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Clinical Studies

Differences in surgical outcome after anterior corpectomy and reconstruction with an expandable cage with rectangular footplates between thoracolumbar and lumbar osteoporotic vertebral fracture

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A R T I C L E I N F O

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Elderly people
Clinical outcome
Complication
Cage subsidence
Screw loosening

A B S T R A C T

Background: Anterior and posterior spinal fixation (APSF) can provide rigid structural anterior column support in patients with osteoporotic vertebral fracture (OVF). A new rectangular footplate designed based on biomechanical studies of endplates provides better resistance to subsidence. However, differences in characteristics exist between the thoracolumbar and lower lumbar spine. The purpose of this study was to evaluate the surgical outcomes following APSF using an expandable cage with rectangular footplates in the thoracolumbar/lumbar region.

Methods: Consecutive patients who underwent APSF for OVF at multiple centers were retrospectively reviewed. Clinical and radiographic evaluations were performed by dividing the patients into thoracolumbar (TL, T10–L2) and lumbar (L, L3–L5) groups. Surgical indications were incomplete neurologic deficit or intractable back pain with segmental spinal instability. Surgical outcomes including the Japanese Orthopaedic Association (JOA) score and reoperation rate were compared between TL and L groups.

Results: Sixty-nine patients were followed-up for more than 12 months and analyzed. Operative intervention was required for 35 patients in the TL group and 34 patients in the L group. Mean ages in the TL and L groups were 76.5 years and 75.1 years, respectively. Intra-vertebral instability was more frequent in the TL group ($p<0.001$). Screw fixation range was significantly longer in the TL group ($p=0.012$). The rate of cage subsidence did not differ significantly between the TL group (46%) and L group (44%). Reoperation rate tended to be higher in the TL group ($p=0.095$). Improvement ratio of JOA score was significantly better in the L group (60%) than in the TL group (46.9%, $p=0.029$).

Conclusion: APSF using an expandable cage was effective to treat OVF at both lumbar and thoracolumbar levels. However, the improvement ratio of the JOA score was better in the L group than in the TL group.

Introduction

The rate of spinal surgery for elderly patients has dramatically increased over recent decades with the continued increases in life expectancy. Problems associated with spinal surgeries for these patients are an increased frequency of comorbidities, more severe spinal degeneration and osteoporosis due to reduced bone mineral density, and so on.[1] Among these, osteoporotic vertebral fracture (OVF) is a major concern, causing not only back pain, but also neurological deficits and kyphotic/scoliotic spinal deformities leading to deterioration of quality of life (QOL).[2] Despite a basic consensus that OVF treatment includes conservative therapy with bracing and administration of anti-osteoporotic drugs, surgical intervention may be considered when those treatments prove ineffective.

Various surgical methods are available for OVF. To select the surgical method, shorter operation time and reduced invasiveness are critical factors for elderly patients to avoid complications.[3] Vertebroplasty

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(VP)/kyphoplasty (KP) is indicated for non-union with intra-vertebral instability or OVF in the very early stage because of its minimum invasiveness and favorable clinical results.[4, 5]

However, more invasive spinal surgeries are required in cases where VP/KP is inadequate.[6] Various surgical methods with a combined- or solely posterior/anterior approach have been reported, such as in-situ fixation, posterolateral decompression and fusion, lumbar interbody fusion, osteotomy, vertebral column resection and replacement.[7-9] However, the most suitable procedure for OVF remains unclear. *In-situ* fusion provides improvements in pain and neurological deficit without decompression, but cannot correct the spinal alignment.[10] Spinal osteotomy, including posterior vertebral column resection, offers advantages to correct the sagittal imbalance for rigid kyphotic spine after OVF, but its surgical invasiveness is relatively high among those surgeries.[11-13]

Anterior surgery for OVF was first reported in the 1990s using a Kaneda plating system with an artificial ceramic bone graft substitute.[14] Anterior spinal reconstruction can provide several advantages, such as rigid structural anterior column support and preservation of intact posterior elements and nerves.[8] However, cage subsidence followed by kyphotic changes and the high invasiveness of the anterior approach are serious problems in osteoporotic elderly patients, so anterior surgery for OVF has thus been avoided.

A newly developed rectangular footplate designed based on the biomechanical studies of endplates has been shown to provide more resistance to subsidence.[15-17] Recent advances in the lateral approach have enabled minimally invasive anterior spinal reconstruction in the thoracolumbar and lumbar regions for elderly patients.[18] However, several features differ between the thoracolumbar and lower lumbar spine.[19] The thoracolumbar area is the junction from the kyphotic to lordotic alignments. The lower lumbar spine has a lordotic alignment and is more likely to cause canal stenosis through degenerative changes. The pathogenesis and clinical outcomes of surgery for OVFs might therefore differ depending on the level.

The purpose of this study was to clarify clinical features of OVF occurring in the thoracolumbar and lumbar regions by demonstrating surgical outcomes of anterior and posterior spinal fixation (APSF) using an expandable cage with rectangular footplates.

Materials and methods

Patient population

This was a multicenter retrospective cohort study. From 2015 to 2019, consecutive patients who underwent lateral approach corpectomy and reconstruction for intra- or inter-vertebral instability after OVF were enrolled retrospectively. Five hospitals participated in the study. All patients had spinal instability with incomplete neurologic deficit or severe back pain. Patients were grouped according to the fracture level (thoracolumbar (TL): T11–L2 or lumbar (L): L3–L5) or type of instability (intra-vertebral or inter-vertebral). All patients were followed-up for > 12 months. This study was approved by the institutional review board of Osaka City University (approval no. 3170). The need to obtain informed consent was waived based on the retrospective design and anonymization of patient identifiers.

Clinical information

The clinical records were reviewed for demographic data, instability type, operation time (min), estimated blood loss (EBL, ml), performance status (PS, Common Toxicity Criteria, version 2.0), comorbidities and perioperative complications. Information regarding comorbidities at surgery, such as Parkinson disease and history of steroid use, was collected. Bone mineral density (BMD) at the femoral neck was determined using dual-energy x-ray absorptiometry (DEXA). However, the protocol was not standardized in each institution. Information on previous surgeries at the corpectomy site was obtained and divided into lumbar decompression, VP/KP and posterior instrumentation. The severity of pain was subjectively assessed by each patient using a visual analogue scale (VAS) to represent the average level of back pain that the patient felt in the previous 1 week. The Japanese Orthopaedic Association (JOA) score was used to assess the efficacy of treatment for low back pain (total 29 points). The improvement rate of each clinical outcome was calculated using the following formulae: [Improvement rate of JOA score (%) = 100 × (final JOA score - preoperative JOA score) ÷ (29 - preoperative JOA score)].

Image assessment

Radiographic evaluation was performed on all patients and included analysis of pre- and postoperative local kyphosis, parameters of sagittal alignment (sagittal vertical axis [SVA], pelvic incidence [PI], lumbar lordosis [LL], sacral slope [SS], thoracic kyphosis [TK], and T1 pelvic angle [TPA]) and incidence of cage subsidence.[20-22] Local kyphotic angle was defined as the angle between the inferior endplate of the vertebra above and the superior endplate of the vertebra below the fractured vertebra and expressed as negative for kyphotic deformity.[23] Intra-vertebral instability was defined as angular motion of the fractured vertebral body with cleft between flexed and extended positions. Inter-vertebral instability was defined as a change in disc height > 2 mm with deformation of the vertebral body between flexed and extended positions. Subsidence was defined as a more than 2-mm reduction in segmental height due to implant migration into the adjacent endplates.[24]

Surgical indication and techniques

APSF was indicated for OVF based on intractable back pain or neurologic deficits due to residual spinal instability only when those symptoms clearly disappeared in the supine position. APSF was not indicated for sagittal malalignment with local rigid kyphosis. The combined anterior–posterior procedure consisted of a lateral approach corpectomy and vertebral reconstruction with an expandable titanium cage comprising rectangular footplates (X-Core2®; Nuvasive, San Diego, CA) followed by posterior percutaneous pedicle screw fixation (PPS) after position change.

No decompression of neural elements was carried out and all procedures were performed under the same anesthesia in this series. Bone grafting was carried out around the cage using artificial tricalcium phosphate particles and resected rib fragments. Range of posterior fixation was unregulated, and depended on the preference of the surgeon.

Statistical analysis

Patient characteristics were compared between TL and L groups. The χ^2 test or Fisher's exact test was used for categorical variables and the t-test was used for continuous variables. Analysis of covariance was used to compare the three groups. To establish whether significant differences existed in postoperative clinical or radiologic outcomes between the two groups, a restricted maximum likelihood, mixed-model regression was used. In addition, the JOA improvement was compared according to age (<80 and ≥80 years), T-score (≤-2.5 and >-2.5) and body mass index (BMI) (<18.5, 18.5–25.0 and >25.0 kg/m^2). To evaluate the interaction of fracture level with each factor, analysis covariance was used. Statistical test results were considered significant for values of $p<0.05$. All P-values were two-sided. All analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC).

Results

A total of 72 patients were enrolled in this study. Two patients were lost to follow-up and 1 patient died 2 months after surgery due to pneu-

Table 1
Comparison of demographic data between thoracolumbar and lumbar corpectomy with an expandable cage

	Thoracolumbar (n=35) mean or N (SD or %)		Lumbar (n=34) mean or N (SD or %)		P-value
Age (years)	76.5	(5.9)	75.1	(7.2)	0.362
Follow up period (months)	24.0	(13)	24.6	(13.4)	0.846
Sex (female)	22	(63)	27	(79)	0.130
BMI	23.0	(3.4)	23.4	(3.9)	0.661
BMD(T-score)	-2.3	(0.8)	-2.2	(0.9)	0.686
Medicine for osteoporosis					
Bisphosphonate	3	(9)	4	(12)	0.131
Denosumab	2	(6)	3	(9)	
Teriparatide	24	(69)	14	(41)	
Romosozumab	3	(9)	2	(6)	
Others	0	(0)	1	(3)	
None	3	(9)	10	(29)	
Parkinson disease	3	(9)	3	(9)	1.000
Steroid use	2	(6)	8	(24)	0.036
Surgical history					
Lumbar decompression	3	(9)	3	(9)	
Vertebral augmentation	2	(6)	3	(9)	
Posterior instrumentation	4	(11)	2	(6)	0.931
Diagnosis					
Intra-vertebral instability	25	(71)	7	(21)	
Inter-vertebral instability	10	(29)	27	(79)	<0.001

SD, standard deviation; BMI, body mass index; BMD, bone mineral density

Table 2
Comparison of surgical complication between thoracolumbar and lumbar corpectomy with an expandable cage

	Thoracolumbar (n=35) mean or n (SD or %)		Lumbar (n=34) mean or n (SD or %)		P-value
Op time (min)	275	(70.9)	267.6	(77.9)	0.679
Blood loss (g)	270.6	(291)	308.4	(357.4)	0.631
Fixation range					
1 above 1 below	15	(43)	25	(73)	0.012
Adjacent vertebral fracture	8	(23)	6	(18)	0.591
Infection	2	(6)	1	(3)	1
Reoperation	5	(14)	1	(3)	0.095
Cage subsidence	17	(46)	16	(44)	0.898

SD, standard deviation

monitis. A final total of 69 patients was followed-up for > 12 months and analyzed, comprising 35 in the TL group and 34 patients in the L group requiring operative intervention.

Comparison of baseline data and surgical complication

Table 1 compares demographic data between TL and L groups. Mean ages in the TL and L groups were 76.5 and 75.1 years, respectively. Bone mineral density and medication for osteoporosis did not differ significantly between groups. Oral steroid usage was more frequent in the L group (24%) compared with the TL group (6%; p=0.036). In terms of diagnosis, intra-vertebral instability was more frequent in the TL group (71%) than in the L group (21%; p<0.001). Table 2 shows the fixation range and complications. Fixation range was significantly longer in the TL group (p=0.012). The rate of surgical site infection did not differ significantly between groups, but the reoperation rate tended to be higher in the TL group (14%) than in the L group (3%, p=0.095). The rate of cage subsidence did not differ significantly between the TL group (46%) and L group (44%).

Comparison of clinical and radiological outcomes

Clinical outcomes are shown in Table 3. VAS of back pain and performance status were significantly improved after surgery and showed no significant difference between TL and L groups. However, the improvement rate of JOA score was significantly better in the L group (60%) than in the TL group (46.9%, p=0.029). Table 4 shows the radiological outcomes. Local kyphosis and PI-LL were significantly improved after surgery, but not in SVA, PT and TPA. Local kyphosis was more severe in the TL group than in the L group before surgery. Therefore, Δ (preop - final) showed a tendency toward better correction in the TL group (22.5°) than in the L group (17.8°, p=0.069).

JOA improvement ratio was 53.7% and 50.7% (age <80 and ≥80 years, respectively; p=0.645), 51.8% and 57.3% (T-score ≤-2.5 and >-2.5; p=0.482) and 51.4%, 55.8% and 52.1% (BMI <18.5, 18.5–25.0 and >25.0 kg/m^2, respectively; p=0.783). P-values for interactions of fracture level (TL and L) with age, T-score and BMI were 0.645, 0.482 and 0.616, respectively.

Representative cases

TL group

An 84-year-old woman presented with intractable back pain and non-union of OVF at L1. Preoperative functional x-ray showed intra-vertebral instability between flexed and extended positions (Fig. 1A, 1B). Both endplates were diminished at the fractured level in reconstructed sagittal CT images (Fig. 1C).

She underwent APSF with posterior two-above-two-below PPS fixation (Fig. 1D). Screw loosening on the cranial side without cage subsidence was observed at 2 years after surgery (Fig. 1E). Reconstructive coronal CT confirmed rigid bony union around the cage (Fig. 1F) and

Table 3
Comparison of clinical outcome between thoracolumbar and lumbar corpectomy with an expandable cage

	Thoracolumbar (n=35) mean or N (SD or %)		Lumbar (n=34) mean or N (SD or %)		P-value
VAS of back pain					
Pre	81.6	(18.2)	76	(24.1)	0.277
Final	32.7*	(25.2)	25.6*	(28.2)	0.276
Δ	48.9	(29.8)	50.2	(31.6)	0.856
JOA score					
Pre	9.8	(4.7)	9.4	(4.5)	0.669
Final	19.2*	(4.4)	21.1*	(5)	0.113
Improvement ratio	46.9	(28.3)	60.0	(19.8)	0.029
Performance status					
Pre					
0	0	(0)	0	(0)	0.159
1	0	(0)	2	(6)	
2	7	(20)	6	(18)	
3	14	(40)	19	(56)	
4	14	(40)	7	(21)	
Final					
O	0	(0)	1	(3)	0.476
1	17	(49)	16	(47)	
2	14	(40)	16	(47)	
3	4	(11)	1	(3)	
4	0	(0)	0	(0)	
Improvement number	32*	(91)	30*	(88)	0.894

SD, standard deviation; VAS, visual analogue scale; JOA score, Japanese orthopaedic association score
* $P<0.05$ between pre and final values.

Table 4
Comparison of radiological outcome between thoracolumbar and lumbar corpectomy with an expandable cage

	Thoracolumbar (n=35) mean or N (SD or %)		Lumbar (n=34) mean or N (SD or %)		P-value
Local kyphosis					
Preop	25.7	(9.9)	4.5	(17.3)	<0.001
Immediate postop	3.2	(10.6)	-13.3	(8.4)	<0.001
Final	8.6*	(12)	-10.8*	(8.7)	<0.001
Δ(preop-final)	22.5	(7.8)	17.8	(12.9)	0.069
Correction loss (%)	29.3	(37)	23.7	(40.9)	0.559
SVA					
Preop	108	(47.4)	115	(45.5)	0.568
Final	88.4	(40.7)	90.1	(51.9)	0.883
Δ	11.9	(49.5)	20.5	(63.2)	0.574
PT					
Preop	28.4	(7.3)	28.9	(11.7)	0.838
Final	25.4	(8.8)	25.9	(8.2)	0.796
Δ	2.4	(9.7)	2.7	(9.9)	0.921
TPA					
Preop	32.6	(10)	33.5	(9.9)	0.733
Final	27.9	(8.6)	29.9	(10.1)	0.388
Δ	2.7	(9.3)	2.4	(9.5)	0.906
PI-LL					
Preop	38.2	(15.8)	30.1	(19.5)	0.075
Final	25.3*	(14)	21.2*	(15.9)	0.285
Δ	12.9	(13.9)	8.9	(16.6)	0.302

SD, standard deviation; SVA, Sagittal vertical axis; PT, Pelvic tilt; TPA, T1 Pelvic Angle; PI-LL, Pelvic incidence- Lumbar lordosis
* $P<0.05$ between pre and final values.

the VAS for back pain improved from 80 mm before surgery to 20 mm at 2 years after surgery.

L group

A 77-year-old, bedridden woman presented with back pain and radiculopathy. Inter-vertebral instability was seen after L4 OVF. Preoperative functional x-ray showed inter-vertebral instability between flexed and extended positions (Fig. 2 A, 2B). CT images showed vacuum phenomena in both adjacent inter-vertebral discs (Fig. 2C).

She underwent APSF with one-above-one-below (1A1B) PPS fixation. At follow-up after 2 years, lateral and antero-posterior plain radiographs showed no evidence of cage subsidence or screw loosening (Fig. 2D, 2E). She acquired independent gait postoperatively. VAS of back pain improved from 100 mm before surgery to 41 mm at 2 years after surgery.

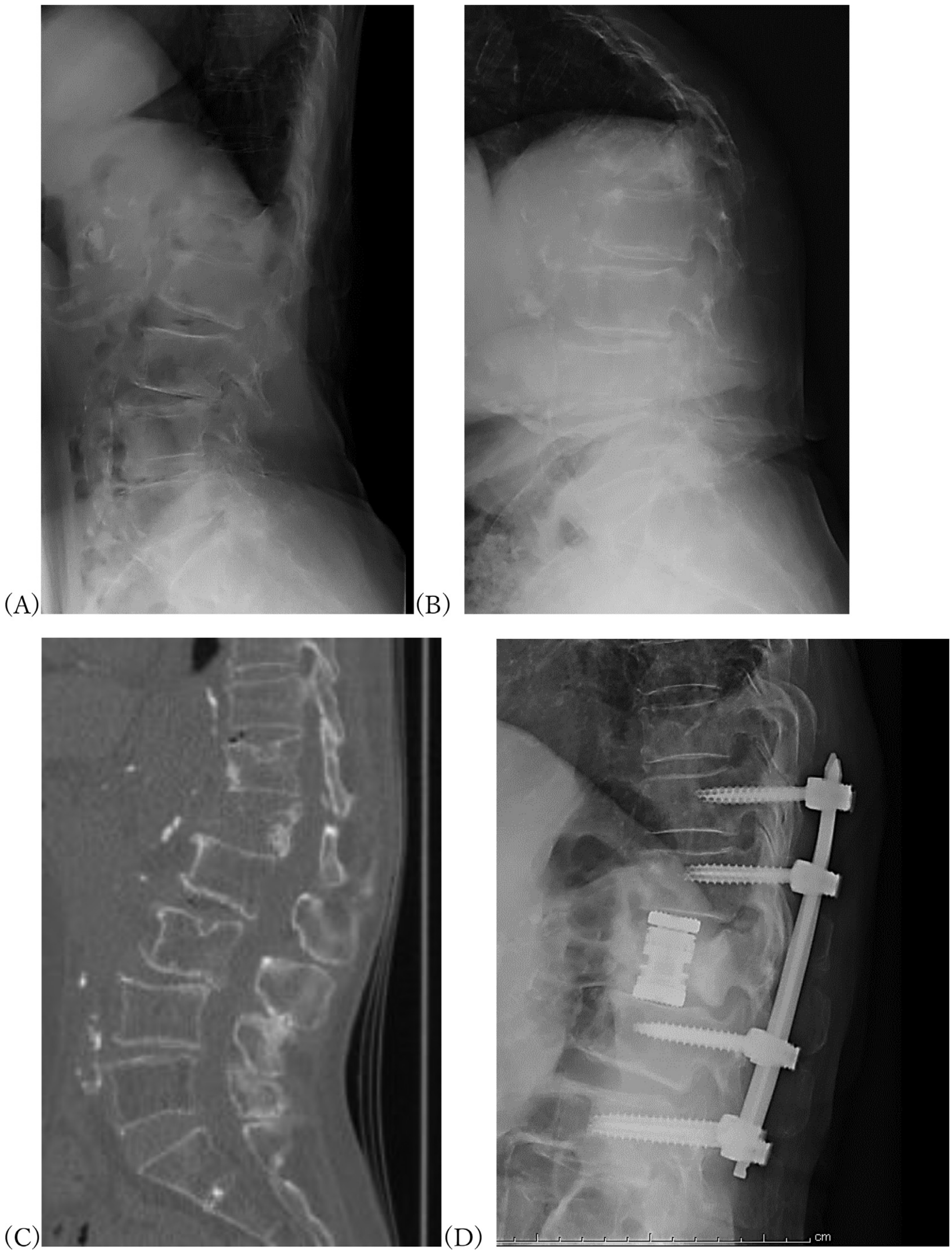


Fig. 1. An 84-year-old woman suffering from intractable back pain with non-union of OVF at L1. Preoperative functional x-ray shows intra-vertebral instability without cementing space (A, B). Both endplates are diminished at the fractured level on reconstructed sagittal CT (C). Lateral radiographs show the situation immediately after surgery (D). Lateral radiographs at 2 years after surgery show screw loosening and subsidence of cage (E), although CT at 2 years after surgery shows bony union (F).

Discussion

This appears to be the first study to reveal differences in the characteristics of patients with OVF who underwent APSF between thoracolumbar or lumbar lesions. Approximately 70% of OVF occurs at the thoracolumbar level and the rate of lumbar OVF is less than 20%.[25-28] Rates of surgery in the TL and L groups might be predicted to show the same proportions as rates of OVF occurrence. However, our results showed that almost the same number of patients belonged to both TL and L groups (35 and 34 patients, respectively). In our institutions, OVF patients receive initial conservative treatment for a couple of months, then vertebroplasty/balloon kyphoplasty (VP/BKP) (±PSF) is preferentially performed if indicated.[5, 29] Thus, no indications for VP/BKP (±PSF) were seen for patients included in this cohort. The main reason to avoid VP/BKP was the lack of a safe cavity that could hold the injected cement material. Our surgical indication for APSF was instability-

(E)

(F)

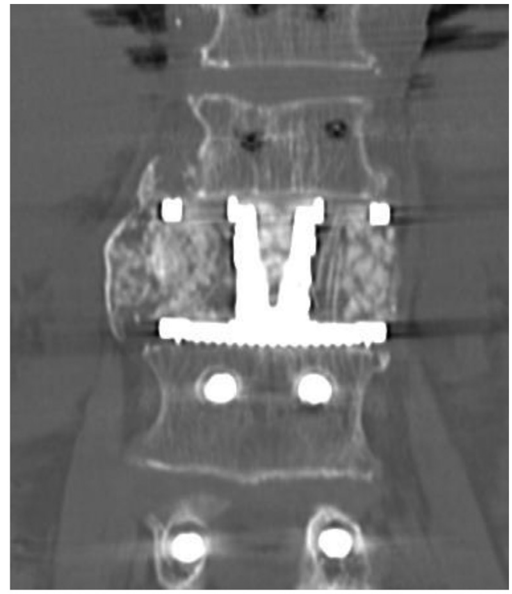


Fig. 1. Continued

induced intractable back pain or neurological deficits. We divided patients into two groups according to the type of instability (intra- or inter-vertebral instability) because each type showed different clinical features. Intra-vertebral instability arose from non-union of the fractured vertebra and manifested mainly as back pain. Inter-vertebral instability was due to the resultant vertebral deformity after bony union that induced spondylolisthesis between adjacent vertebrae and caused radiculopathy.[30] The rate of inter-vertebral instability was much higher in the L group (79%) than in the TL group (29%), as the bone union rate is higher for lumbar lesions than for thoracolumbar lesions.[26, 29] This might indicate that deformity and inter-vertebral instability in the lumbar region was more likely to cause intractable back pain or neurological impairment.

Regarding spinal surgery for OVF, cage subsidence due to osteoporotic vertebrae is a big concern. Previous reports have revealed a high incidence of cage subsidence following surgery.[31] Closkey et al. reported that cage subsidence correlated with the size of the contact area between the cage and endplate, and others have reported that bone mineral density is an important determinant of cage subsidence.[32] An in vitro biomechanical study revealed that use of peripheral vertebral endplate is ideal to support the cage.[16, 17] We thus used rectangular wide-foot-plate expandable cages in this series. However, cage subsidence >2 mm was recognized in nearly 40% of cases in both groups. Additional operations were performed in 5 cases (progressive kyphosis due to cage subsidence, 2; adjacent vertebral fracture (AVF), 2; posterior decompression, 1) in the TL group and in 1 case (AVF, 1) in the L group. Additional cage subsidence-related surgery was only performed in 2 cases (2.9%) in this series, in which apparent subsidence occurred during surgery in 1 case and subsidence was evident immediately after the initial surgery in the other. Other cases of subsidence did not affect the clinical results, but were radiographically recognized early after the initial surgery. Whether those results were due to technical or biomechanical reasons remains unclear. Load on the adjacent vertebra is higher in the locally kyphotic region than in the lordotic region, which may theoretically result in higher cage subsidence in the TL group, but the frequency of subsidence did not differ significantly between groups.[33] Endplate injury should be avoided when expanding the cage. [31]

In APSF for elderly OVF patients, surgical invasiveness and postoperative pulmonary complications are important concerns, because the extrapleural approach requires a long operation time and high invasiveness.[8, 34] An extrapleural approach with rib and partial diaphragm resection was required in most cases from the TL group, but operation time and EBL did not differ significantly from that in the L group (TL/L: 275 min/268 min, 271 ml/308 ml), and thus were much shorter and less than those for conventional open surgery.[12, 35, 36] Use of the recently developed minimally invasive lateral approach may have contributed to reducing the operation time and EBL.[37] As for perioperative complications, one case of contralateral segmental artery injury and another case of hemothorax caused by intercostal artery injury were recognized and treated conservatively (both in the TL group). No complications other than AVF were seen in the L group. The complication rate of APSF for lumbar OVF was thus less than that for the thoracolumbar region, although operation time and EBL were almost the same.

A PPS fixation system was used to reduce surgical invasiveness.[38] Differences in fixation range from posterior approach depend on several factors, such as surgeon preference, timing of the operation and peripheral circumstances of the fractured vertebra, because these issues were not standardized in this series. Nearly 50% of patients in the TL group underwent 1A1B fixation (e.g., L1–L3 fixation for L2 vertebral body replacement). Meanwhile, nearly 80% of patients in the L group underwent 1A1B fixation. The mechanical load to the vertebral body differs according to the spinal level. Load is higher in the anterior portion of the vertebra at the kyphotic thoracolumbar junction, but is much higher in posterior elements such as facet joints or spinal processes in the lumbar region.[33] Posterior reinforcement for thoracolumbar regions is thus recommended to avoid overload on the cage-bone contact area in the TL group, whereas 1A1B fixation is sufficient in the lumbar region because of the lordotic alignment. This may be supported by our results that no implant failure was seen in the L group. No significant difference in AVF frequency was seen between groups (TL group, 23%; L group, 18%), so no predictive factors were identified in this study.

Clinical indices such as VAS, PS and JOA scores showed significant improvement in both groups (Table 3). Preoperative VAS score was significantly decreased at final follow-up (TL group, 81.6 to 32.7; L group, 76 to 25.6). Diminution and residual VAS at final follow-up were almost the same as results previously reported for OVF surgeries, including VP/BKP.[5, 27, 39] As for performance status, nearly 90% of patients improved by more than 1 level after surgery, with no significant difference between groups. However, the JOA score improvement ratio was significantly better in the L group (60.0%) than in the TL group (46.9%; $p<0.05$). One potential reason for the poor improvement ra-

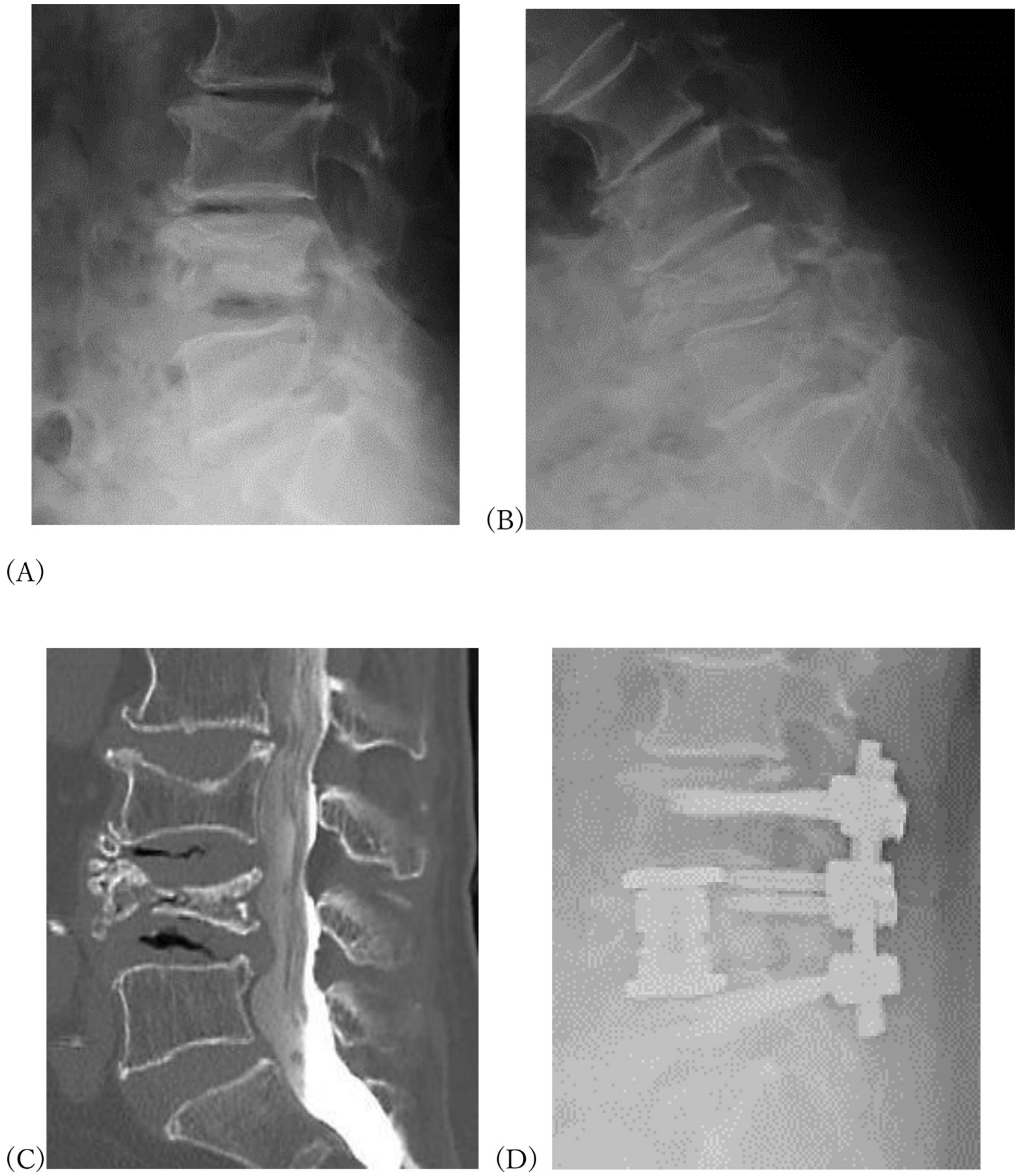


Fig. 2. A 77-year-old, bedridden woman suffering back pain and radiculopathy. Inter-vertebral instability after L4 OVF is evident. Preoperative functional x-ray shows inter-vertebral instability between flexed and extended positions (A, B). CT shows vacuum phenomenon in both adjacent inter-vertebral discs (C). She underwent APSF with one-above-one-below PPS fixation. At the 2-year follow-up, lateral and antero-posterior plain radiographs show no evidence of cage subsidence or screw loosening (D, E).

tio was the high rate of reoperation in the TL group. All revision cases needed extension of the fixation range due to adjacent vertebral fracture. The thoracolumbar junction represents an inflection point where the spinal curvature transitions from kyphotic to lordotic, which may cause more severe fracture and a greater likelihood of a need for reoperation.

Radiographic analysis showed that improvement of local kyphosis was obtained in both groups, but loss of correction was recognized in 29.3% of the TL group and 23.7% of the L group. Final correction of local kyphosis was 22.5° in the TL group and 17.8° in the L group, better than previously reported.[8, 27, 30, 31] PI-LL improved nearly 10° in both groups, but final PI-LL was 25.3° in the TL group and 21.2° in the L group, out of the range of calculated values for ideal spino-pelvic alignment (PI-LL ≤ 10°).[40] However, the clinical results showed good improvement in this series. The pathology of elderly OVF patients should thus be differentiated from that of sagittal malalignment among younger patients.

Several limitations must be considered regarding retrospective data reviews. First, selection biases may exist for the surgical methods and fixation range, as this was a multicenter cohort study. Analysis of bone quality using modalities such as DEXA was not performed because each institute used different machines and measurement protocols. Despite this limitation, the present study appears to be the first to compare clinical results of APSF between the thoracolumbar and lumbar regions. Second, the sample size might have been too small to assess differences in outcome such as reoperation rate and back pain, although the sample size was sufficient to assess differences in the JOA score. Post hoc power analysis was conducted to evaluate the difference in reoperation rate with α=0.05, power=0.8 and chi-square test. Reoperation rate in the TL and L groups were estimated as 14% and 3%, respectively.

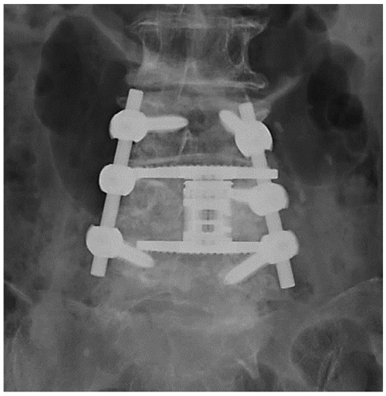
(E) 

Fig. 2. Continued

Sample size was calculated as 169 patients. Therefore, further study is necessary.

In conclusion, anterior corpectomy and reconstruction with an expandable cage with rectangular footplates appears effective to treat OVF at both lumbar and thoracolumbar levels. However, reoperation tended to be more common in the thoracolumbar group, which might have resulted in poorer improvement ratios in this group. The present results should be confirmed in a larger cohort to ensure the generalizability of our findings.

Sources of funding

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IRB approval

This study was approved by the institutional review board of Osaka City University (approval no. 3170). The need to obtain informed consent was waived based on the retrospective design and anonymization of patient identifiers.

Declaration of Competing Interest

All authors declare that they have no conflict of interest.

References

[1] Fehlings MG, Tetreault L, Nater A, Choma T, Harrop J, Mroz T, Santaguida C, Smith JS. The aging of the global population: the changing epidemiology of disease and spinal disorders. Neurosurgery 2015;77(Suppl 4):S1–5. doi:10.1227/NEU.0000000000000953.

[2] Fechtenbaum J, Cropet C, Kolta S, Horlait S, Orcel P, Roux C. The severity of vertebral fractures and health-related quality of life in osteoporotic postmenopausal women. Osteoporos Int 2005;16:2175–9. doi:10.1007/s00198-005-2023-0.

[3] Saleh A, Thirukumaran C, Mesfin A, Molinari RW. Complications and readmission after lumbar spine surgery in elderly patients: an analysis of 2,320 patients. Spine J 2017;17:1106–12. doi:10.1016/j.spinee.2017.03.019.

[4] Minamide A, Maeda T, Yamada H, Murakami K, Okada M, Enyo Y, Nakagawa Y, Iwasaki H, Tsutsui S, Takami M, Nagata K, Hashizume H, Yukawa Y, Schoenfeld AJ, Simpson AK. Early versus delayed kyphoplasty for thoracolumbar osteoporotic vertebral fractures: The effect of timing on clinical and radiographic outcomes and subsequent compression fractures. Clin Neurol Neurosurg 2018;173:176–81. doi:10.1016/j.clineuro.2018.07.019.

[5] Hoshino M, Takahashi S, Yasuda H, Terai H, Watanabe K, Hayashi K, Tsujio T, Kono H, Suzuki A, Tamai K, Ohyama S, Toyoda H, Dohzono S, Kanematsu F, Hori Y, Nakamura H. Balloon kyphoplasty versus conservative treatment for acute osteoporotic vertebral fractures with poor prognostic factors: propensity score matched analysis using data from two prospective multicenter studies. Spine (Phila Pa 1976) 2019;44:110–17. doi:10.1097/BRS.0000000000002769.

[6] Takahashi S, Hoshino M, Yasuda H, Hori Y, Ohyama S, Terai H, Hayashi K, Tsujio T, Kono H, Suzuki A, Tamai K, Toyoda H, Dohzono S, Sasaoka R, Kanematsu F, Terakawa M, Nakamura H. Characteristic radiological findings for revision surgery after balloon kyphoplasty. Sci Rep 2019;9:18513. doi:10.1038/s41598-019-55054-5.

[7] Kashii M, Yamazaki R, Yamashita T, Okuda S, Fujimori T, Nagamoto Y, Tamura Y, Oda T, Ohwada T, Yoshikawa H, Iwasaki M. Surgical treatment for osteoporotic vertebral collapse with neurological deficits: retrospective comparative study of three procedures–anterior surgery versus posterior spinal shorting osteotomy versus posterior spinal fusion using vertebroplasty. Eur Spine J 2013;22:1633–42. doi:10.1007/s00586-013-2759-8.

[8] Kanayama M, Ishida T, Hashimoto T, Shigenobu K, Togawa D, Oha F, Kaneda K. Role of major spine surgery using Kaneda anterior instrumentation for osteoporotic vertebral collapse. J Spinal Disord Tech 2010;23:53–6. doi:10.1097/BSD.0b013e318193e3a5.

[9] Takenaka S, Mukai Y, Hosono N, Fuji T. Major surgical treatment of osteoporotic vertebral fractures in the elderly: a comparison of anterior spinal fusion, anterior-posterior combined surgery and posterior closing wedge osteotomy. Asian Spine J 2014;8:322–30. doi:10.4184/asj.2014.8.3.322.

[10] Ataka H, Tanno T, Yamazaki M. Posterior instrumented fusion without neural decompression for incomplete neurological deficits following vertebral collapse in the osteoporotic thoracolumbar spine. Eur Spine J 2009;18:69–76. doi:10.1007/s00586-008-0821-8.

[11] Dreimann M, Hempfing A, Stangenberg M, Viezens L, Weiser L, Czorlich P, Eicker SO. Posterior vertebral column resection with 360-degree osteosynthesis in osteoporotic kyphotic deformity and spinal cord compression. Neurosurg Rev 2018;41:221–8. doi:10.1007/s10143-017-0840-1.

[12] Okuda S, Oda T, Yamasaki R, Haku T, Maeno T, Iwasaki M. Surgical outcomes of osteoporotic vertebral collapse: a retrospective study of anterior spinal fusion and pedicle subtraction osteotomy. Global Spine J 2012;2:221–6. doi:10.1055/s-0032-1331461.

[13] Kim SK, Chung JY, Park YJ, Choi SW, Seo HY. Modified pedicle subtraction osteotomy for osteoporotic vertebral compression fractures. Orthop Surg 2020;12:388–95. doi:10.1111/os.12589.

[14] Kaneda K, Asano S, Hashimoto T, Satoh S, Fujiya M. The treatment of osteoporotic-posttraumatic vertebral collapse using the Kaneda device and a bioactive ceramic vertebral prosthesis. Spine (Phila Pa 1976) 1992;17:S295–303. doi:10.1097/00007632-199208001-00015.

[15] Bailey CS, Sjovold SG, Dvorak MF, Fisher CG, Oxland TR. The strength profile of the thoracolumbar endplate reflects the sagittal contours of the spine. Spine (Phila Pa 1976) 2011;36:124–8. doi:10.1097/BRS.0b013e3181cc8a32.

[16] Grant JP, Oxland TR, Dvorak MF. Mapping the structural properties of the lumbosacral vertebral endplates. Spine (Phila Pa 1976) 2001;26:889–96. doi:10.1097/00007632-200104150-00012.

[17] Pekmezci M, McDonald E, Kennedy A, Dedini R, McClellan T, Ames C, Deviren V. Can a novel rectangular footplate provide higher resistance to subsidence than circular footplates? An ex vivo biomechanical study. Spine (Phila Pa 1976) 2012;37:E1177–81. doi:10.1097/BRS.0b013e3182647c0b.

[18] Kanemura T, Satake K, Nakashima H, Segi N, Ouchida J, Yamaguchi H, Imagama S. Understanding retroperitoneal anatomy for lateral approach spine surgery. Spine Surg Relat Res 2017;1:107–20. doi:10.22603/ssrr.1.2017-0008.

[19] Oishi Y, Nakamura E, Murase M, Doi K, Takeuchi Y, Hamawaki JI, Sakai A. Lower lumbar osteoporotic vertebral fractures with neurological symptoms might have two different pathogeneses according to early magnetic resonance images. Acta Neurochir (Wien) 2019;161:2211–22. doi:10.1007/s00701-019-04045-6.

[20] Legaye J, Duval-Beaupère G, Hecquet J, Marty C. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J 1998;7:99–103. doi:10.1007/s005860050038.

[21] Vialle R, Levassor N, Rillardon L, Templier A, Skalli W, Guigui P. Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. J Bone Joint Surg Am 2005;87:260–7. doi:10.2106/JBJS.D.02043.

[22] Qiao J, Zhu F, Xu L, Liu Z, Zhu Z, Qian B, Sun X, Qiu Y. T1 pelvic angle: a new predictor for postoperative sagittal balance and clinical outcomes in adult scoliosis. Spine (Phila Pa 1976) 2014;39:2103–7. doi:10.1097/BRS.0000000000000635.

[23] Alanay A, Pekmezci M, Karaeminogullari O, Acaroglu E, Yazici M, Cil A, Pijnenburg B, Genç Y, Oner FC. Radiographic measurement of the sagittal plane deformity in patients with osteoporotic spinal fractures evaluation of intrinsic error. Eur Spine J 2007;16:2126–32. doi:10.1007/s00586-007-0474-z.

[24] Barsa P, Suchomel P. Factors affecting sagittal malalignment due to cage subsidence in standalone cage assisted anterior cervical fusion. Eur Spine J 2007;16:1395–400. doi:10.1007/s00586-006-0284-8.

[25] Suzuki N, Ogikubo O, Hansson T. The prognosis for pain, disability, activities of daily living and quality of life after an acute osteoporotic vertebral body fracture: its relation to fracture level, type of fracture and grade of fracture deformation. Eur Spine J 2009;18:77–88. doi:10.1007/s00586-008-0847-y.

[26] Tsujio T, Nakamura H, Terai H, Hoshino M, Namikawa T, Matsumura A, Kato M, Suzuki A, Takayama K, Fukushima W, Kondo K, Hirota Y, Takaoka K. Characteristic radiographic or magnetic resonance images of fresh osteoporotic vertebral fractures predicting potential risk for nonunion: a prospective multicenter study. Spine (Phila Pa 1976) 2011;36:1229–35. doi:10.1097/BRS.0b013e3181f29e8d.

[27] Hosogane N, Nojiri K, Suzuki S, Funao H, Okada E, Isogai N, Ueda S, Hikata T, Shiono Y, Watanabe K, Kaito T, Yamashita T, Fujiwara H, Nagamoto Y, Terai H, Tamai K, Matsuoka Y, Suzuki H, Nishimura H, Tagami A, Yamada S, Adachi S, Ohtori S, Orita S, Furuya T, Yoshii T, Ushio S, Inoue G, Miyagi M, Saito W, Imagama S, Ando K, Sakai D, Nukaga T, Kiyasu K, Kimura A, Inoue H, Nakano A,

Harimaya K, Kawaguchi K, Yokoyama N, Oishi H, Doi T, Ikegami S, Shimizu M, Futatsugi T, Kakutani K, Yurube T, Oshima M, Uei H, Aoki Y, Takahata M, Iwata A, Seki S, Murakami H, Yoshioka K, Endo H, Hongo M, Nakanishi K, Abe T, Tsukanishi T, Ishii K. Surgical Treatment of Osteoporotic Vertebral Fracture with Neurological Deficit-A Nationwide Multicenter Study in Japan. Spine Surg Relat Res 2019;3:361–7. doi:10.22603/ssrr.2019-0004.

[28] Ballane G, Cauley JA, Luckey MM, El-Hajj Fuleihan G. Worldwide prevalence and incidence of osteoporotic vertebral fractures. Osteoporos Int 2017;28:1531–42. doi:10.1007/s00198-017-3909-3.

[29] Takahashi S, Hoshino M, Takayama K, Iseki K, Sasaoka R, Tsujio T, Yasuda H, Sasaki T, Kanematsu F, Kono H, Toyoda H, Nakamura H. Predicting delayed union in osteoporotic vertebral fractures with consecutive magnetic resonance imaging in the acute phase: a multicenter cohort study. Osteoporos Int 2016;27:3567–75. doi:10.1007/s00198-016-3687-3.

[30] Nakajima H, Uchida K, Honjoh K, Sakamoto T, Kitade M, Baba H. Surgical treatment of low lumbar osteoporotic vertebral collapse: a single-institution experience. J Neurosurg Spine 2016;24:39–47. doi:10.3171/2015.4.SPINE14847.

[31] Uchida K, Kobayashi S, Nakajima H, Kokubo Y, Yayama T, Sato R, Timbihurira G, Baba H. Anterior expandable strut cage replacement for osteoporotic thoracolumbar vertebral collapse. J Neurosurg Spine 2006;4:454–62. doi:10.3171/spi.2006.4.6.454.

[32] Closkey RF, Parsons JR, Lee CK, Blacksin MF, Zimmerman MC. Mechanics of interbody spinal fusion. Analysis of critical bone graft area. Spine (Phila Pa 1976) 1993;18:1011–15. doi:10.1097/00007632-199306150-00010.

[33] Nishida N, Ohgi J, Jiang F, Ito S, Imajo Y, Suzuki H, Funaba M, Nakashima D, Sakai T, Chen X. Finite Element Method Analysis of Compression Fractures on Whole-Spine Models Including the Rib Cage. Comput Math Methods Med 2019;2019:8348631. doi:10.1155/2019/8348631.

[34] Sudo H, Ito M, Kaneda K, Abumi K, Kotani Y, Nagahama K, Minami A, Iwasaki N. Anterior decompression and strut graft versus posterior decompression and pedicle screw fixation with vertebroplasty for osteoporotic thoracolumbar vertebral collapse with neurologic deficits. Spine J 2013;13:1726–32. doi:10.1016/j.spinee.2013.05.041.

[35] Watanabe K, Katsumi K, Ohashi M, Shibuya Y, Hirano T, Endo N, Kaito T, Yamashita T, Fujiwara H, Nagamoto Y, Matsuoka Y, Suzuki H, Nishimura H, Terai H, Tamai K, Tagami A, Yamada S, Adachi S, Yoshii T, Ushio S, Harimaya K, Kawaguchi K, Yokoyama N, Oishi H, Doi T, Kimura A, Inoue H, Inoue G, Miyagi M, Saito W, Nakano A, Sakai D, Nukaga T, Ikegami S, Shimizu M, Futatsugi T, Ohtori S, Furuya T, Orita S, Imagama S, Ando K, Kobayashi K, Kiyasu K, Murakami H, Yoshioka K, Seki S, Hongo M, Kakutani K, Yurube T, Aoki Y, Oshima M, Takahata M, Iwata A, Endo H, Abe T, Tsukanishi T, Nakanishi K, Hikata T, Suzuki S, Isogai N, Okada E, Funao H, Ueda S, Shiono Y, Nojiri K, Hosogane N, Ishii K. Surgical outcomes of spinal fusion for osteoporotic vertebral fracture in the thoracolumbar spine: Comprehensive evaluations of 5 typical surgical fusion techniques. J Orthop Sci 2019;24:1020–6. doi:10.1016/j.jos.2019.07.018.

[36] Suk SI, Kim JH, Lee SM, Chung ER, Lee JH. Anterior-posterior surgery versus posterior closing wedge osteotomy in posttraumatic kyphosis with neurologic compromised osteoporotic fracture. Spine (Phila Pa 1976) 2003;28:2170–5. doi:10.1097/01.BRS.0000090889.45158.5A.

[37] Lehmen JA, Gerber EJ. MIS lateral spine surgery: a systematic literature review of complications, outcomes, and economics. Eur Spine J 2015;24(Suppl 3):287–313. doi:10.1007/s00586-015-3886-1.

[38] Tian F, Tu LY, Gu WF, Zhang EF, Wang ZB, Chu G, Ka H, Zhao J. Percutaneous versus open pedicle screw instrumentation in treatment of thoracic and lumbar spine fractures: A systematic review and meta-analysis. Medicine (Baltimore) 2018;97:e12535. doi:10.1097/MD.0000000000012535.

[39] Taiji R, Takami M, Yukawa Y, Hashizume H, Minamide A, Nakagawa Y, Nishi H, Iwasaki H, Tsutsui S, Okada M, Okada S, Teraguchi M, Murata S, Kozaki T, Yamada H. A short-segment fusion strategy using a wide-foot-plate expandable cage for vertebral pseudarthrosis after an osteoporotic vertebral fracture. J Neurosurg Spine 2020:1–8. doi:10.3171/2020.5.SPINE2062.

[40] Schwab FJ, Blondel B, Bess S, Hostin R, Shaffrey CI, Smith JS, Boachie-Adjei O, Burton DC, Akbarnia BA, Mundis GM, Ames CP, Kebaish K, Hart RA, Farcy JP, Lafage V(ISSG) ISSG. Radiographical spinopelvic parameters and disability in the setting of adult spinal deformity: a prospective multicenter analysis. Spine (Phila Pa 1976) 2013;38:E803–12. doi:10.1097/BRS.0b013e318292b7b9.