45°	24	26	

[a] Chi-square test.
[b] The patients with L4/5, L5/6 and L5/S1 disc herniation except for far-lateral herniation in L4/5 numbered 100.
[c] Significant difference.

cesses. For example, Gd-DTPA will be very useful in delineating meningiomas, which can be isointense with brain on multiple pulse sequences (5).

The use of Gd-DTPA–enhanced MR imaging facilitates the differentiation of postoperative scar tissue from a recurrent disc herniation. On the early postinjection images, scar tissue is consistently enhanced, but disc material is not enhanced because of its avascular nature (6,14). Other tissues enhanced by Gd-DTPA are the epidural venous plexus, the dorsal root ganglion, and epidural fibrosis surrounding the herniated disc (2,3,15). There have been only a few reports concerning nerve root enhancement. Ross et al. (15) reported that the nerve roots in the lumbar spine were enhanced diffusely in a patient with intrathecal seeding of lymphoma. Boden et al. (2) recently described some decompressed nerve roots as being enhanced at 3 weeks, but consistently absent within 6 months following the surgery. They also mentioned that postoperative nerve root enhancement had not correlated with the presence of radicular symptoms (2). According to Hueftle et al. (6), normal nerve roots showed no enhancement postoperatively. There have been no reports on preoperative nerve root enhancement.

In the present study, the relations between nerve root enhancement and other parameters, including radicular pain intensity, the duration of radicular pain, SLR limitation, and neurological deficits, were investigated before and after surgery. Preoperative nerve root enhancement was seen in patients with severe radicular pain (7), shorter duration of radicular pain, and more restricted SLR. Moreover, the patients with shorter durations of radicular pain had lower radicular pain scores. The degree of SLR is generally considered to correlate with sciatic pain intensity. Thelander et al. (20) described SLR as being further restricted in those patients with more severe sciatic pain. On the other hand, no significant relation was found between nerve root enhancement and neurological deficits. Neither patient age nor the location of herniation affected nerve root enhancement. These results indicate that preoperative nerve root enhancement reflects radicular pain intensity rather than the degree of neurological deficits.

The pathogenesis of radiculopathy associated with lumbar disc herniation is considered to be the result of a blood flow disturbance in the nerve root due to mechanical compression (17,21) and an inflammatory reaction caused by chemical mediators leaking from a

TABLE 3. *Correlation between nerve root enhancement (NRE) and duration of radicular pain*[a]

	With NRE	Without NRE	p Value[b]
Duration (weeks)	45 (3.9 ± 3.0)	70 (10.9 ± 17.2)	0.008[c]

[a] n (mean ± SD).
[b] Significant difference.
[c] Unpaired *t* test.

TABLE 5. *Correlation between nerve root enhancement (NRE) and neurological deficits*

	With NRE (n = 45)	Without NRE (n = 70)	p Value[a]
Motor weakness			
Strong (≥4)	40	64	0.899[b]
Weak (≤3)	5	6	
Sensory disturbance			
Mild (≥50%)	34	61	0.178[b]
Severe (<50%)	11	9	

[a] Chi-square test.
[b] Not significant.
Muscle strength was evaluated using manual muscle testing. Sensory disturbance of the lower extremities was assessed in comparison with intact abdominal wall sensitivity.

TABLE 6. *Influence of patient's age and location of disc herniation*

	With NRE (n = 45)	Without NRE (n = 70)	p Value[a]
Age (years)			
≥65	3	11	0.248[b]
<65	42	59	
Level of disc herniation			
Upper lumbar (≥L3/4)	5	6	0.899[b]
Lower lumbar (≤L4/5)	40	64	
Horizontal location			
Far-lateral	3	7	0.779[b]
Intraspinal	42	63	

[a] Chi-square test.
[b] Not significant.

degenerative nucleus pulposus (11,12,18). Experimental studies using a nerve root compression model revealed that compression of a nerve root damages the blood-nerve barrier (8,13,17,21). Subsequently, this results in an increased permeability of the endoneurial blood vessels and the formation of intraneural edema. Kobayashi et al. (8) showed that intravenously administrated macromolecules, such as Evans blue albumin and horseradish peroxidase, leaked from endoneurial vessels into the endoneurial space in acute nerve root compression models. They concluded that this was owing to loss of integrity of the blood-nerve barrier. Similarly, altered vascular permeability in response to inflammatory mediators may result in venous congestion and intraneural edema (11,18). The intraneural edema may induce an increase in endoneurial fluid pressure (9). This results in a "compartment syndrome" within the nerve root, which may impair its nutritional supply and, thus, the function of the nerve root (10). Rydevic et al. (17) described acute compression of a normal nerve root as inducing numbness rather than pain. However, if the nerve root is a site of inflammation, even a minor distortion of the nerve root induces radiating pain.

The presumption of the mechanism underlying nerve root enhancement is as follows: nerve root enhancement represents the leakage of Gd-DTPA from endoneurial vessels into the endoneurial space, secondary to an increase in permeability of the endoneurial capillaries in the affected nerve root. In other words, root enhancement corresponds to intraneural edema. This suggests that intraneural edema causes radicular pain rather than neurologic deficits.

Although 58.7% of patients demonstrated postoperative nerve root enhancement, no correlation was observed with radicular symptoms. In spite of clinical improvement, the nerve root enhancement remained unchanged after surgery in 75.0% of the patients with preoperative enhancement, whereas, 40.9% of the patients without preoperative root enhancement demonstrated postoperative enhancement despite relief from radicular pain and neurological recovery. The possibility of postoperative enhancement occurring is due to mechanical damage to the nerve root by surgery. Boden et al. (2) also speculated that postoperative enhancement was due to surgical invasion. Moreover, they presumed that the root enhancement represents increased nerve root metabolism or a reparative process in the affected nerve root. The clinical significance of postoperative nerve root enhancement remains unclear.

A small enhanced signal along a nonaffected nerve root must be differentiated from nerve root enhancement. This finding was observed in 6.1% of our cases and was seen tracking cephalad toward the upper lumbar level. This enhancement was assumed to be made in the radicular vein. An especially large vein may undergo this enhancement in consideration of its direction and morphology (4).

In general, selective radiculography is indicated for the patients in whom determination of affected nerve roots is difficult, such as cases where there is a discrepancy between the level of disc herniation and neurologic manifestations. Because Gd-DTPA–enhanced MR imaging can depict pathological changes in the affected nerve root, this modality may have potential application as the first examination for such patients. However, in this study, it was not proved that enhanced MR imaging can be used to identify an affected nerve root in the absence of other positive tests. Further study needs to be carried out to prove this point. Moreover, enhanced MR imaging has a few limitations. Firstly, there is relatively poor sensitivity (39.1%) in detecting an affected nerve root before surgery. Secondly, a difference in pain scores of 0.6 ± 0.5 or 0.8 ± 0.4 for preoperative enhancement versus nonenhancement, while statistically significant for the group, indicates considerable overlap, which may limit usefulness for the individual patient. More detailed investigation of this method will be necessary in the future.

CONCLUSION

Gd-DTPA–enhanced MR imaging depicted not only morphology but also pathological changes in nerve roots compressed by intervertebral disc herniation. Preoperative nerve root enhancement reflects

the radicular pain intensity rather than the degree of neurological deficits, whereas postoperative enhancement does not correlate with radicular symptoms. Nerve root enhancement represents intraneural edema of the affected nerve root. Thus, it is shown that Gd-DTPA–enhanced MR imaging is a potential method for the identification of an affected nerve root in patients with a discrepancy between the level of disc herniation and neurological manifestations.

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