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ORIGINAL ARTICLE - SPINE TRAUMA

Lower lumbar osteoporotic vertebral fractures with neurological symptoms might have two different pathogeneses according to early magnetic resonance images

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Abstract

Background Most osteoporotic vertebral fractures (OVFs) occur in the thoracolumbar area without neurological symptoms. The pathogenesis and clinical results of symptomatic lower lumbar OVFs have not been analysed. We aimed to retrospectively investigate the risk factors for the occurrence of neurological symptoms in patients with lower lumbar OVFs and to assess the clinical results of these symptoms using magnetic resonance (MR) images.

Methods Of the 104 patients enrolled, 21% reported neurological symptoms. We divided OVFs with neurological symptoms into various types using early MR images and investigated the risk factors for each type. Clinical results of symptomatic patients were also evaluated.

Results Symptomatic patients with lower lumbar OVFs mainly had one of two fracture types, indicated by total low and superior/inferior low-intensity signals on T1-weighted images. A multivariate logistic regression analysis showed that a smaller canal area and longer disease duration were risk factors for all patients. For patients with OVFs indicated by total low intensity, symptomatic patients had a significantly smaller canal area than non-symptomatic patients. For patients with OVFs indicated by superior/inferior low intensity, symptomatic patients had a significantly higher frequency of L4 and L5 vertebral fractures, longer disease duration, smaller canal area, smaller angle between the facets, and higher frequency of coexisting degenerative spondylolisthesis than non-symptomatic patients. Symptomatic patients with OVFs indicated by total low intensity had poorer clinical results regarding walking ability than symptomatic patients with OVFs indicated by superior/inferior low intensity.

Conclusions Lower lumbar OVFs with neurological symptoms might have two different pathogeneses according to early MR images. Compared with symptomatic patients with OVFs indicated by superior/inferior low intensity, symptomatic patients with OVFs indicated by total low intensity may require different treatment strategies to avoid symptoms.

Keywords Osteoporotic vertebral fracture · Lower lumbar spine · Magnetic resonance imaging · Neurological symptoms · Lumbar canal stenosis · Intervertebral instability

Introduction

An increase in the number of older people who experience an osteoporotic vertebral fracture (OVF) is a problem in developed countries [9]. Most OVFs occur in the thoracolumbar area (T11, T12, L1, and L2) without neurological symptoms. However, several cases of neurological symptoms due to non-union, progress of kyphosis of the affected OVF, or instability around the fracture site have been reported [1, 7, 8, 10, 13, 14].

Recently, there have been a few reports of lower lumbar OVFs (L3, L4, L5) with neurological symptoms [2, 11, 12]. Several different points are present between the thoracolumbar and lower lumbar spine. The thoracolumbar

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area is the junction from the kyphotic alignment to lordotic alignment, and the spinal column contains the spinal cord, conus medullaris, and cauda equina; the lower lumbar spine has lordotic alignment, and the spinal column includes only the cauda equina. In the elderly population, canal stenosis caused by degenerative change is more frequently found in the lower lumbar area than in the thoracolumbar area. Accordingly, the pathogenesis and clinical results of symptomatic lower lumbar OVFs might be different from those of symptomatic thoracolumbar OVFs.

Findings observed in early magnetic resonance (MR) images of the affected vertebrae were strongly correlated with the diagnosis and prognosis of OVFs in the thoracolumbar area. Previous studies demonstrated that the total low-intensity signals on T1-weighted (T1W) MR images [5, 6] and diffuse low-intensity or confined high-intensity signals on T2-weighted (T2W) MR images [15] suggested higher vertebral collapse and pseudarthrosis conversion rates in the affected vertebrae than indicated by other MR images. Other previous studies demonstrated that the majority of lower lumbar OVF patients with neurological symptoms had strongly collapsed vertebrae with a retropulsed bony fragment, reduced vertebral height, and subsequent instability [11, 12]. Therefore, early MR images might be useful for analysing the pathogenesis that causes neurological symptoms and clinical prognosis in symptomatic lower lumbar OVFs, but these factors have not been analysed in detail.

We investigated whether neurological symptomatic patients with lower lumbar OVFs had specific fracture types by using early MR images. Next, we investigated the risk factors of the occurrence of neurological symptoms of patients with these fracture types in lower lumbar OVFs. Then, we assessed the clinical results of symptomatic cases with these fracture types.

Materials and methods

Subjects

We retrospectively reviewed the medical records of 669 consecutive patients with new OVF who visited our hospital for the first time between 2012 and 2015. Inclusion criteria were OVFs in the lower lumbar vertebrae (L3, L4, L5) that had been diagnosed as new OVFs using findings from early MR images, including low intensity on T1W MR images and high intensity on short T1 inversion recovery (STIR) images. Patients who had previously undergone lumbar surgery, who had a fracture after a major injury, or who had an infection, tumour, or any other disease that would induce pathological fractures were excluded from the study. Therefore, 104 patients (16%) were enrolled and 565 patients were excluded because they had no lower lumbar OVFs (Fig. 1).

Analysis of the fracture type based on early MR images

Early MR images of the affected OVF were evaluated using the T1W MR image-based frequency classification (total, superior/inferior, anterior/posterior, and centre low intensity) as described by Kanchiku [5, 6] and the T2W MR image-based frequency classification (confined high, diffuse high, confined low, diffuse low, and normal intensity) as described by Tsujio [15]. To permit calculations of the intraclass correlation coefficients, an evaluation was repeated for the same 50 patients over the course of 1 month and kappa coefficients were determined.

Analysis of the risk factors for the occurrence of neurological symptoms

The following parameters were investigated retrospectively as candidate factors: age, sex, OVF site, disease duration, degree of collapse of the OVF, canal area of the affected disc level, angle between the facets at the affected disc level, frequency of the coexistence of degenerative spondylolisthesis at the affected disc level, and bone mineral density (BMD) of the hip.

The frequencies of L4 and L5 OVFs were investigated. The disease duration was defined as the time between the onset of symptoms and the first visit to our hospital, and it was divided into three categories: within 1 month, between 1 and 3 months, and more than 3 months from the onset. The degree of collapse was assessed through standing or sitting plain lateral radiographs using the grade of semiquantitative classification (0–3) as described by Genant [4]. For those with multiple lower lumbar OVFs, the affected vertebra was defined as the most collapsed vertebra. The canal area was defined as the area of the dural sac on T2W axial MR images (MRT-2003/P2 1.5 T; Toshiba, Tokyo, Japan) as a slice of the affected disc level. The angle between the facets was measured as the angle between the right and left lines drawn from the intersection between the facet joints on axial T2W MR images as a slice of the affected disc level.

The affected disc level was usually adjacent to the OVF and had canal or foraminal stenosis that compressed the nerve roots, resulting in leg pain and neurological abnormalities. If the correlation between the disc level and symptoms was not clear, then final confirmation was attained through selective nerve root infiltration.

Plain radiographs and MR images were obtained within 1 week after the patient's first visit to our hospital. The BMD of the total proximal hip area was measured with dual-energy X-ray absorptiometry (DXA/PRODIGY; GE Healthcare, Little Chalfont, England) within 6 months of the first visit and expressed as a percentage of young adult mean (20–44 years of age). The MR images were captured digitally

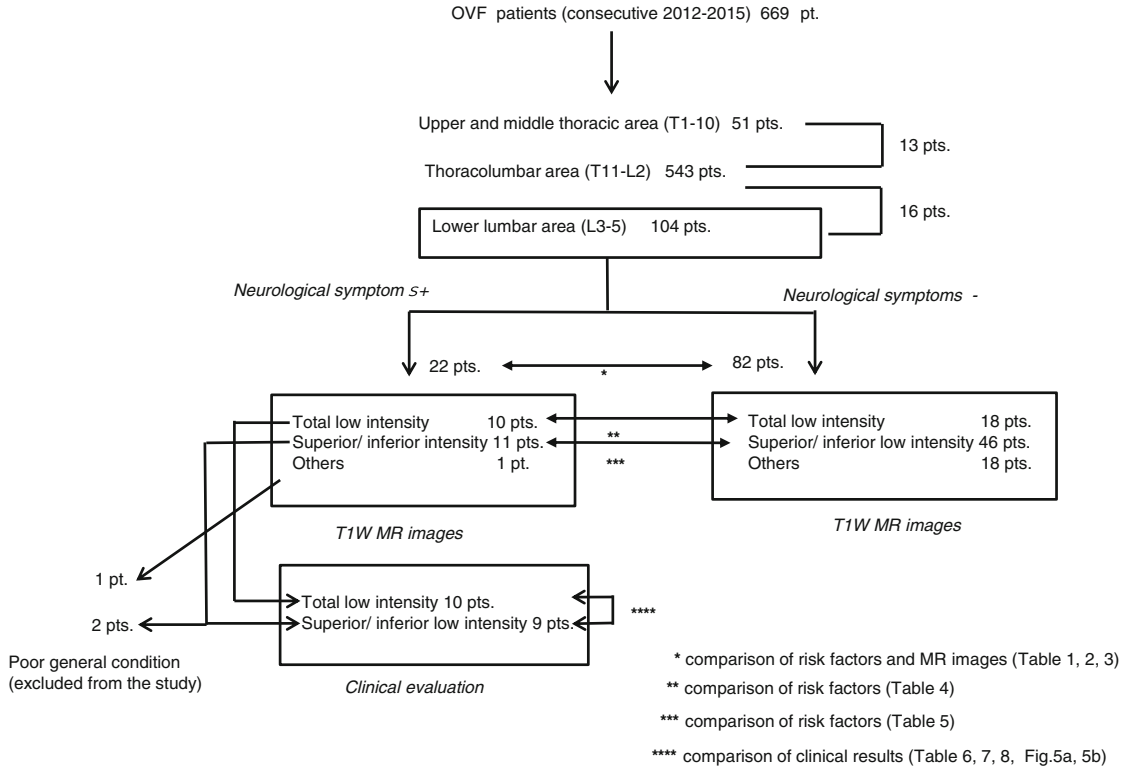


Fig. 1 Patient selection flow chart for this study of the 669 consecutive OVF patients; we enrolled 104 patients (16%) whose OVFs were in the lower lumbar vertebrae. There were 22 neurological/symptomatic patients and 82 non-symptomatic patients. Patients with neurological symptoms mainly had one of two fracture types, indicated by total low (45%) and superior/inferior low-intensity (50%) signals on T1W MR images. Risk factors for the occurrence of neurological symptoms were compared between neurological/symptomatic and non-symptomatic patients with lower lumbar OVFs indicated by total low and superior/inferior low intensity on T1W MR images. Clinical results of patients with neurological symptoms were compared between patients with lower lumbar OVFs indicated by total low intensity (10 patients) and patients with lower lumbar OVFs indicated by superior/inferior low intensity (9 patients) after excluding patients in poor general condition. MR magnetic resonance, OVF osteoporotic vertebral fracture, pt patient, T1W T1-weighted

and viewed using image analysis software on a Synapse viewer (Fujifilm Medical Co., Tokyo, Japan). Measurements were obtained using the digital measuring tools included in the software package. A single surgeon who was blinded to the patients' data performed the measurements.

Treatments

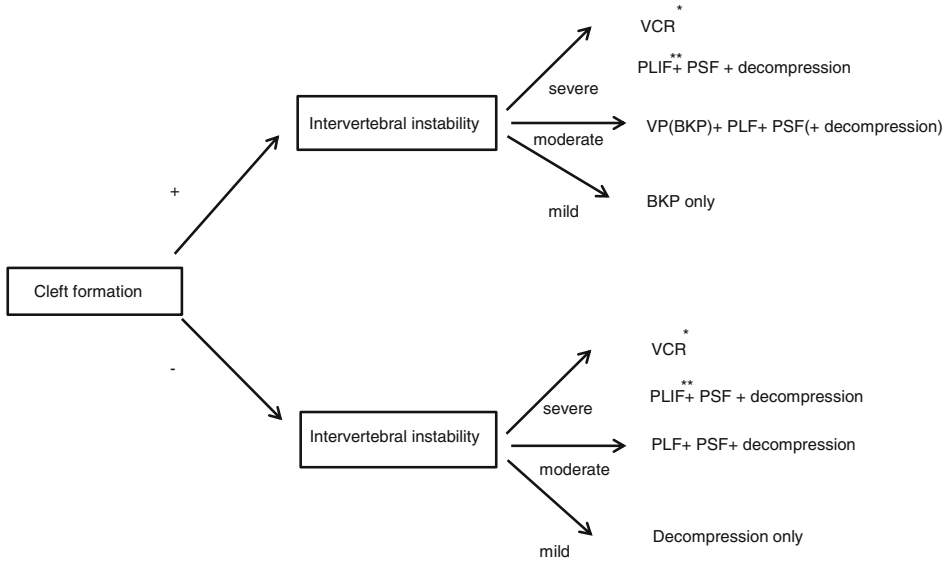
Figure 2 shows our surgical treatment policy for lower lumbar OVF with neurological symptoms. We performed conservative treatment for seven patients. Three of them had a poor general condition. Decompression only was performed for three patients who had undergone conservative treatment first but had not shown improvement despite bone union at the OVF site. Balloon kyphoplasty (BKP) only and combined BKP and pedicle screw fixation (PSF) were performed for two patients who had cleft formation at the OVF site. We performed decompression, PSF, and posterolateral fusion (PLF) or posterior lumbar interbody fusion (PLIF) for 10 patients. One of the 10 patients had cleft formation at the OVF site. PSF was performed at the OVF site and at two or more intact vertebrae above and below the affected site.

Outcomes

We evaluated the clinical results for 19 patients according to the Japanese Orthopaedic Association Back Pain Evaluation Questionnaire (JOABPEQ) [3]. Three patients were excluded from the study because of a previous poor condition. The JOABPQ includes five domains: low back pain, lumbar function, walking ability, social life function, and mental health. We compared the scores (0–100) of these domains before treatment and at the final follow-up examination (average, 29 months; range, 12–53 months). The visual analogue scale (VAS) questionnaire (with scores of 0–10) was used to assess low back pain, pain in the buttocks and lower limb, and numbness in the buttocks and lower limb.

Statistical analysis

Differences between groups were examined for statistical significance using an unpaired t test, paired t test, or χ^2 test (Fig. 1). A multivariate logistic regression analysis was performed to assess independent risk factors for the



*: VCR was selected in the case of severe intervertebral instability at both upper and lower disc levels of OVF site

**: PLIF was selected in the case of severe intervertebral instability at an affected site or increased bone fragility at the vertebrae

Fig. 2 Schematic showing the surgical treatment policy for lower lumbar OVF. In the case of poor general conditions or mild neurological symptoms, conservative treatment was selected first. Surgical treatment was selected if the neurological symptoms were severe or if conservative treatments were not effective. Cleft formation of the vertebra at the OVF site and intensity of intervertebral instability at the affected site were determining factors when selecting surgical procedures. BKP balloon kyphoplasty, OVF osteoporotic vertebral fracture, PLF posterolateral fusion, PLIF posterior lumbar interbody fusion, PSF pedicle screw fixation, VCR vertebral column resection, VP vertebroplasty. Single asterisk denotes VCR was selected in the case of severe intervertebral instability at both upper and lower disc levels of OVF site. Double asterisk denotes PLIF was selected in the case of severe intervertebral instability at an affected site or increased bone fragility at the vertebrae

occurrence of neurological symptoms, and odds ratios were calculated with the 95% confidence interval. $p < 0.05$ was considered significant. An analysis was performed with SPSS (version 14.0; SPSS Inc., Chicago, IL, USA).

Results

Subject characteristics

Of the 104 patients, 21 were men and 83 were women; the average age was 81 years. The OVF sites were L3 for 62 patients, L4 for 36 patients, and L5 for 15 patients. Single-level lower lumbar OVFs were observed in 95 patients, and double levels were found in nine patients. Sixteen patients also had thoracolumbar OVFs (Fig. 1).

All 104 patients had low back pain, and 22 (21%) reported neurological symptoms (Fig. 1). Symptoms included unilateral radicular leg pain in 15 patients, cauda equina signs in six patients, and muscle weakness of the lower limb in two patients (one patient had both leg pain and muscle weakness). The affected disc level was L3–4 for 10 patients and L4–5 for 12 patients. Three patients had foraminal stenosis that was presumably correlated with their neurological symptoms.

Types of lower lumbar OVFs based on early MR images

The kappa coefficients of the evaluation using T1W and T2W MR image-based frequency classifications were 0.80 and 0.85, respectively.

Table 1 shows a comparison of the fracture types, which were determined with early MR images, of all patients in the neurological symptom and non-symptomatic groups. Patients with neurological symptoms mainly had one of two fracture types, indicated by total low (45%) and superior/inferior low-intensity (50%) signals on T1W MR images. However, no specific fracture types were observed on T2W MR images.

Patients with OVFs indicated by total low intensity had a much higher rate of neurological symptoms (45 vs 22%), whereas the proportion of symptomatic to non-symptomatic patients was almost the same for patients with OVFs indicated by superior/inferior low intensity (50 vs 56%) on T1W MR images. Symptomatic patients had a significantly higher frequency of total low-intensity signals on T1W MR images and diffuse low intensity on T2W MR images than non-symptomatic patients. All OVFs indicated by diffuse low intensity on T2W MR images with neurological symptoms ($n = 3$) also showed low intensity on T1W MR images.

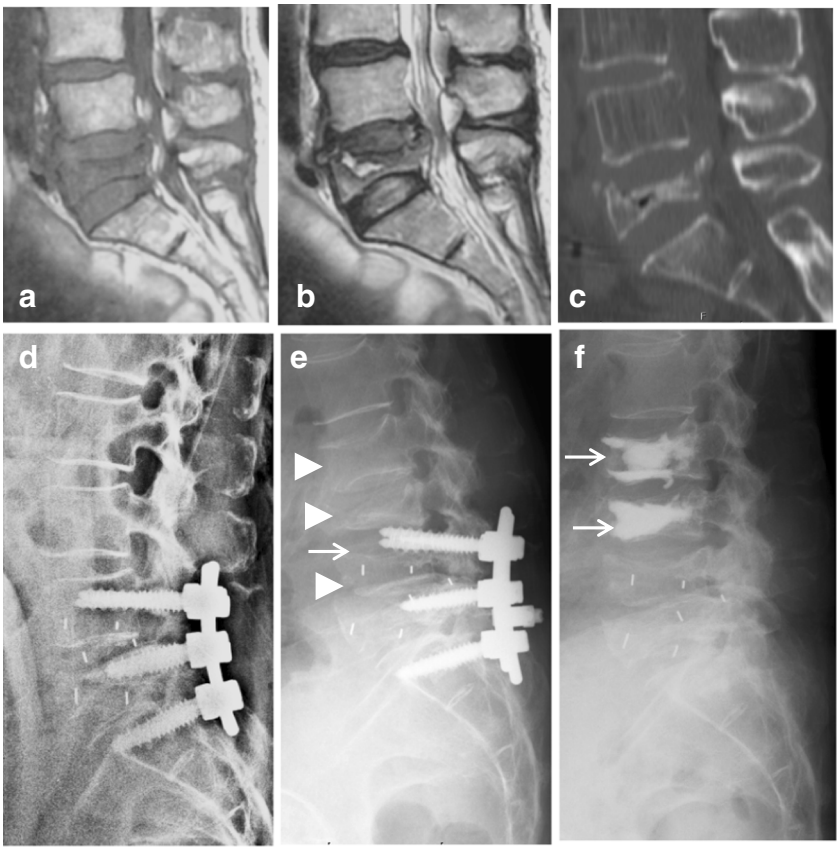


Fig. 3 A 65-year-old woman had an L5 vertebral fracture indicated by total low intensity on T1W MR images with neurological symptoms. Preoperative T1W (**a**) and T2W (**b**) MR images indicated total low intensity and confined high intensity within the L5 vertebra, respectively. Canal stenosis was found at the L4–5 level. A sagittal CT (**c**) showed a small cleft formation within the L5 vertebra. One month later, decompression of L4–5 and PLIF were performed at L4-S1 (**d**). At 7 months postoperatively, L2–4 vertebral fractures (arrowheads), loosening of pedicle screws (arrow), and subsidence of a cage appeared (**e**). At 1 year postoperatively, pedicle screws were removed and BKP was performed at L2 and L3 (arrows) (**f**). BKP balloon kyphoplasty, CT computed tomography, MR magnetic resonance, PLIF posterior lumbar interbody fusion, T1W T1-weighted, T2W T2-weighted

Table 1 Type of lower lumbar OVFs based on early MR images

	Neurological symptomatic patients		Non-symptomatic patients		Total
Patients	22		82		104
T1W images					
Total low intensity	10*	(45%)	18	(22%)	28
Superior/inferior low intensity	11	(50%)	46	(56%)	57
Anterior/posterior low intensity	1	(5%)	4	(5%)	5
Centre low intensity	0		14	(17%)	14
T2W images					
Confined high intensity	5	(23%)	14	(17%)	19
Diffuse high intensity	1	(5%)	3	(4%)	4
Confined low intensity	13	(59%)	51	(62%)	64
Diffuse low intensity	3†	(14%)	1	(1%)	4
Normal	0		13	(16%)	13

Data are number of patients (%)

OVF osteoporotic vertebral fracture, *MR* magnetic resonance, *T1W* T1- weighted, *T2W* T2-weighted

*$p < 0.05$, †$p < 0.01$

Fig. 4 An 85-year-old woman had an L4 vertebral fracture indicated by superior/inferior low intensity on T1W MR images with neurological symptoms. Preoperative T1W (**a**) and T2W (**b**) MR images indicated superior low intensity and confined low intensity within the L4 vertebra, respectively. Lumbar spinal stenosis with degenerative spondylolisthesis was found at the L3–4 level. A sagittal CT (**c**) showed a vertebral fracture at the upper level of the L4 vertebra. Two months later, decompression of L3–4 and PLF and PLIF were performed at L3–5 (**d**). At 2 years after surgery, the L3–5 vertebrae were almost fused (**e**). CT computed tomography, MR magnetic resonance, PLF posterolateral fusion, PLIF posterior lumbar interbody fusion, T1W T1-weighted, T2W T2-weighted

Representative cases of patients with lower lumbar OVFs indicated by total low and superior/inferior low intensity on T1W MR images are shown in Figs. 3 and 4, respectively.

Risk factors for the occurrence of neurological symptoms for all lower lumbar OVF patients

Patients with neurological symptoms had a significantly higher frequency of L4 and L5 vertebral fractures, longer disease duration, higher degree of affected vertebral collapse, smaller canal area, and higher frequency of coexisting degenerative spondylolisthesis than non-symptomatic patients (Fig. 1, Table 2). The multivariate logistic regression analysis showed that risk factors included a longer disease duration and smaller canal area (Table 3).

Risk factors for the occurrence of neurological symptoms for patients with lower lumbar OVFs indicated by total low and superior/inferior low intensity on T1W MR images

For patients with lower lumbar OVFs indicated by total low intensity on T1W MR images, symptomatic patients had a significantly smaller canal area than non-symptomatic patients (Fig. 1, Table 4). In contrast, for patients with lower lumbar OVFs indicated by superior/inferior low intensity on T1W MR images, symptomatic patients had a significantly higher frequency of L4 and L5 vertebral fractures, longer disease duration, smaller canal area, smaller angle between the facets, and higher frequency of coexisting degenerative spondylolisthesis than non-symptomatic patients (Fig. 1, Table 5).

Clinical results of patients with neurological symptoms and lower lumbar OVFs indicated by total low and superior/inferior low intensity on T1W MR images

Table 6 shows the treatment methods used for symptomatic patients with lower lumbar OVFs indicated by total low and superior/inferior low intensity on T1W MR images. BKP was performed only for patients with OVFs indicated by total low intensity, and decompression only was performed for those with OVFs indicated by superior/inferior low intensity.

According to the clinical results of the symptomatic patients with lower lumbar OVFs indicated by total low and superior/inferior low intensity on T1W MR images, the average score of almost every domain of the JOABPEQ was

Table 2 Risk factors of the occurrence of neurological symptoms in all lower lumbar OVF patients

	Neurological symptomatic patients	Non-symptomatic patients	Significance
Patients	22	82	
Age	79.0 ± 6.8	81.9 ± 7.4	NS
Sex (men/women)	2/20	19/63	NS
Affected vertebra (vertebral number)			
Total	24	89	
L3	5	57	
L4	12	24	
L5	7	8	
Frequencies of L4 and L5 OVFs (number of patients (%))	17 (77%)	29 (35%)	$p < 0.001$
Disease duration[a]	1.7 ± 0.8	1.2 ± 0.5	$p < 0.005$
Degree of collapse of the OVF	2.2 ± 0.6	1.8 ± 0.7	$p < 0.05$
Canal area (mm^2)	86.4 ± 32.9	163.2 ± 50.0	$p < 0.001$
Angle between the facets (°)	67.2 ± 18.5	73.1 ± 20.1	NS
Frequency of the coexistence of degenerative spondylolisthesis (number of patients (%))	11 (50%)	11 (13%)	$p < 0.001$
BMD of the hip (% YAM)[b]	70.1 ± 11.2	67.4 ± 13.4	NS

Data are number of patients (%) or mean ± standard deviation

OVF osteoporotic vertebral fracture, *BMD* bone mineral density, *% YAM* percentage of the young adult mean (20–44 years of age), *NS* not significant

[a] Category 1: within 1 month; 2: between 1 and 3 months; and 3: more than 3 months from the onset

[b] Data on BMD of 4 symptomatic patients and 32 non-symptomatic patients were not able to be collected

greater at the time of the final follow-up than that before treatment; the average score for walking ability for patients with OVFs indicated by total low intensity was not greater (Fig. 5a). The average VAS score for pain in the buttocks and lower limb was significantly lower at the time of the final follow-up than before treatment for patients with OVFs indicated by superior/inferior low intensity (Fig. 5b). Moreover, symptomatic patients with OVFs indicated by total low intensity had significantly less improvement in walking ability than did symptomatic patients with OVFs indicated by superior/inferior low intensity (Table 7).

Table 8 shows the complications of symptomatic patients with lower lumbar OVFs indicated by total low and superior/inferior low intensity on T1W MR images. OVFs with lumbar kyphosis (> 10°) tended to recur more often in symptomatic patients with OVFs indicated by total low intensity than in those with OVFs indicated by superior/inferior low intensity ($p = 0.069$); three of these patients underwent BKP during the follow-up period (Fig. 3).

Discussion

In this study, symptomatic patients were mainly classified as patients with OVFs indicated by total low and superior/inferior low intensity on T1W MR images. A smaller canal area was the main risk factor for all patients and patients with OVFs indicated by total low and superior/inferior low intensity on T1W MR images. However, symptomatic patients with OVFs indicated by superior/inferior low intensity had a significantly higher frequency of L4 and L5 vertebral fractures, longer disease duration, smaller angle

Table 3 Independent risk factors of occurrence of neurological symptoms by logistic regression analysis in all lower lumbar OVF patients

	Odds ratio	Confidence interval of 95%	Significance
Disease duration[a]	6.194	1.980–19.379	$p = 0.002$
Canal area (mm^2)	0.953	0.933–0.974	$p < 0.001$

Multivariate logistic regression analysis was performed to OVF site, disease duration, degree of collapse of the OVF, canal area, and frequency of the coexistence of degenerative spondylolisthesis

OVF osteoporotic vertebral fracture

[a] Category 1: within 1 month; 2: between 1 and 3 months; and 3: more than 3 months from the onset

Table 4 Risk factors for the occurrence of neurological symptoms in the patients with lower lumbar OVFs indicated by total low intensity on T1W MR images

	Neurological symptomatic patients	Non-symptomatic patients	Significance
Patients	10	18	
Age	77.3 ± 7.6	82.1 ± 8.1	NS
Sex (men/women)	0/10	4/14	NS
Frequencies of L4 and L5 OVFs (number of patients (%))	8 (80%)	9 (50%)	NS
Disease duration[a]	2.0 ± 0.8	1.6 ± 0.7	NS
Degree of collapse of the OVF	2.3 ± 0.7	2.1 ± 0.8	NS
Canal area (mm^2)	101.1 ± 29.8	169.7 ± 52.2	$p < 0.005$
Angle between the facets (°)	73.9 ± 14.0	69.8 ± 24.0	NS
Frequency of the coexistence of degenerative spondylolisthesis (number of patients (%))	4 (40%)	2 (11%)	NS
BMD of the hip (% YAM)[b]	68.9 ± 14.0	63.6 ± 14.4	NS

Data are number of patients (%) or mean ± standard deviation

OVF osteoporotic vertebral fracture, *T1W* T1-weighted, *MR* magnetic resonance, *BMD* bone mineral density, *% YAM* percentage of the young adult mean (20–44 years of age), *NS* not significant

[a] Category 1: within 1 month; 2: between 1 and 3 months; and 3: more than 3 months from the onset

[b] Data on BMD of 3 non-symptomatic patients were not able to be collected

between the facets, and higher frequency of coexisting degenerative spondylolisthesis than non-symptomatic patients. In addition, symptomatic patients with OVFs indicated by total low intensity had significantly fewer clinical results than those with OVFs indicated by superior/inferior low intensity. This strongly suggested that lower lumbar OVFs with neurological symptoms might have two different pathogeneses according to early MR images. In this study, 21% of patients reported neurological symptoms, and 14% underwent surgery for a lower lumbar OVF. OVFs usually occur in the thoracolumbar area; in one study, 3% of patients reported neurological symptoms [14]. In our study, 24 patients (4%) among all OVF patients (669 patients) underwent surgery for neurological symptoms. Therefore, lower lumbar OVFs might create a greater risk for neurological symptoms than thoracolumbar OVFs. This may be because of the higher frequency of canal stenosis at the lower lumbar area in elderly people.

Table 5 Risk factors for the occurrence of neurological symptoms in the patients with lower lumbar OVFs indicated by superior/inferior intensity on T1W MR images

	Neurological symptomatic patients	Non-symptomatic patients	Significance
Patients	11	46	
Age	80.4 ± 6.3	81.7 ± 6.5	NS
Sex (men/women)	2/9	8/38	NS
Frequencies of L4 and L5 OVFs (number of patients (%))	8 (73%)	15 (33%)	$p < 0.05$
Disease duration[a]	1.5 ± 0.8	1.1 ± 0.4	$p < 0.05$
Degree of collapse of the OVF	2.0 ± 0.4	1.7 ± 0.7	NS
Canal area (mm^2)	72.1 ± 32.0	171.5 ± 46.0	$p < 0.001$
Angle between the facets (°)	61.1 ± 21.3	76.6 ± 19.6	$p < 0.05$
Frequency of the coexistence of degenerative spondylolisthesis (number of patients (%))	7 (64%)	8 (17%)	$p < 0.005$
BMD of the hip (% YAM)[b]	71.5 ± 7.1	67.8 ± 12.2	NS

Data are number of patients (%) or mean ± standard deviation

OVF osteoporotic vertebral fracture, *T1W* T1-weighted, *MR* magnetic resonance, *BMD* bone mineral density, *% YAM* percentage of the young adult mean (20–44 years of age), *NS* not significant

[a] Category 1: within 1 month; 2: between 1 and 3 months; and 3: more than 3 months from the onset

[b] Data on BMD of 3 symptomatic patients and 18 non-symptomatic patients were not able to be collected

Table 6 Treatment methods of neurological symptomatic patients with lower lumbar OVFs indicated by total low and superior/inferior low intensity on T1W MR images

	Patients	Conservative treatment	BKP or BKP + PLF	Decompression only	PLF or PLIF (fusion area)[a]
Symptomatic patients with OVFs indicated by total low intensity	10	3	2	0	5 (2.6 ± 0.9 segments)
Symptomatic patients with OVFs indicated by superior/inferior low intensity	9	1	0	3	5 (2.4 ± 0.5 segments)

Data are number of patients and fusion area showed mean ± standard deviation

OVF osteoporotic vertebral fracture, *T1W* T1-weighted, *MR* magnetic resonance, *BKP* balloon kyphoplasty, *PLF* posterolateral fusion, *PLIF* posterior lumbar interbody fusion

[a] There were no significant differences in the proportion of treatment with fusion and length of the fusion area between the two groups

The total low intensity on T1W MR images indicated a wide area of damage within the vertebrae and a high risk of collapse or pseudoarthrosis [5, 6], which might have aggravated pre-existing lumbar canal stenosis [11, 12]. Patients with OVFs indicated by total low intensity had a much higher rate of neurological symptoms (Table 1). Accordingly, in this study, patients with OVFs indicated by total low intensity may have been at a higher risk for the development of neurological symptoms than those with OVFs indicated by superior/inferior low intensity on T1W MR images.

In contrast, the superior/inferior low intensity on T1W MR images indicated mild damage within the affected vertebrae and a small risk of collapse or pseudoarthritis. However, longer disease duration may lead to delayed diagnosis and treatment, which interfere with normal fracture healing. The smaller angle between the facets and higher frequency of coexisting degenerative spondylolisthesis indicated that there was a high risk of intervertebral instability in the affected vertebrae, which is often found in the L4 and L5 vertebrae. Therefore, for symptomatic patients with OVFs indicated by superior/inferior low intensity, intervertebral instability increased after an OVF developed, which deteriorated the pre-existing canal stenosis, resulting in the occurrence of neurological symptoms.

Symptomatic patients with OVFs indicated by total low intensity had significantly less improvement in walking ability

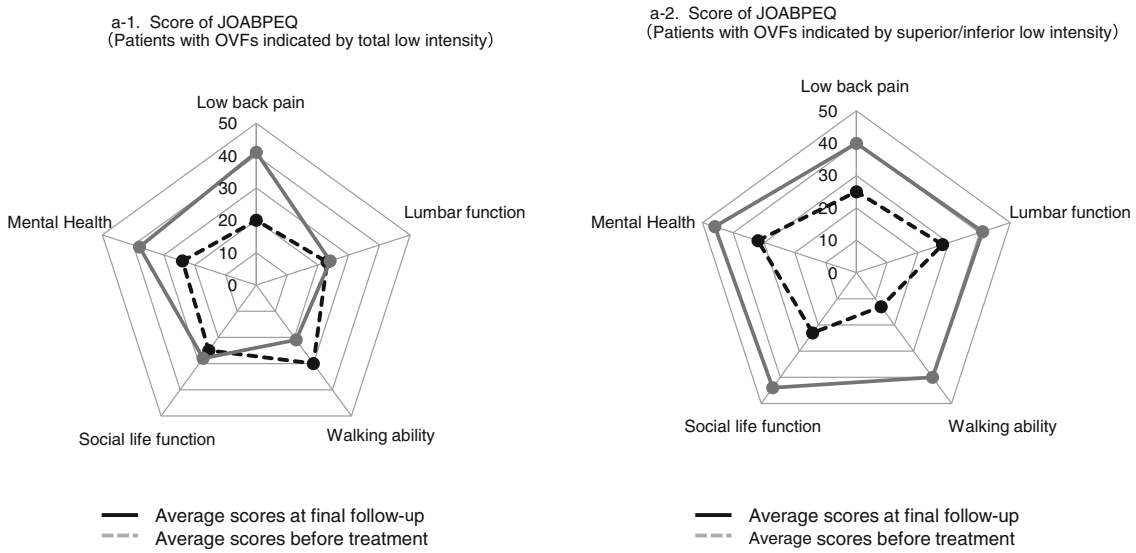


Fig. 5 Clinical results of patients who reported neurological symptoms after lower lumbar osteoporotic vertebral fractures indicated by total low and superior/inferior low intensity on T1W MR images. The scores for almost every domain of the JOABPEQ were greater at the time of the final follow-up examination than before treatment in both groups; scores for walking ability of patients with OVFs indicated by total low intensity were not greater (**a**). The VAS score for pain in the buttocks and lower limb was significantly lower at the time of the final follow-up than before treatment for patients with OVFs indicated by superior/inferior low intensity (**b**). JOABPEQ Japanese Orthopaedic Association Back Pain Evaluation Questionnaire, MR magnetic resonance, OVF osteoporotic vertebral fracture, T1W T1-weighted, VAS visual analogue scale

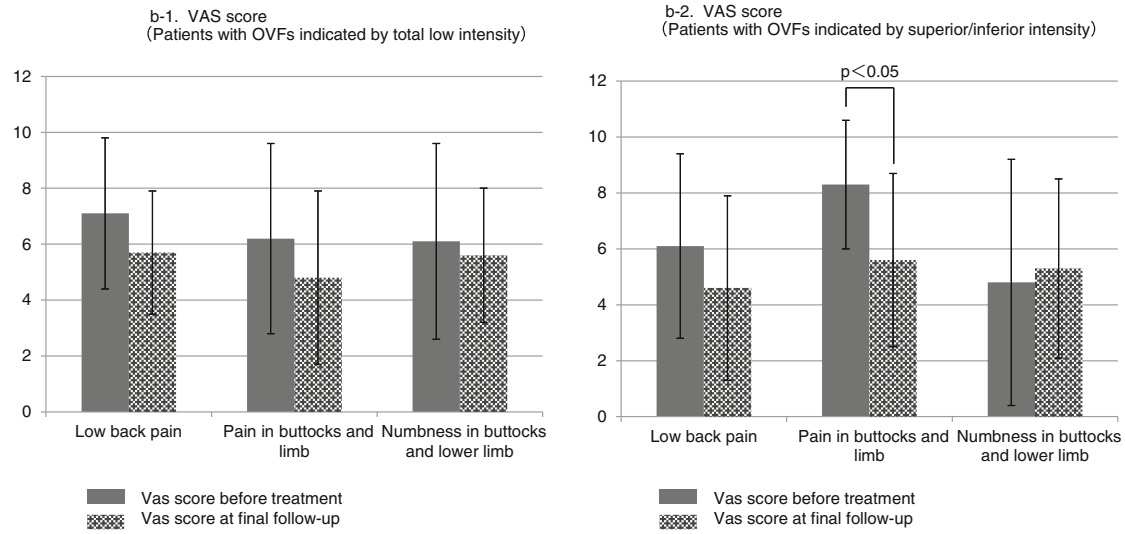


Fig. 5 continued.

Table 7 Clinical results of neurological symptomatic patients with lower lumbar OVFs indicated by total low and superior/inferior low intensity on T1W MR images

	Symptomatic patients with OVFs indicated by total low intensity	Symptomatic patients with OVFs indicated by superior/inferior low intensity	Significance
Domains of JOABPE-Q	Increased scores	Increased scores	
Low back pain	21.9 ± 32.3	14.2 ± 53.0	NS
Lumbar function	0.7 ± 20.0	12.9 ± 42.6	NS
Walking ability	− 8.6 ± 35.9	26.2 ± 28.5	$p < 0.05$
Social life function	3.8 ± 18.8	21.0 ± 31.9	NS
Mental health	14.4 ± 16.4	13.9 ± 19.5	NS
VAS scores	Decreased scores	Decreased scores	
Low back pain	14.2 ± 26.1	15.2 ± 39.3	NS
Pain in the buttock and lower limb	14.4 ± 40.6	27.7 ± 30.0	NS
Numbness in the buttock and lower limb	5.5 ± 38.8	− 5.0 ± 33.8	NS

Data are mean ± standard deviation

OVF osteoporotic vertebral fracture, *T1W* T1-weighted, *MR* magnetic resonance, *JOABPEQ* Japanese Orthopaedic Association Back Pain Evaluation Questionnaire, *VAS* visual analog scale, *NS* not significant

than symptomatic patients with OVFs indicated by superior/inferior low intensity on T1W MR images. One reason for this is that OVFs with lumbar kyphosis tended to recur more often in symptomatic patients with OVFs indicated by total low intensity than in those with OVFs indicated by superior/inferior low intensity. This complication was found after fusion surgery in two patients, BKP in one patient, and conservative treatment in two patients with OVFs indicated by total low intensity. Nakajima et al. [11] found that postoperative kyphosis combined with postoperative re-fracture and instrumentation failure led to deterioration of the clinical results after fusion surgery for lower lumbar OVFs. Although there were no significant differences in BMD between the symptomatic patients with OVFs indicated by total low and superior/inferior low intensity on T1W MR images, symptomatic patients with OVFs indicated by total low intensity might have had increased bone fragility compared to those with OVFs indicated by superior/inferior low intensity.

Symptomatic patients with OVFs indicated by total low intensity may be at a higher clinical risk than those with OVFs indicated by superior/inferior low intensity on T1W MR images. Because patients with OVFs indicated by total low and superior/inferior low intensity may have different pathogeneses of neurological symptoms, symptomatic patients with OVFs indicated by total low intensity may require different treatment strategies. Early administration of strong medicine to treat osteoporosis, early surgical treatment before the collapse of OVFs, and longer PSF augmented with a hook system or Tech Milon tape may contribute to successful outcomes.

This study had some limitations. First, the sample size was small because lower lumbar OVFs generally occur at a lower frequency than thoracolumbar OVFs. Second, because the patients were elderly and some had comorbidities, the overall clinical outcome was quite poor and long-term follow-up was

Table 8 Complications of neurological symptomatic patients with lower lumbar OVFs indicated by total low and superior/inferior low intensity on T1W MR images

	Patients	Recurrence of OVFs	Recurrence of OVFs with lumbar kyphosis[a]	Recurrence of neurological symptoms	Reoperation
Symptomatic patients with OVFs indicated by total low intensity	10	6 (10)	5 (9)	1	3[b]
Symptomatic patients with OVFs indicated by superior/inferior low intensity	9	3 (4)	1 (2)	2	1[c]

Data are number of patients (number of vertebrae)

OVF osteoporotic vertebral fracture, *T1W* T1-weighted, *MR* magnetic resonance;

[a] Lumbar kyphotic angle (L1-S1) was increased more than 10° after OVFs

[b] All the reoperations were BKP due to recurrence of OVFs

[c] The reoperation was laminectomy due to stenosis adjacent to fusion site

difficult. Treatments should begin for those patients as soon as possible. Third, we were not able to collect all data regarding BMD.

Conclusion

Patients with neurological symptoms and lower lumbar OVFs mainly had one of two fracture types, as indicated by total low and superior/inferior low-intensity signals on T1W MR images. Patients with lower lumbar OVFs indicated by total low and superior/inferior low intensity had different risk factors for the occurrence of neurological symptoms. Symptomatic patients with OVFs indicated by total low intensity had poorer clinical results than those with OVFs indicated by superior/inferior low intensity. Therefore, lower lumbar OVFs with neurological symptoms may have two different pathogeneses according to early MR images. Compared with patients with OVFs indicated by superior/inferior low intensity, symptomatic patients with lower lumbar OVFs indicated by total low intensity might require different treatment strategies to avoid symptoms.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Ethical approval The ethics committee for human research at our hospital approved the study protocol, and informed consent to undergo an examination and operation was obtained from all patients. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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