Surgical treatment of low lumbar osteoporotic vertebral collapse: a single-institution experience

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OBJECTIVE Low lumbar osteoporotic vertebral collapse (OVC) has not been well documented compared with OVC of the thoracolumbar spine. The differences between low lumbar and thoracolumbar lesions should be studied to provide better treatment. The aim of this study was to clarify the clinical and imaging features as well as outcomes of low lumbar OVC and to discuss the appropriate surgical treatment.

METHODS Thirty patients (10 men; 20 women; mean age 79.3 ± 4.7 years [range 70–88 years]) with low lumbar OVC affecting levels below L-3 underwent surgical treatment. The clinical symptoms, morphological features of affected vertebra, sagittal spinopelvic alignment, neurological status before and after surgery, and surgical procedures were reviewed at a mean follow-up period of 2.4 years.

RESULTS The main clinical symptom was radicular leg pain. Most patients had old compression fractures at the thoracolumbar level. The affected vertebra was flat-type and concave or H-shaped type, not wedge type as often found in thoracolumbar OVC. There were mismatches between pelvic incidence and lumbar lordosis on plain radiographs. On CT and MR images, foraminal stenosis was seen in 18 patients (60%) and canal stenosis in 24 patients (80%). Decompression with short fusion using a posterior approach was performed. Augmentations of vertebroplasty, posterolateral fusion, and posterior lumbar interbody fusion were performed based on the presence/absence of local kyphosis of lumbar spine, cleft formation, and/or intervertebral instability. Although the neurological and visual analog scale scores improved postoperatively, 8 patients (26.7%) developed postoperative complications mainly related to instrumentation failure. In patients with postoperative complications, lumbar spine bone mineral density was significantly low, but the spinopelvic alignment showed no correlation when compared with those without complications.

CONCLUSIONS The main types of low lumbar OVC were flat-type and concave type, which resulted in neurological symptoms by retropulsed bony fragments generating foraminal stenosis and/or canal stenosis. For patients with low lumbar OVC, decompression of the foraminal and canal stenosis with short fusion surgery via posterior approach can improve neurological symptoms. Since these patients are elderly with poor bone quality and other complications, treatments for both OVC and osteoporosis should be provided to achieve good clinical outcome.

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KEY WORDS osteoporotic vertebral collapse; low lumbar spine; clinical feature; surgery; clinical outcome

THE incidence of vertebral body fracture associated with osteoporosis increases as the population ages.^{2,12} Most cases can be managed conservatively, but cases with neurological complications should be treated surgically to allow patients early return to daily life activities. About 30% of patients with vertebral body fracture present with progressive collapse, 13% show vertebral nonunion, and 3% develop osteoporotic vertebral collapse (OVC) with neurological deficits.²⁵ Osteoporotic vertebral fractures commonly affect the thoracolumbar

spine; however, they are also often found in low lumbar spine levels. In this regard, a large number of patients have been reported with thoracolumbar osteoporotic vertebral fractures and collapse, and various treatment modalities have been described to date, including both surgical and conservative therapies.^{5,10} However, there are only a few reports on treatment of patients with low lumbar OVC.

Lesions at the thoracolumbar junction manifest specific neurological symptoms since that level of the spinal column contains a complex of nerve structures, such as the

ABBREVIATIONS BMD = bone mineral density; JOA = Japanese Orthopaedic Association; LL = lumbar lordosis; OVC = osteoporotic vertebral collapse; PI = pelvic incidence; PLF = posterolateral fusion; PLIF = posterior lumbar interbody fusion; PSF = pedicle screw fixation; PT = pelvic tilt; PTH = parathyroid hormone; SS = sacral slope; VAS = visual analog scale; VCR = vertebral column resection; VP = vertebroplasty.

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spinal cord, conus medullaris, and cauda equina. The objective neurological symptoms caused by thoracolumbar OVC do not only include motor weakness but also urinary disturbance and/or significant sensory disturbance. On the other hand, the low lumbar spine presents lordotic alignment, and the spinal column contains only cauda equina. Because of these anatomical features, no neurological complications are encountered in low lumbar OVC, and the rate of surgical indication may be lower compared with thoracolumbar lesions. However, it is also important to study other differences between low lumbar OVC and thoracolumbar lesions: clinical status, neurological symptoms, radiological findings, and surgical strategies.

Surgical treatment of the osteoporotic spine is challenging, and various surgical procedures using a variety of techniques have been advocated in the management of OVC. Importantly, most patients who receive surgical treatment are elderly, and prolonged surgical stress may involve risks. Therefore, the important question of how to improve surgery for OVC remains somewhat unanswered. Especially for low lumbar OVC, the same treatment used for thoracolumbar lesion might not be suitable. Posterior decompression surgery alone is not sufficient for these patients because neurological symptoms may result from retropulsed bony fragments and vertebral instability. Watanabe et al.²⁹ evaluated the surgical results of lumbar spinal canal stenosis associated with compression fracture at L3–5 and reported that the mean recovery rate of the Japanese Orthopaedic Association (JOA) score at final follow-up was 50.4% in patients who underwent posterior decompression surgery and 66.7% in patients who underwent posterior intervertebral fusion surgery.

In the present study, we describe the clinical and radiological features and outcome of 30 consecutive patients with low lumbar OVC and associated neurological symptoms who underwent surgical treatment. Intervertebral cleft is a highly suggestive sign of osteonecrosis and has dynamic mobility indicating instability within the fracture. Because additional support of the anterior column might be necessary to provide stabilization and pain relief, we stratified these patients by the presence of cleft formation. The primary purpose of this study was to discuss the appropriate choice of surgical treatment and outcome for low lumbar OVC. For this purpose, we examined the differences in clinical and imaging features and associated neurological symptoms of low lumbar OVC compared with those of thoracolumbar lesions.

Methods

Study Design, Inclusion, and Exclusion

We retrospectively reviewed the medical records of 123 patients who underwent surgeries for OVC between 1993 and 2013 at our university medical center. Among these patients, we enrolled 30 patients (10 men and 20 women) (24.4%) whose affected vertebral levels were below L-3. The affected vertebrae were L-3 collapse in 12 patients, L-4 in 13, and L-5 in 5. The mean age at surgery was 79.3 ± 4.7 years (range 70–88 years). All 30 patients initially received conservative treatment, but neurological symptoms subsequently developed and/or vertebral collapse

progressed gradually. Of these 30 patients, cleft formation was identified on the radiographs and MR images at the affected vertebra in 14 patients. None of the patients had comorbidities that directly caused sensory or motor deficits in the lower extremities.

Surgeries

The surgeries for patients with cleft formation at affected vertebra ($n = 14$) were vertebroplasty (VP) in 2 patients and the combination of decompression, VP, pedicle screw fixation (PSF), and posterolateral fusion (PLF) in 12 patients. We have favored since approximately 2005 a method by which vertebral reconstruction was performed with hydroxyapatite blocks or calcium phosphate cement filling via the pedicle of the fractured vertebra and supplemented by fixation of the vertebrae above and below with PSF. For patients without cleft formation ($n = 16$), we performed decompression, PSF, and PLF in 10 patients, and posterior lumbar interbody fusion (PLIF) in 4 patients. In 2 cases (cleft formation was identified in 1 patient), correction osteotomy (Ponte osteotomy, pedicle subtraction osteotomy, and vertebral column resection [VCR]) was performed. The 2 senior surgeons (H.B. and K.U.) performed all surgeries using a uniform technique. To avoid bias, the same surgeons were excluded from postoperative evaluation.

Outcomes

The clinical symptoms, low-back pain, radicular leg pain, and cauda equine sign, were assessed and stratified by the presence of cleft formation. The neurological status of each patient was assessed according to the JOA scoring system, and the postoperative neurological improvement rate was calculated using the following formula: $(\text{postoperative follow-up JOA score} - \text{preoperative JOA score}) \times 100 / (29 - \text{preoperative JOA score})$. All patients completed a 10-point visual analog scale (VAS) as an assessment of their pain. Neurological outcomes, VAS scores, imaging, and postoperative complications of these patients were followed for ≥ 1 year (3 and 6 months and every year after operation; mean 2.4 years, range 1.0–4.5 years). The human ethics review committee of our institution approved the study protocol, and a signed informed consent was obtained from each patient before enrollment in the study.

Radiological Assessment

Radiological studies comprised plain lumbopelvic radiographs (neutral, flexion, and extension views), CT scanning (CT/T 8800, General Electric), and high-resolution MRI (1.5 Tesla Signa, General Electric).

On the plain radiographs, we assessed other vertebral collapses (if any), the type of vertebral collapse, intervertebral instability, and sagittal spinopelvic alignment before and after surgery. Each OVC was classified into 1 of 3 different types based on its appearance on the lateral projection in neutral position, as described in previous reports,^{4,15,17,22} including 1 report by our group^{3,26,27} (Fig. 1). In Type 1, or wedge-type collapse, the ratio of the anterior height of the vertebral body to its posterior height was $< 60\%$. Type 2 encompassed flat fracture or vertebra plana-like fracture with uniform compression. Type 3 included

FIG. 1. Illustrations showing the 3 types of OVC classified according to appearance on lateral radiographs and MR images. For wedge collapse (**Type 1**), the ratio of anterior height to posterior height of the vertebral body is less than 60%. Flat or vertebra plana (**Type 2**) has uniform compression that is often associated with the appearance of intervertebral cleft formation. Concave collapse (**Type 3**) shows anterior spur, sclerotic changes, or H shape. Arrows indicate regions of collapse.

concave or H-shaped fracture with anterior spur formation or sclerotic change. Type 2 collapse is often associated with the appearance of intervertebral cleft formation on radiographs or MR images.^{6,13}

We assessed the following parameters to determine the spinopelvic alignment^{11,21}: pelvic incidence (PI), defined as the angle between a line joining the center of the upper endplate of S-1 to the axis of the femoral heads and a line perpendicular to the upper endplate of S-1; lumbar lordosis (LL), defined as the angle between tangent lines to the inferior endplates of L-1 and superior endplates of S-1; pelvic tilt (PT), defined as the angle between a vertical line and the line joining the middle of the sacral plate and the axis of the femoral heads; sacral slope (SS), defined as the angle between the endplate of S-1 and a horizontal line. On the sagittal, axial, and coronal CT scans and MRI images, we assessed the presence of foraminal stenosis and canal stenosis (Fig. 2). Bone mineral density (BMD) of the lumbar spine (L1–4) in the posteroanterior projection was measured with dual-energy x-ray absorptiometry (QDR 1000, Hologic), and the results are expressed in g/cm². Plain radiographs and CT scans were followed up 3 and 6 months and every year postoperatively. Two independent observers were responsible for radiological assessment, and both were blinded to the data related to surgery.

Statistical Analysis

Clinical and radiological findings were assessed by observers independent of the principal surgeons (H.N. and

K.H.). All values are expressed as mean $\pm$ SD. Differences between groups were examined for statistical significance using Wilcoxon signed-rank test or Mann-Whitney U-test. A probability value less than 0.05 was considered to represent a statistically significant difference. All statistical analyses were conducted using the SPSS software (version 15.0, SPSS).

Results

Clinical Symptoms and Surgical Outcomes

Table 1 summarizes the symptoms of the 30 patients with low lumbar OVC stratified by the presence of cleft formation. The majority of patients with cleft formation at the affected vertebra complained of both severe low-back pain (85.7%) and radicular pain (85.7%), while the incidence of low-back pain was much lower (25.0%) in those without cleft formation than those with radicular pain (93.8%). The mean JOA score improved significantly from 13.8 ± 5.5 preoperatively to 22.4 ± 5.9 at follow-up; the mean improvement rate was $61.4\% \pm 24.8\%$. The mean VAS pain score improved significantly from 8.1 ± 1.3 preoperatively to 3.5 ± 2.1 at follow-up. There was no significant difference in JOA score or VAS pain score among those with cleft formation or surgical procedures.

Image Findings in Patients With Low Lumbar OVC

Assessment of the plain radiographs showed that most patients (25 patients [83.3%]) presented with old compression fractures at the thoracolumbar level. With regard to

FIG. 2. Representative preoperative radiological images showing foraminal stenosis, canal stenosis, and intervertebral instability. **A:** Parasagittal (left) and axial (right) CT scans showing foraminal stenosis (arrows). **B:** T2-weighted MR image showing canal stenosis (arrow). **C:** Dynamic sagittal radiograph (left) and sagittal CT scan (right) showing intervertebral instability.

TABLE 1. Symptoms of patients with low lumbar vertebral collapse*

Symptom	Cleft Formation in Affected Vertebra	
	Present	Absent
Low-back pain	12/14 (85.7)	4/16 (25.0)
Radicular pain	12/14 (85.7)	15/16 (93.8)
Cauda equina sign	5/14 (35.7)	4/16 (25.0)

* Data are number of patients/total number of patients (%).

the type of OVC, none of the patients had Type 1 vertebral collapse (wedge-type), 16 patients had Type 2 (flat-type), and 14 patients had Type 3 (concave or H-shaped type). Fourteen patients (87.5%) with Type 2 vertebral collapse had cleft formation at the affected vertebra. In 11 patients (36.7%), intervertebral instability was evident between the upper and affected vertebra. In all of these patients, there was no cleft formation at the affected vertebra; 11 (68.8%) of 16 patients without cleft formation demonstrated intervertebral instability. Table 2 provides the means and SDs of sagittal spinopelvic alignment before and at the last available follow-up after surgery. LL decreased ($16.5^\circ \pm 10.2^\circ$), and a mismatch between PI and LL ($30.4^\circ \pm 10.0^\circ$) was detected in patients with low lumbar OVC. However, it was difficult for the surgical subjects selected in this study to achieve proper spinopelvic alignment after treatment. Examination of CT scans and MR images showed foraminal stenosis in 18 (60.0%) of 30 patients as well as canal stenosis in 24 (80.0%) of 30 of the patients.

Postoperative Complications and Related Factors

Postoperative complications occurred in 8 patients (26.7%), including progression of vertebral collapse in 4 and loosening and migration of pedicle screws in 8; these complications developed within 6 months after surgery (Table 3). The migration of pedicle screws occurred in 5 patients after VP + PSF + PLF and in 3 patients after PSF + PLF; most of these postoperative complications occurred before bone union of PLF. Among these patients, 2 showed vertebral collapse progression at adjacent vertebra and kyphotic changes associated with loosened pedicle screws; revision surgeries were performed in both patients. Table 4 provides summary data on sagittal alignment and bone density in relation to postoperative complications.

TABLE 2. Sagittal spinopelvic alignment before and after surgery*

Alignment	Before Surgery	Follow-Up	p Value†
PI‡	46.3 ± 6.0		—
LL	16.5 ± 10.2	20.5 ± 10.2	0.316
PT	17.4 ± 7.5	16.4 ± 7.3	0.387
SS	28.9 ± 6.0	29.9 ± 7.5	0.352
PI – LL	30.4 ± 10.0	26.5 ± 12.7	0.406

* Data are mean angle in degrees ± SD.

† Based on Wilcoxon signed-rank test.

‡ Value is a patient-specific characteristic and remains unchanged after surgery.

TABLE 3. Postoperative complications

Complication & Level	No. of Cases	Postop Period (mos)
Progression of vertebral collapse		
Affected vertebra	1	6
Adjacent vertebra	2	5 and 6
Remote vertebra	1	3
Loosening and migration of pedicle screw		
Upper level	8	3–6

There was no change in sagittal spinopelvic alignment after surgery in relation to postoperative complications. However, lumbar spine BMD was significantly lower in patients with postoperative complications ($p = 0.048$).

Discussion

The aim of this study was to clarify the clinical and imaging features as well as outcomes of low lumbar OVC and to discuss the appropriate surgical treatment. The major findings of our research were 1) the morphological features of OVC in patients with low lumbar vertebra are flat-type (Type 2) and concave or H-shaped type (Type 3) with old compression fracture at the thoracolumbar lesion; 2) intervertebral cleft was evident mainly in Type 2 collapse while intervertebral instability was evident mainly in Type 3 collapse; 3) the main clinical symptom in these patients is radicular leg pain originating from foraminal stenosis by retropulsed bony fragments; 4) for patients with cleft formation at the affected vertebra, we recommend VP-augmented short-segment fixation; 5) for patients without cleft formation at the affected vertebra, we recommend PLIF or PLF according to the presence of intervertebral instability; and 6) the high postoperative complication rates could be due to vertebral fragility and/or old age.

OVC is treated surgically in patients with severe and intractable back pain, neurological complications, and/or impending paralysis. Significant clinical challenges must be acknowledged when performing surgical treatment, including the advanced age of the patients, fragility of the vertebra, and presence of serious comorbidities. In this study, the mean age of the patients at surgery was 79.3

TABLE 4. Comparison of patients with and without complications*

Alignment	Surgery	w/ Complications	w/o Complications	p Value†
PI	—	45.4 ± 6.3	46.9 ± 6.2	0.690
LL	Before	21.5 ± 9.1	16.4 ± 8.9	0.391
	After	24.7 ± 5.9	18.6 ± 11.6	0.270
PI – LL	Before	26.5 ± 10.8	31.4 ± 10.0	0.480
	After	22.7 ± 8.1	30.1 ± 13.0	0.481
Lumbar spine BMD (g/cm ²)	Before	0.60 ± 0.08	0.68 ± 0.05	0.048

* Data are mean angle in degrees ± SD except where otherwise indicated.

† Based on Mann-Whitney U-test.

FIG. 3. Illustrations showing pathomechanism of low lumbar OVC.

A: Diagrams showing existing thoracolumbar compression and decreasing LL (L1–S1) seen in most patients (*left and center*), with middle and/or posterior loading to low lumbar spine increasing (*right*) following spinal alignment changes. **B and C:** Diagram depicting cases of flat-type (B) and concave or H-shaped type (C) collapse, where foraminal stenosis and/or canal stenosis by the bony fragments are often seen. **D:** Illustration showing intervertebral instability between affected and upper vertebra often seen in cases of concave or H-shaped type OVC.

years, which is considerably older than patients with thoracolumbar vertebral collapse (70.3 years) described in our previous study.²⁷ The average lumbar spine BMD of these patients was 0.64 g/cm², indicating poor bone quality. Due to anatomical differences between thoracolumbar and low lumbar lesions with regard to nerve structures and spinal alignment, the treatment strategies for the 2 lesions are also different.

OVC are divided into several types according to their

appearance on radiological studies: a wedge-type compression fracture (Type 1) exhibiting progressive kyphosis; a flat-type fracture (Type 2) with osteonecrosis or pseudarthrosis, often exhibiting intervertebral cleft formation; and a concave or H-shaped fracture (Type 3) associated with anterior spur or sclerotic changes. In the present study, vertebral collapse was classified into 3 types based on its appearance on preoperative lateral radiographs. We found that the main types of low lumbar OVC were flat-type (Type 2) and concave or H-shaped type (Type 3), not the wedge type (Type 1), as often found in thoracolumbar OVC. The different proportions are probably related to differences in the pathomechanisms of low lumbar OVC and thoracolumbar lesions. Based on the results of the present study, most patients with low lumbar OVC presented with old compression fractures at the thoracolumbar lesion, with decreased LL. This is because the types of OVC between thoracolumbar and low lumbar lesions were different; middle and/or posterior low lumbar spine loading is increased following spinal alignment changes (Fig. 3A). In the flat-type (Type 2) and concave or H-shaped type (Type 3) low lumbar OVC, neurological symptoms result from retropulsed bony fragments causing foraminal stenosis and/or canal stenosis^{8,19} (Fig. 3B and C). In general, foraminal stenosis is classified into anteroposterior stenosis “transverse stenosis” and craniocaudal stenosis “vertical stenosis.” Protrusion of the posterior wall of the vertebral body and facet hypertrophy can cause anteroposterior compression with or without canal stenosis. On the other hand, reduced vertebral body height with bony defect at the caudal side of the affected vertebra is detected in some cases, and when under the upper pedicle can cause craniocaudal compression in a fractured spine.²⁰ Some cases of concave or H-shaped type (Type 3) vertebra showed sclerotic changes, with higher chance of intervertebral instability between affected and upper vertebra (Fig. 3D). In these situations,

FIG. 4. Schematic showing the surgical strategy for low lumbar OVC. The procedure used was based on the following factors: kyphotic changes in the lumbar spine, intervertebral cleft formation, and intervertebral instability. The number of patients in procedures denoted by the dotted arrows was small. PSO = pedicle subtraction osteotomy. Figure is available in color online only.

FIG. 5. Case of a 70-year-old woman with burst fracture at the anterior column of L-3 and local kyphosis due to OVC is representative of correction osteotomy for local kyphotic changes in the lumbar spine. **A and B:** Dynamic radiographs showing vertebral instability. **C:** Radiograph showing the vacuum phenomenon in both L2–3 and L3–4 discs. **D:** Sagittal T2-weighted MR image showing compression of the dural tube between L2–3 and L3–4 levels. **E:** Radiograph taken after VCR with vertebral body replacement and PSF (L1–5) was performed.

direct decompression of nerve tissue and reconstruction of the spinal column is required.

With regard to the surgical strategy for thoracolumbar OVC, from a biomechanical point of view, when only the anterior column is injured among the three Denis-defined columns and characteristic progressive kyphosis is evident, combined anterior decompression and fusion is the ideal choice.^{9,27} However, for low lumbar OVC, the posterior approach may be the ideal surgical option because the main pathology, fractured bone, is located at the middle and posterior parts of the affected vertebra; the decompression procedure for lumbar canal and intervertebral foramen is easier and the anterior approach to low lumbar spine is difficult; and an anterior approach poses risks to abdominal organs and vessels, which could cause serious complications in elderly patients. Figure 4 shows the

surgical strategies for low lumbar OVC based on our observations and experience in the present study. Although our primary method of short fusion using a posterior approach was considered the less stressful or less invasive operation to resolve back pain and radicular leg pain, correction osteotomy and long fusion were performed in a few cases to restore spine alignment¹⁸ (Figs. 4 and 5). Although most cases of low lumbar OVC presented decreased LL, they rarely exhibited kyphotic changes since the ratio of wedge-type collapse was low. For patients with cleft formation at the affected vertebra, VP + PS + PLF are recommended (Figs. 4 and 6). In our previous study on thoracolumbar OVC, we reported that VP-augmented short-segment fixation seems to offer immediate spinal stability, and the effect seemed equivalent to that of anterior reconstruction.^{26,28} Similar to low lumbar OVC,

FIG. 6. Case of an 80-year-old man with L-3 flat-type collapse and intervertebral cleft formation, who presented with severe low-back pain and bilateral radicular leg pain, is representative of patients with cleft formation at affected vertebra. **A:** Preoperative sagittal radiograph showing L-3 collapse (flat-type). **B–E:** Preoperative parasagittal (B) and axial (C) CT scans and axial (D) and sagittal (E) T2-weighted MR images showing L-3 collapse (arrowhead) with intervertebral cleft formation and canal stenosis by bony fragments (arrows) that had retropulsed into the spinal canal and can be seen between L2–3 and L3–4. **F and G:** Postoperative sagittal (F) and coronal (G) radiographs showing VP at L-3 with PSF and PLF (L2–4).

FIG. 7. Case of a 74-year-old woman with L-4 flat-type collapse and intervertebral cleft formation, who is representative of patients who required revision surgery. **A and B:** Preoperative lateral plain radiograph (A) and sagittal T2-weighted MR image (B) showing flat-type collapse (arrow) and an intervertebral cleft, respectively. **C:** Postoperative radiograph showing the result of initial surgery, VP at L-4. **D:** Sagittal T2-weighted MR image and axial CT scan (inset) showing evidence of progression of collapse of the affected vertebra (arrow) 6 months after the initial surgery and compression of the dural tube between L3–4 and L4–5 levels produced by bony fragments retropulsed into the spinal canal (asterisk). **E:** Radiograph showing the results of revision surgery, decompression with PSF (L2–S1) and PLF (L3–5). **F:** Radiograph showing progression of collapse of the upper end of the fixation and adjacent vertebra with loosened pedicle screw at 5 months after revision surgery.

VP is available for the stability of the collapsed vertebra. However, VP without short fusion (only VP) is not recommended because the load on middle and/or posterior lesions of the affected vertebra increased in this group, and collapse of the affected vertebra could easily progress. The clinical outcome of VP without short fusion for patients with vertebral body height loss of $\geq 70\%$ is poor in most cases with Type 2 or Type 3 collapse.¹ Figure 7 presents 1 of the 2 cases who required revision surgery. In this case, 6 months after VP without fusion for OVC at L-4, the L-4 vertebra recollapsed where retropulsed bony fragments in the spinal canal generated neurological deficits. Revision surgery including decompression + PSF (L2–S1) + PLF was performed, but the upper end of the fixation and adjacent vertebra collapsed following

screw loosening. In patients without cleft formation, the affected vertebra often showed sclerotic changes. In cases without evidence of intervertebral instability on radiological images, PSF (screw also inserted in the affected vertebra) + PLF are recommended (Figs. 4 and 8). It is advantageous in such cases to insert pedicle screws in the affected vertebra because most of these vertebrae present sclerotic changes, providing good anchor for the spine. In cases with intervertebral instability, the upper vertebra is usually slipped; therefore, PLIF is recommended (Figs. 4 and 9). The PLIF procedure provides excellent clinical outcome for both canal stenosis and foraminal stenosis.³⁰

The mean neurological score improved significantly postoperatively; however, the rate of postoperative complications (26.7%), mainly related to the instrumenta-

FIG. 8. Case of a 73-year-old woman with L-3 concave type collapse, who is representative of patients with concave sclerotic collapse without intervertebral instability. **A:** Preoperative lateral plain radiograph showing L-3 collapse (arrow). **B:** Preoperative CT scan showing foraminal stenosis by bony fragments retropulsed into the intervertebral foramen (arrow). Axial view (inset). **C:** Preoperative sagittal T2-weighted MR image showing canal stenosis at the L2–3 level (arrow). **D:** Radiograph showing decompression with PSF (L3–5) with sclerotic changes affecting the vertebra and PLF (L3–5). **E:** Intraoperative photograph showing bony fragments that had retropulsed into the intervertebral foramen and compressed left L-3 root (yellow arrow). **F:** Photograph showing decompression of the left L-3 root (yellow arrow) performed via medial foraminotomy. Figure is available in color online only.

FIG. 9. Case of a 73-year-old woman with L-4 flat-type collapse and intervertebral instability between L-3 and L-4, who is representative patients with intervertebral instability. **A and B:** Preoperative anteroposterior (A) and lateral plain (B) radiographs showing that the intervertebral instability included lateral shift. **C:** Preoperative CT scan showing upper endplate destruction and sclerotic changes in the L-4 vertebra. **D:** Preoperative sagittal MR image showing canal stenosis at the L3–4 level. **E and F:** Radiographs showing the results of PLIF at L3–4.

tion, was not low in this study. Our results indicate that the surgical procedure of short fusion with posterior approach cannot correct the mismatch between LL and PI. However, the sagittal spinopelvic alignment was not different between patients with and without postoperative complications in the present study, while the lumbar spine BMD was significantly lower in patients with postoperative complications. Although the PSF method can achieve strong spinal fixation, the severity of osteoporosis plays a major role in the pullout force of the screws.^{23,24} These results indicate that it is not necessary to correct the sagittal alignment in patients with low lumbar OVC, except in cases requiring long fusion or multiple site of fixation for accepting lesser degrees of deformity correction and avoiding ending instrumentation within kyphotic segments or when the severity of osteoporosis is very high.^{7,14} To avoid these postoperative complications, it may be necessary to implement some augmentation, such as use of a supplemental hook system or sublaminar cables combined with standard short segment PSF,²⁴ together with treatment of osteoporosis, for example, using parathyroid hormone (PTH).¹⁶

This study had certain limitations. First, patients in this series were elderly, and it was impossible to follow 11 of 30 patients because 9 patients died of other diseases and 2 patients could not visit our hospital postoperatively due to excessive travel distance and/or physical disability. We could only check the final follow-up data for these patients from the medical records or telephone interview. Imaging and mean follow-up period in these patients was only 2.4 years (1.0–4.5 years). Another limitation was the use of PTH and/or some augmentations in surgeries in the patients seen in recent years. It is possible this study underrepresents the true failure or complication rate. Second, since the study was a small retrospective case series, multivariate analysis of each parameter was not possible. For these limitations, further investigation of a large number of cases is required to assess the surgical outcome and to

design a validated algorithm for low lumbar OVC. However, since a few reported studies have examined patients with low lumbar OVC, the present study on the clinical status, neurological symptoms, radiological findings of such patients, no doubt, provides important information regarding surgical strategies and outcome.

Conclusions

The morphological features of OVC in patients with low lumbar vertebra are flat-type and concave or H-shaped type. In these, foraminal stenosis, canal stenosis, and/or intervertebral instability are found, and severe radicular leg pain may occur. For these patients, decompression and short fusion surgery via a posterior approach can improve the neurological symptoms. However, these patients present at advanced age, with poor bone quality and other comorbidities, where the rate of postoperative complications related to the instrumentation is less than ideal. Surgical strategy and treatment of osteoporosis are both important in these patients.

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Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Nakajima, Uchida. Acquisition of data: Nakajima, Honjoh, Sakamoto, Kitade. Analysis and interpretation of data: Nakajima, Honjoh, Sakamoto. Drafting the article: Nakajima. Critically revising the article: Uchida. Reviewed submitted version of manuscript: Uchida, Baba. Statistical analysis: Nakajima, Honjoh. Administrative/technical/material support: Uchida. Study supervision: Baba.

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