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

Masafumi Kashii · Ryoji Yamazaki · Tomoya Yamashita · Shinya Okuda · Takahito Fujimori · Yukitaka Nagamoto · Yuichi Tamura · Takenori Oda · Tetsuo Ohwada · Hideki Yoshikawa · Motoki Iwasaki

Received: 25 November 2012 / Revised: 22 January 2013 / Accepted: 18 March 2013 / Published online: 3 April 2013
© Springer-Verlag Berlin Heidelberg 2013

Abstract

Purpose In general, osteoporotic vertebral collapse (OVC) with neurological deficits requires sufficient decompression of neural tissues to restore function level in activities of daily living (ADL). However, it remains unclear as to which procedure provides better neurological recovery. The primary purpose of this study was to compare neurological recovery among three typical procedures for OVC with neurological deficits. Secondary purpose was to compare postoperative ADL function.

Methods We retrospectively reviewed data for 88 patients (29 men and 59 women) with OVC and neurological deficits who underwent surgery. Three typical kinds of surgical procedures with different decompression methods were used: (1) anterior direct neural decompression and reconstruction (AR group: 27 patients), (2) posterior spinal shorting osteotomy with direct neural

decompression (PS group: 36 patients), and (3) posterior indirect neural decompression and short-segment spinal fusion combined with vertebroplasty (VP group: 25 patients). We examined clinical results regarding neurological deficits and function level in ADL and radiological results.

Results The mean improvement rates for neurological deficits and ADL function level were 60.1 and 55.0 %, respectively. There were no significant differences among three groups in improvement rates for neurological deficits or ADL function level. The VP group had a significantly lower estimated mean blood loss (338 mL) and mean duration of surgery (229 min) than both the AR and PS groups ($p < 0.001$).

Conclusion Direct neural decompression is not always necessary, and the majority of patients can be treated with a less-invasive procedure such as short-segment posterior spinal fusion with indirect decompression combined with vertebroplasty. The high-priority issue is careful evaluation of patients' general health and osteoporosis severity, so that the surgeon can choose the procedure best suited for each patient.

Keywords Osteoporotic vertebral collapse · Delayed paralysis · Anterior surgery · Posterior spinal shorting osteotomy · Vertebroplasty

M. Kashii (✉) · T. Fujimori · Y. Nagamoto · H. Yoshikawa · M. Iwasaki
Department of Orthopedic Surgery, Faculty of Medicine,
Graduate School of Medicine, Osaka University,
2-2 Yamadaoka, Suita, Osaka 565-0871, Japan
e-mail: mkashii-osk@umin.ac.jp

R. Yamazaki · S. Okuda · T. Oda
Department of Orthopedic Surgery, Osaka Rousai Hospital,
1179-3 Nagasonecho, Sakai, Osaka 591-8025, Japan

T. Yamashita · T. Ohwada
Department of Orthopedic Surgery, Kansai Rousai Hospital,
3-1-69 Inabasou, Amagasaki, Hyogo 660-8511, Japan

Y. Tamura
Department of Orthopedic Surgery, Toyonaka Municipal
Hospital, 4-14-1 Shibahara, Toyonaka, Osaka 560-8565, Japan

Introduction

The majority of osteoporotic vertebral fractures (VFs) are successfully treated conservatively with bed rest and a spinal orthosis. However, in some cases vertebral nonunion

or vertebral necrosis occurs, inducing retropulsion of bony fragments into the spinal canal, progression of kyphosis, instability at the fracture site, and finally, neural compression [1]. Taneichi et al. [2] have reported that there is progressive collapse in about 30 % of VFs, vertebral nonunion in 13 %, and osteoporotic vertebral collapse (OVC) with neurological deficits in 3 %. Patients' quality of life (QOL) and their independence are severely affected by OVC with neurological deficits, and the incidence of OVC is increasing as the population ages rapidly.

In general, OVC with neurological deficits is a candidate for surgical treatment to decompress neural tissues. Neurological recovery leads to restore function level in activities of daily living (ADL) as the final goal. Many studies have shown that in OVC, spinal fusion and vertebral column reconstruction using various surgical techniques tend to decrease neurological deficits [3–13]. There are three recognized procedures: anterior instrumentation surgery [3–6], posterior spine-shortening osteotomy [7–9], and short-segment posterior spinal fusion (PSF) using vertebroplasty [10–13]. Each procedure has advantages and disadvantages. The advantages of anterior instrumentation surgery are direct resection of retropulsed bony fragments and reconstruction of a stable anterior spinal column [3–6]. However, using only anterior neural decompression and fusion is not easy in patients with serious comorbidities and severe bone fragility. Kanayama et al. [4] reported that 19 % of patients with OVC undergoing anterior instrumentation surgery also needed additional posterior reinforcement surgery. The advantages of posterior surgery with dissection of retropulsed posterior cortex, including posterior spinal shortening osteotomy, are direct neural decompression and correction of kyphotic deformity [7–9]. However, these procedures carry a risk of neural tissue damage in the management of fractured posterior cortex or spinal column shortening, and longer PSF is often necessary to stabilize the osteoporotic spinal column. Short-segment PSF with indirect decompression using vertebroplasty is an optional surgical procedure for elderly patients in generally poor health who are at high risk for serious surgical complications [10–13]. However, there is a possibility of leakage of bone cement into the spinal canal after vertebroplasty and insufficiency of anterior column support and neural decompression [14].

A few reports have compared clinical results for these procedures [5, 6]. No reports have compared clinical results among surgical procedures with different decompression procedures. Therefore, we conducted a retrospective, multicenter comparative study of clinical results as to neurological recovery, and postoperative ADL function for three surgical procedures, most commonly used to treat OVC with neurological deficits.

Materials and methods

Patient population

We retrospectively reviewed the case histories of 88 patients (29 men and 59 women) with OVC and neurological deficits who underwent spinal surgery between 2000 and 2009 at Osaka University and 3 affiliated hospitals. The study was approved by the ethics review boards of our institutions and was in compliance with the Helsinki Declaration. Patients had a mean age of 75.2 years (median 75.5 range 55–88 years) at surgery. The mean duration of follow-up was 35.5 months (range 24–123 months). All patients with vertebral fractures (VFs) were treated conservatively, and none had neurological deficits immediately after injury. Surgical treatment was indicated for the patients with progressive neurological deficits caused by vertebral collapse. Of 88 patients, 55 (62.5 %) had obvious causes of injury, such as a short fall or a fall from a great height; the other 33 (37.5 %) had no obvious causes of injury.

Inclusion and exclusion criteria

Patients with paraplegia or bladder and bowel dysfunction caused by compression of the spinal cord, conus medullaris, or cauda equina were candidates for surgical treatment. All patients with neurological deficits reported pain, such as low back pain, back pain, and leg pain. However, no surgical treatment was given to patients with no neurological deficits and whose only symptom was pain. No patients enrolled in our study had pathological fractures with primary spinal tumors, metastatic spinal tumors, myelomas, spinal infections, or metabolic bone diseases such as osteomalacia and hyperparathyroidism. No patients had had previous surgery on the collapsed vertebra or received any dialysis. Patients with acute burst fracture due to major trauma were excluded from the study.

Surgical procedures

We used three surgical procedures in 88 patients: (1) anterior neural decompression and reconstruction (AR group: 27 patients), (2) posterior spinal shortening osteotomy with direct neural decompression (PS group: 36 patients), and (3) posterior indirect neural decompression and short-segment spinal fusion combined with vertebroplasty (VP group: 25 patients) (Fig. 1).

There were no clear criteria for the selection of any of these three procedures in the participating facilities. However, each of the three procedures was used for a specific treatment strategy. The AR group was mainly selected for patients without prevalent VFs at other levels,

Fig. 1 Radiographs of 3 typical surgical procedures for vertebral collapse with neurological deficits (**a, c, e**, anteroposterior view, **b, d, f**, lateral view). **a, b** Postoperative plain radiographs at 2 years after anterior neural decompression and reconstruction surgery (AR group). **c, d** Postoperative plain radiographs at 2 years after posterior spinal shortening osteotomy with direct neural decompression surgery (PS group). **e, f** Postoperative plain radiographs at 2 years after posterior

indirect neural decompression and short-segment spinal fusion combined with vertebroplasty (VP group). *AR* Anterior neural decompression and reconstruction, *PS* posterior spine-shortening osteotomy with direct neural decompression, *VP* posterior indirect neural decompression and short-segment spinal fusion combined with vertebroplasty

whereas the PS group was for patients with osteoporosis with prevalent single or multiple VFs, secondary osteoporosis (rheumatoid arthritis or glucocorticoid-induced osteoporosis), or neural compression by posterior elements. The treatment strategies for the PS group and the VP group were similar, but the VP group was for older patients with more serious comorbidities.

In the AR group, anterior neural decompression and vertebral body reconstruction was performed using the

transpleural or extrapleural approach [3]. Vertebral body reconstruction was performed using autologous bone or bioactive apatite-wollastonite glass-ceramic (Cerabone, Nippon Electric Glass Co., Ltd., Otsu, Japan), and was augmented by the plate-and-rod system (Kaneda Anterior Scoliosis System, DePuy Spine, Inc., Raynham, MA, USA) [3]. For the PS group, we resected the posterior spinal element and bilateral pedicles via a posterior approach [7, 8]. Any anterior bony fragment that protruded into

neural tissues was removed via a posterior approach, and posterior spinal shortening between the adjacent vertebrae of the affected vertebra was performed using the pedicle screw-and-rod system. PSF from 2 or 3 levels above to 2 or 3 levels below the affected vertebra was usually performed. For the VP group, vertebroplasty using calcium phosphate cement ([CPC] Biopex, Pentax Co., Tokyo) was performed using a transpedicular approach. We choose CPC cement for these patients because CPC carry little risk of neural tissue damage induced by heat of cement polymerization. Posterior indirect decompression was performed using partial laminectomy at the affected vertebral level. None of the patients in the VP group received treatments for a retropulsed posterior cortex such as dissection of bony fragments or impaction of bony fragments into the vertebral body. PSF from 1 or 2 levels above to 1 or 2 levels below the affected vertebra was performed using the pedicle screw-and-rod system. The number of fused vertebra, the duration of surgery, estimated intraoperative blood loss, and intraoperative complications were examined using medical records. We performed all of the operations at the 4 hospitals with which we are collectively affiliated.

Clinical examination

We retrospectively reviewed clinical findings such as pain relief, neurological status, function level in ADL, radiographic results, and postoperative complications. We evaluated clinical results at the point of 2 years after surgery.

We made use of a simplified assessment method easily understood by the elderly to evaluate surgical outcomes. Preoperative and postoperative pain (low back pain or back pain and leg pain) in each patient was assessed and rated on a scale of 0–3 points, where 3 points indicated no pain or negligible pain, 2 points indicated mild pain (no treatment needed), 1 point indicated moderate pain (controllable with painkillers), and 0 points indicated severe pain

(uncontrollable despite use of painkillers). Preoperative and postoperative neurological impairment was assessed using scores on the modified Frankel grading system [15] (Table 1). Preoperative and postoperative function level in ADL was assessed by the scoring system established by the Ministry of Health, Welfare, and Labor of Japan (Table 2). This scoring system is well recognized and is approved by the Long-Term Care Insurance System for dependent elderly Japanese people [16, 17]. Roughly, the J levels indicate an ability to move about independently; A levels indicate housebound status but an ability to move about with assistance; B levels indicate chairbound status, which usually indicates wheelchair use; and C levels indicate bedbound status. Pain relief rate, neurological improvement rate, and improvement rate in ADL function level were calculated as follows: the score at the 2-year postoperative follow-up evaluation minus the preoperative score was divided by the full score minus the preoperative score, and then multiplied by 100 (%). The surgeons who performed the operations also performed the physical examinations and recorded examination findings in patients' medical records. All scoring of medical records was performed by one observer (M.K.).

Radiological examinations

Preoperative plain radiographs, plain computed tomography (CT) images (sometimes CT myelographs) and magnetic resonance images were taken for all patients. In all patients, CT images showed the protrusion of posterior wall into the spinal canal, and magnetic resonance images also showed the compression of neural tissues by a protruding bony fragment. Plain radiographs were reviewed before surgery, immediately after surgery, and at 2 years after surgery. Due to the paralysis, it was impossible for all patients to take standing radiographs before surgery and just after surgery and to assess global sagittal balance. We examined the local kyphotic angle (LKA) between the

Table 1 Evaluation of neurological impairment using the modified Frankel grading system

Grade	Neurological status	Score (points)
A	Complete motor and sensory loss	0
B	Preserved sensation only; voluntary motor function absent	1
C	Preserved motor less than fair grade (nonfunctional for any useful purpose)	2
D1	Preserved motor at lowest functional grade (3+/5+) and/or with bowel or bladder paralysis and normal or reduced voluntary motor function	3
D2	Preserved motor at mid-functional grade (3+ to 4 +/5+) and/or neurogenic bowel or bladder dysfunction	4
D3	Preserved motor at high-functional grade (4+ to 5+) and normal voluntary bowel or bladder function	5
E	Complete motor and sensory function normal (may still have abnormal reflexes)	6

Adapted from Bradford and McBride [15] with permission

Table 2 Scores for the evaluation of function in ADL

Category	ADL status	Score (points)
C2 (bedbound)	Unable to roll over in bed independently	0
C1 (bedbound)	Able to roll over in bed independently	1
B2 (chairbound)	Unable to transfer to wheelchair independently	2
B1 (chairbound)	Able to transfer to wheelchair independently	3
A2 (housebound)	Goes out rarely, with assistance	4
A1 (housebound)	Goes out frequently, with assistance	5
J2 (able to go out independently)	Goes around the neighborhood	6
J1 (able to go out independently)	Goes out using public transport and goes a long way away from home	7

The independence level of persons regarding ADL (C2–J1) was determined by an algorithm from the Ministry of Health, Welfare, and Labor of Japan

ADL Activities of daily living

fused vertebrae which was measured using lateral radiographs because there was no better alternative (Fig. 2). Compared with plain radiographs before surgery and at the 2 years after surgery, the presence or absence of subsequent VFs was assessed. All radiographic measurements were performed by one observer (M.K.).

Statistical analysis

All data are expressed as the mean or the mean $\pm$ SD or the mean $\pm$ SD (median, 95 % confidence interval [CI]). Probability values of <0.05 were considered to indicate statistical significance. The associations were expressed as the results of the Pearson correlation coefficient test. The significance of differences among 3 procedures were assessed by one-way analysis of variance and then with the Tukey–Kramer honestly significant difference procedures for multiple comparisons. The power analysis for one-way ANOVA was performed on the condition that (groups = 3, between variance = 0.5, within variance = 1.8, significance level = 0.05, power = 0.90). All statistical analyses were performed using JMP software (version 8.0.1; SAS Institute, Inc., Cary, NC, USA).

Results

Patients' demographics

Table 3 shows the demographics for all 88 patients. The power and sample size calculation confirms that a sample size of 24 for each group looks acceptable. Those in the VP group were significantly older than those in the AR group and those in the PS group (AR group, 73.6 ± 6.9 years [median 75, 95 % CI 70.9–76.3]; PS group, 74.62 ± 65.9 years [median 74, 95 % CI 72.2–76.2]; VP group, 78.3 ± 5.4 years [median 80, 95 % CI 76.0–80.5];

$p = 0.012$). There was a larger percentage of women in the PS group than in either the AR group or the VP group (AR group, 51.9 %; PS group, 86.1 %; VP group, 56.0 %). One patient had injured 2 vertebral bodies (T7 and T12), but the other 87 patients had injured single vertebral bodies. Eighty-one patients (92.0 %) had an affected vertebral body in the thoracolumbar spine (T11–L2), and 42 patients (47.7 %) had a history of prevalent VFs. There were no significant differences among the 3 groups for preoperative back or low back pain, leg pain, or preoperative neurological score, but preoperative ADL function scores were significantly lower in the VP group than in the other AR and PS groups.

Clinical outcomes

Clinical outcomes are listed in Table 4. Mean neurological scores improved from 2.9 ± 0.7 points before surgery to 4.8 ± 1.3 points at 2 years after surgery, a mean improvement rate of 60.1, and 48 % of all patients had full neurological recovery. Mean ADL function score improved from 2.0 ± 1.3 points (chairbound level with assistance) before surgery to 4.7 ± 1.6 points (housebound level and going out with or without assistance) at 2 years after surgery, a mean improvement rate of 55.0 %. 63 patients (71.6 %) represented good ADL (ADL score of J1–A2) and 25 patients (28.4 %) represented poor ADL (ADL score of B1–C2). Even though full neurological recovery, 11 patients represented poor ADL and did not experience improved function in ADL.

Among the 3 groups, there were no significant differences in the gaps between preoperative and postoperative pain score, neurological score, and ADL function score (Table 4). There were also no significant differences in improvement in rates of low back pain or back pain ($p = 0.27$), leg pain ($p = 0.74$), neurological deficits ($p = 0.35$), or ADL function scores ($p = 0.15$).

Fig. 2 Radiographs before and after posterior indirect neural decompression and short-segment spinal fusion combined with vertebroplasty for vertebral collapse with neurological deficits. **a** Preoperative plain radiograph with the patient supine. **b** Preoperative plain

radiograph with the patient standing. **c** Plain radiograph immediately after surgery. **d** Plain radiograph at 2 years after surgery. The local kyphotic angle between the fused vertebrae was measured using the lateral radiographs and was defined as the angle between the 2 lines

The mean number of fused vertebrae was 4.25 ± 1.46 (range 3–9) (Fig. 3). Estimated blood loss was $1,092 \pm 1,162$ mL (range 200–7,040 mL), and the mean duration of surgery was 334 ± 116 min (range 125–700 min). Patients in the VP group lost significantly less blood and needed significantly less time in surgery than did patients in the AR group and those in the PS group (estimated blood loss: $1,420 \pm 1,464$ mL [median 950, 95 % CI 841–1,999] for the AR group, $1,377 \pm 1,054$ mL [median 1,207, 95 % CI

1,015–1,739] for the PS group, 338 ± 326 mL [median 260, 95 % CI 203–472] for the VP group [$p < 0.001$]; duration of surgery: 360 ± 81 min [median 360, 95 % CI 328–393] for the AR group, 387 ± 113 min [median 348, 95 % CI 349–425] for the PS group, 229 ± 80 min [median 205, 95 % CI 196–262] for the VP group [$p < 0.001$]). Short-segment PSF with indirect decompression using vertebroplasty was less-invasive surgical procedure than the other 2 procedures.

Table 3 Demographics and clinical outcomes

Variables	AR group	PS group	VP group
Number of the patients	27	36	25
Age (years)	73.6 ± 6.9	74.2 ± 5.9	78.3 ± 5.4
Sex: male/female (<i>n</i>)	13/14	5/31	11/14
Body mass index (kg/m ²)	21.2 ± 2.8	22.7 ± 3.5	21.3 ± 2.8
Incidence of traumatic events (%)	55.6	63.9	68.0
Presence of prevalent VFs (%)	26.1	62.1	52.0
Number of collapsed vertebrae			
Above T10	1	1	1
T11	0	4	4
T12	17	18	7
L1	8	12	8
L2	1	2	2
Below L3	0	1	3
Preoperative pain score			
Low back pain or back pain	1.2 ± 0.8	1.3 ± 1.1	1.1 ± 1.0
Leg pain	1.9 ± 1.1	1.8 ± 1.1	1.9 ± 1.3
Preoperative neurological score	3.1 ± 0.6	3.0 ± 0.7	2.6 ± 0.7
Preoperative ADL score	2.4 ± 1.4	2.1 ± 1.2	1.4 ± 1.1

Values are shown as mean ± SD

ADL Activities of daily living, *AR* anterior neural decompression and reconstruction, *PS* posterior spinal shortening osteotomy with direct neural decompression, *VF* vertebral fracture, *VP* posterior indirect neural decompression and short-segment spinal fusion combined with vertebroplasty

Radiological outcomes

Radiological data are listed in Table 5. The preoperative LKA at standing or sitting was $36.0^\circ \pm 11.7^\circ$ (median 35, 95 % CI 31.3–38.1). The preoperative LKA was corrected to $11.2^\circ \pm 8.9^\circ$ (median 12, 95 % CI 9.0–13.3) immediately after surgery, but the LKA at 2 years after surgery decreased to $25.1^\circ \pm 10.5^\circ$ (median 26, 95 % CI 22.1–28.0), and the correction loss rate was 56 %. There are many causes of LKA correction loss, including VFs within spinal fusion, subsidence of anterior support, breakage of anterior support such as fragmented CPC, pedicle screw loosening due to osteoporosis, and disc motion between fused vertebrae. Among 3 groups, the VP group had a higher correction loss rate (AR group, 54 %; PS group, 43 %; VP group, 88 %). However, the Pearson correlation coefficient test revealed no association between neurological recovery and the LKA at 2 years after surgery. There was also no association between improvement of ADL function scores and the LKA at 2 years after surgery.

After surgery, 49 patients (55 %) had VFs. Of 88 patients, 31 (35 %) had VFs within the fused level, 23

(26 %) at the adjacent level, and 17 (19 %) at the nonadjacent level. The majority of VFs within the fused level occurred at the uppermost vertebra, and some patients had all 3 types of VFs. The PS group had the highest incidence of subsequent VFs within the fused level, at the adjacent level, and at the nonadjacent level (incidence of total subsequent VFs: AR group, 26 %; PS group, 71 %; VP group, 38 %). Of particular note, the PS group had a higher incidence of subsequent osteoporotic VFs at the nonadjacent level than both the AR and the VP groups. Posterior spinal shortening osteotomy produced better correction of kyphotic deformity and longer PSF resulted in better maintenance of restored sagittal spinal alignment within the fused level. However, with correction of kyphotic deformity by posterior spinal shortening osteotomy, there was a higher incidence of subsequent VFs in elderly patients with osteoporosis.

Complications

Seven of 88 patients (8.0 %) had a dural tear during surgery, and no patient had any additional procedures after surgery. There were 11 patients with massive bleeding (>2,000 ml) and hemorrhagic shock. In these patients, neurological recovery was obtained and 10 of all 11 patients with massive bleeding and hemorrhagic shock represented good ADL. Massive bleeding and hemorrhagic shock had no impact to deteriorate the functional outcomes. Nine of 88 patients (10.2 %) had a deep surgical site infection (SSI) after spinal instrumentation surgery (AR group, 2 cases; PS group, 4 cases; VP group, 3 cases), and 2 of those 9 patients had septic shock. Unfortunately, all 9 patients also underwent additional surgery such as irrigation and early on after surgery, and they were forced to keep quiet in bed and be restricted in many aspects in daily life. Neurological recovery was obtained in these patients, but 7 of all 9 patients with SSI represented poor ADL. In the PS group, transient neurological deterioration after spinal shortening occurred in 2 patients (5.6 %). In the VP group, there was no leakage of CPC into the spinal canal after vertebroplasty, but CPC breakage was encountered in 5 patients (20 %) and CPC subsidence was encountered in 2 (8 %).

Regarding systemic complications, 3 of 88 patients (3.4 %) had hemorrhagic shock after surgery and 2 (2.3 %) had severe postoperative pneumonia. However, no patients died.

Discussion

A number of reports have discussed surgical results for patients with OVC and neurological deficits, but there are

Table 4 Clinical outcomes for patients with osteoporotic vertebral collapse and neurological deficits

Variables	AR group		PS group		VP group		<i>p</i> value
	Preop	Postop	Preop	Postop	Preop	Postop	
Score for low back or back pain	1.2 ± 0.8	2.0 ± 0.5	1.3 ± 1.1	1.9 ± 0.7	1.1 ± 1.0	1.9 ± 0.8	
Score gap	0.8 ± 0.9		0.7 ± 1.1		0.9 ± 1.2		NS
Improvement rate (%)	44		35		44		NS
Leg pain score	1.9 ± 1.1	2.6 ± 0.7	1.8 ± 1.1	2.7 ± 0.7	1.9 ± 1.3	2.7 ± 0.6	
Score gap	0.8 ± 1.1		1.0 ± 1.2		0.9 ± 1.3		NS
Improvement rate (%)	66		75		75		NS
Neurological score	3.1 ± 0.6	4.8 ± 0.9	3.0 ± 0.7	5.0 ± 1.0	2.6 ± 0.7	4.5 ± 1.1	
Score gap	1.7 ± 1.3		1.9 ± 1.4		1.9 ± 1.3		NS
Improvement rate (%)	58		66		56		NS
ADL score	2.4 ± 1.4	5.3 ± 1.6	2.1 ± 1.2	4.8 ± 1.5	1.4 ± 1.1 ^b	4.1 ± 1.6 ^b	
Score gap	2.9 ± 1.8		2.6 ± 1.9		2.8 ± 1.6		NS
Improvement rate (%)	63		55		49		NS

Values are shown as mean ± SD

One-way analysis of variance: $p < 0.05$; statistically significant difference, *NS* not significant

Score gap = postop score – preop score. Improvement score: Score gap was divided by the full score minus the preop score, and then multiplied by 100 (%)

ADL Activities of daily living, *AR* anterior neural decompression and reconstruction, *preop* preoperative, *postop* postoperative (2 years after surgery), *PS* posterior spinal shortening osteotomy with direct neural decompression, *VP* posterior indirect neural decompression and short-segment spinal fusion combined with vertebroplasty

^a Significant difference (AR vs. PS)

^b Significant difference (AR vs. VP)

^c significant difference (PS vs. VP)

Fig. 3 Surgical invasiveness of 3 typical surgical procedures for vertebral collapse with neurological deficits (^asignificantly different at $p < 0.05$ [AR vs. PS], ^bsignificantly different at $p < 0.05$ [AR vs. VP], ^csignificantly different at $p < 0.05$ [PS vs. VP])

few comparative reviews of clinical results for the various surgical procedures [5, 6]. We found no significant differences with respect to pain relief, neurological improvement, or improvement in ADL function scores among 3 recognized surgical procedures. Surgery for OVC with neurological deficits was considered to be effective regardless of the type of procedure used.

Our study is the first to compare outcomes for surgery with indirect decompression and surgery with direct decompression for OVC with neurological deficits. We found no significant differences in pain relief, neurological improvement, or improvement in ADL function scores between surgery with indirect decompression (the VP group) and surgery with direct decompression (the AR and PS groups). These findings mean that direct neural decompression is not always necessary for the treatment of OVC with neurological deficits mainly caused by spinal instability at the site of collapse. So far, the main objectives of surgery for OVC were sufficient neural decompression and the restoration of good sagittal spinal alignment, but recent studies reveal that it is more important to eliminate spinal instability at the collapsed site [18–20]. Recent studies also reveal that patients with OVC with neurological deficits can be treated by less-invasive surgery such as vertebroplasty alone [20], PSF without decompression [18], or short-segment PSF with or without decompression combined with vertebroplasty [10–12]. Ataka et al. [18] reported that PSF without neural decompression can provide significant neurological improvement and relief of back pain without major complications. They concluded that OVC with neurological deficits is mainly caused by the instability of the fractured vertebra rather than by neural

Table 5 Radiographic outcomes for patients with osteoporotic vertebral collapse and neurological deficits according to the surgical procedure

	AR group	PS group	VP group	<i>p</i> value
LKA within the fused vertebra				
Preop LKA (°)	36.6 ± 9.7	39.3 ± 12.4	30.5 ± 6.1	NS
Postop LKA1 (°)	15.3 ± 8.1	9.0 ± 6.9 ^a	9.7 ± 11.2	<i>p</i> = 0.03
Postop LKA 2 (°)	26.8 ± 10.0	22.1 ± 6.5	27.9 ± 9.4	NS
Correction loss rate of LKA (%)	54	43	88 ^c	<i>p</i> = 0.006
Presence of subsequent VFs				
2 years after surgery (%)				
Within the fused level	26	44	19	
Adjacent level	16	32	29	
Nonadjacent level	11	29	5	
Total	26	71	38	

Values are shown as mean ± SD

One-way analysis of variance *p* < 0.05; statistically significant difference, *NS* No significant difference

Correction loss rate of LKA = (postop LKA2 – postop LKA1)/(preop LKA – postop LKA1)

AR Anterior neural decompression and reconstruction, LKA local kyphotic angle within the fused vertebra, *postop LKA1* LKA immediately after surgery, *postop LKA2* LKA 2 years after surgery, PS posterior spinal shortening osteotomy with direct neural decompression, VP posterior indirect neural decompression and short-segment spinal fusion combined with vertebroplasty

^a Significant difference (AR vs. PS)

^b Significant difference (AR vs. VP)

^c Significant difference (PS vs. VP)

compression, and that neural decompression is not necessary for the treatment of OVC with neurological deficits with dynamic mobility.

Anterior decompression and fusion alone for the treatment of vertebral collapse is not easy in patients with serious comorbidities and severe bone fragility [6, 10, 18, 20]. Fortunately, there were no patients with pulmonary complications in our AR group, but 1 patient did have intractable deep SSIs and required more than 3 additional procedures. Posterior surgeries with dissection of a retro-pulsed posterior cortex, including posterior spine-shortening osteotomy, carry the risk of neural tissue damage. Longer PSF necessary to stabilize an osteoporotic spinal column is seriously invasive in older, fragile patients. Short-segment PSF using vertebroplasty is an option for elderly patients in poor general condition who are at high risk for serious complications. We found this procedure to be less invasive than the other 2 procedures, as evidenced by a significantly smaller estimated blood loss and shorter duration of surgery. There is a possibility of leakage of bone cement into the spinal canal after vertebroplasty, but there was no leakage of CPC in our patients. There is the potential for insufficient anterior column support and increased loss of kyphotic angle correction [14, 21]. In this study, the VP group showed a higher correction loss rate due to CPC breakage and subsidence. However, there is no association between neurological recovery and local kyphotic deformity, and the advantages of short-segment PSF using vertebroplasty far outweigh the disadvantages.

Surgical treatment of OVC with neurological deficits poses some significant clinical challenges: Patients with bone fragility are elderly, and they often have serious comorbidities [6]. Furthermore, the complication rate reported for surgical treatment is 70 % by Nguyen et al. [22]. We believe that the high-priority issue is definitive assessment of patients' general health and osteoporosis severity, so that it is possible to choose the surgical procedure best suited for each patient. We also believe that the majority of patients with OVC with neurological deficits can be treated by less-invasive surgery such as short-segment PSF with or without decompression combined with vertebroplasty. However, we sometimes encounter OVC with neurological deficits mainly caused by a severely retro-pulsed bony fragment, not by spinal instability at the site of collapse, and it is undeniable that a small number of these patients should be treated by a more-invasive procedure such as anterior decompression and reconstruction, posterior spinal shortening, and anterior spinal fusion and PSF. For more-invasive procedures, it is all the more important to carefully evaluate patients regarding both general health and severity of osteoporosis.

The retrospective nature of our multicenter study had several limitations. First, our study population was relatively heterogeneous. When we chose the surgical procedure for each patient, we considered the patient's background and general health. Patients in the VP group were significantly older than patients in the other 2 groups and had a significantly worse preoperative ADL function

status. There were a higher percentage of women in the PS group than in the other groups. Second, there were a relatively large number of surgeons and observers obtaining clinical measurements, resulting in technical variations that hindered interpretation of our results. However, it was difficult to perform prospective studies in a single center because of the rarity of OVC. A well-designed multicenter prospective study is necessary in the future.

In conclusion, it is not always necessary to perform direct neural decompression in comparing clinical results among 3 typical procedures for OVC with neurological deficits. The majority of these patients can be treated by less-invasive procedures such as short-segment PSF with indirect decompression combined with vertebroplasty. The high-priority issue is definitive evaluation of patients' general health and the severity of their osteoporosis, so that the surgeon can choose the procedure best suited for each patient. Success in treating osteoporotic spines is expected to depend on these patients' background, such as the severity of osteoporosis and the extent of comorbidities that induce secondary osteoporosis. Even though full neurological recovery, many patients in this study did not experience improved function in ADL as the final goal. Future studies should examine the effects of medical history, comorbidities, and severity of osteoporosis on surgical outcomes for these patients, along with the factors that predict postoperative functional decline in ADL for these patients.

Acknowledgments Medical editor Katharine O'Moore-Klopf, ELS (East Setauket, NY) provided professional English-language editing of this article before its final acceptance for publication. This work was supported by Health and Labor Sciences Research Grants for Comprehensive Research on Aging and Health from the Ministry of Health, Welfare, and Labor of Japan. None of the authors has any financial interest with any of the commercial entities mentioned in this article.

Conflict of interest None.

References

1. Steel HH (1951) Kümmell's disease. *Am J Surg* 81:161–167
2. Taneichi H, Kaneda K, Oguma T, Kokaji M (2002) Risk factor analysis for osteoporotic vertebral collapse and pseudarthrosis. *Rinsyo Seikeigeka* 37:437–442
3. Kaneda K, Taneichi H, Abumi K, Hashimoto T, Satoh S, Fujiya M et al (1997) Anterior decompression and stabilization with the Kaneda device for thoracolumbar burst fractures associated with neurological deficits. *J Bone Jt Surg Am* 79:69–83
4. Kanayama M, Ishida T, Hashimoto T, Shigenobu K, Togawa D, Oha F et al (2010) Role of major spine surgery using Kaneda anterior instrumentation for osteoporotic vertebral collapse. *J Spinal Disord Tech* 23:53–56
5. Suk SI, Kim JH, Lee SM, Chung ER, Lee JH (2003) Anterior-posterior surgery versus posterior closing wedge osteotomy in posttraumatic kyphosis with neurologic compromised osteoporotic fracture. *Spine* 28:2170–2175
6. Uchida K, Nakajima H, Yayama T, Miyzaki T, Hirai T, Kobayashi S et al (2010) Vertebroplasty-augmented short-segment posterior fixation of osteoporotic vertebral collapse with neurological deficit in the thoracolumbar spine: comparisons with posterior surgery without vertebroplasty and anterior surgery. *J Neurosurg Spine* 13:612–621
7. Saita K, Hoshino Y, Kikkawa I, Nakamura H (2000) Posterior spinal shortening for paraplegia after vertebral collapse caused by osteoporosis. *Spine* 25:2832–2835
8. Shikata J, Yamamuro T, Iida H, Shimizu K, Yoshikawa J (1990) Surgical treatment for paraplegia resulting from vertebral fractures in senile osteoporosis. *Spine* 15:485–489
9. Kim KT, Suk KS, Kim JM, Lee SH (2003) Delayed vertebral collapse with neurological deficits secondary to osteoporosis. *Int Orthop* 27:65–69
10. Matsuyama Y, Goto M, Yoshihara H, Tsuji T, Sakai Y, Nakamura H et al (2004) Vertebral reconstruction with biodegradable calcium phosphate cement in the treatment of osteoporotic vertebral compression fracture using instrumentation. *J Spinal Disord Tech* 17:291–296
11. Korovessis P, Hadjipavlou A, Repantis T (2008) Minimal invasive short posterior instrumentation plus balloon kyphoplasty with calcium phosphate for burst and severe compression lumbar fractures. *Spine* 33:658–667
12. Lee SH, Kim ES, Eoh W (2011) Cement augmented anterior reconstruction with short posterior instrumentation: a less invasive surgical option for Kummell's disease with cord compression. *J Clin Neurosci* 18:509–514
13. Sudo H, Ito M, Abumi K, Kotani Y, Takahata M, Hojo Y et al (2010) One-stage posterior instrumentation surgery for the treatment of osteoporotic vertebral collapse with neurological deficits. *Eur Spine J* 19:907–915
14. Yang SC, Chen WJ, Yu SW, Tu YK, Kao YH, Chung KC (2008) Revision strategies for complications and failure of vertebroplasties. *Eur Spine J* 17:982–988
15. Bradford DS, McBride GG (1987) Surgical management of thoracolumbar spine fractures with incomplete neurologic deficits. *Clin Orthop Relat Res* 218:201–216
16. Campbell JC, Ikegami N (2000) Long-term care insurance comes to Japan. *Health Aff (Millwood)* 19:26–39
17. Matsumoto T, Hoshino M, Tsujio T (2012) Prognostic factors for reduction of activities of daily living following osteoporotic vertebral fractures. *Spine* 37:1115–1121
18. Ataka H, Tanno T, Yamazaki M (2009) Posterior instrumented fusion without neural decompression for incomplete neurological deficits following vertebral collapse in the osteoporotic thoracolumbar spine. *Eur Spine J* 18:69–76
19. Hoshino M, Nakamura H, Terai H, Tsujio T, Nabeta M, Namikawa T et al (2009) Factors affecting neurological deficits and intractable back pain in patients with insufficient bone union following osteoporotic vertebral fracture. *Eur Spine J* 18:1279–1286
20. Saito F, Takahashi K, Tanaka S, Torio T, Iizuka H, Wei C et al (2011) Effects of vertebroplasty for delayed-onset paraplegia caused by vertebral pseudarthrosis. *J Orthop Sci* 16:673–681
21. Neviaser A, Toro-Arbelaiz JB, Lane JM (2005) Is kyphoplasty the standard of care for compression fractures in the spine, especially in the elderly? *Am J Orthop* 34:425–429
22. Nguyen HV, Ludwig S, Gelb D (2003) Osteoporotic vertebral burst fractures with neurologic compromise. *J Spinal Disord Tech* 16:10–19