CLINICAL ARTICLE

Study on the Optimal Surgical Scheme for Very Severe Osteoporotic Vertebral Compression Fractures

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Objective: Therapy of very severe osteoporotic compression fractures (VSOVCF) has been a growing challenge for spine surgeons. Opinions vary regarding the optimal surgical procedure for the treatment of VSOVCF and which internal fixation method is more effective is still under debate, and research on this topic is lacking. This retrospective study was conducted to compare the efficacy and safety of various pedicle screw fixation methods for treating VSOVCF.

Methods: This single-center retrospective comparative study was conducted between January 2015 and September 2020. Two hundred and one patients were divided into six groups according to different surgical methods: 45 patients underwent long-segment fixation (Group 1); 39 underwent short-segment fixation (Group 2); 30 received long-segment fixation with cement-reinforced screws (Group 3); 32 received short-segment fixation with cement-reinforced screws (Group 4); 29 had long-segment fixation combined with kyphoplasty (PKP) (Group 5); and 26 cases had short-segment fixation combined with PKP (Group 6). The clinical records were reviewed and the visual analogue scale (VAS) score and the Oswestry Disability Index (ODI) score were used for clinical evaluation. The vertebral height (VH), fractured vertebral body height (FVBH), and Cobb's angle were objectively calculated and analyzed on lateral plain radiographs. Student's *t*-tests and one-way ANOVA among groups were conducted to analyze the continuous, and the chi-squared test was used to compare the dichotomous or categorical variables. The difference was considered statistically significant when the *P*-value was less than 0.05.

Results: The six groups had similar distributions in age, gender, course of the disease, follow-up period, and injured level. In the postoperative assessment of the VAS score, the surgical intervention most likely to rank first in terms of pain relief was the short-segment fixation with cement-reinforced screws (Group 4). For the functional evaluation, the surgical intervention that is most likely to rank first in terms of ODI score was a short-segment fixation with cement-reinforced screws (Group 4), followed by long-segment fixation (Group 1). The long-segment fixation with cement-reinforced screws was the first-ranked surgical intervention for the maintenance of Cobb's angle and vertebral height, whereas the short-segment fixation performed the worst. The highest overall complication rate was in Group 6 with an incidence of 42.3% (11/26), followed by Group 2 with an incidence of 38.5% (15/39).

Conclusion: For the treatment of VSOVCF, the short-segment fixation with cement-reinforced screws is the most effective and optimal procedure, and should be used as the preferred surgical method if surgeons are proficient in using

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cemented screws; otherwise, directly and unquestionably use long-segment fixation to achieve satisfactory clinical results.

Key words: Cement; Long-segment; Pedicle screw fixation; Short-segment; Very severe osteoporotic vertebral compression fracture

Introduction

Osteoporotic vertebral compression fractures (OVCF) are the hallmark of osteoporosis and by far still the most prevalent fragile fractures.[1] Very severe osteoporotic vertebral compression fractures (VSOCVF), defined as the OVCF with the fractured vertebral body height collapses to less than one-third of its original height.[2,3] Patients with VSOCVF may suffer a lot from debilitating continued back pain, spinal kyphosis, progressive neurologic impairment, additional complicated morbidities, and even worse, a heightened mortality risk, reversely leading to vertebral fracture cascade and substantial risk for additional fractures.[4] Evidence suggests that patients of VSOVCF were refractory to conservative treatment, even worse, some might experience symptomatic deterioration and an increased risk of potentially lethal complications.[5] For the treatment of VSOVCF, manifested as spinal instability or neurological deficits, the consensus is that complete decompression of the nerve, correction of deformity, restoration of collapsed vertebrae, maintenance of sagittal balance, and ideal bone fusion with stable internal fixation are the surgical goals.[6] Whereas the stability of pedicle screws in osteoporotic circumstances is a challenging problem for surgeons, internal fixation-related complications are common and cannot be neglected such as loosening, migration, pullout, and even fracture.[7,8] Nowadays, hot debates still continue about the choice of pedicle screws, lengthening of the instrumentation, cement augmentation, or combination by vertebroplasty to better stabilize the pedicle screws in fragile vertebrae of poor bone quality, however, little is known about the influence of those different methods in treating VSOVCF.[9,10] Also, the choice of proper operative schemes is widely empirical, because standardized treatment for VSOVCF is lack evidentiary support.[11] Comparing the efficacy of long- and short-segment instrumentation in vertebral compressive fractures, a study found the clinical superiority of long-segment fusion,[12] but another study found that clinical and radiographic outcomes were similar and no difference was observed between the two techniques.[13] *et al.* retrospectively examined the 158 cement-augmented screws and 19 non-augmented screws and reported no loosening for both types of screws.[14] But in sharp contrast, in another study, the pedicle screw failure rate was even up to 60% in osteoporotic subjects, while internal fixation reinforcement with cement augmentation was recommended as a viable option in the treatment of OVCF in the elderly.[15] The use of cemented screws does not necessarily ensure a satisfactory postoperative outcome, and a progression of the kyphotic deformity was reported in the OVCF population despite surgical intervention, with subsequent requests for revision surgery.[16] Inconsistently, a recent study reported satisfactory clinical results using pedicle screw fixation combined with vertebroplasty for the treatment of thoracolumbar OVCF and observed no significant changes in restored vertebral height during 2 years of postoperative follow-up.[17] Therefore, important questions regarding how to improve surgical outcomes in OVCF patients accompanied by neurological deficits remain somewhat unanswered. Moreover, to date, no studies have comprehensively analyzed and evaluated the effectiveness, advantages and disadvantages of various internal fixation procedures in the treatment of VSOVCF, and little is known about the influence of different screw types, such as long-segment *versus* short-segment fixation, cement augmented *versus* non-augmented screws, and a comparison of pedicle screw fixation combined with or without cement applied. In addition, very severe osteoporotic vertebral fractures are often accompanied by gross instability, severe deformity, nerve compression, and complex skeletal conditions, making the choice of surgical procedures more complicated and technically demanding. Thus, this single-center retrospective study was conducted in a top-tier hospital to investigate internal fixation modalities and surgical techniques for the treatment of VSOVCF and to comprehensively summarize and compare their efficacy and safety results.

Materials and Methods

Selection Criteria

This single-center retrospective study was approved by the institutional review board and ethics committee of the research institution (No[2021]020).

The inclusion criteria were as follows: (i) patients with single-level thoracolumbar very severe osteoporotic vertebral fractures classified as OF3 and OF4 according to the AO Spine-DGOU Osteoporotic Fracture Classification System;[18] (ii) vertebral fractures were fresh and confirmed by MRI; (iii) lumbar bone mineral density (BMD) T value ≤ -2.5 measured by dual-energy X-ray absorptiometry; and (iv) age $\geq$ 50 years old. The exclusion criteria were as follows: (i) neoplasms of the vertebral column; (ii) history of vertebral fracture, and spinal surgery; (iii) patients with ankylosing spondylitis, psychiatric disorders, or other comorbidities affecting pain and functional assessments; (iv) severe cardiopulmonary diseases or coagulation dysfunction; and (v) incomplete clinical data.

A total of 201 patients (137 females and 64 males) with very severe osteoporotic vertebral fractures treated with pedicle screw internal fixation by the senior surgeons in our medical center between January 2015 and September 2020 were screened and selected for analysis. The choice of surgical approach was based on the patient's comorbidities or physical condition, type of vertebral fracture, financial situation, surgeon's personal experience, and most importantly the choice of the patient. Conventionally, the advantages and disadvantages of these surgical methods had been detailed preoperatively and patients could choose the right surgical treatment for themselves.

General Information

The patients were divided into six groups according to different surgical methods: 45 patients underwent long-segment fixation (Group 1), 39 underwent short-segment fixation (Group 2), 30 received long-segment fixation with cement-reinforced screws (Group 3), 32 received short-segment fixation with cement-reinforced screws (Group 4), 29 had long-segment fixation combined with kyphoplasty (PKP) (Group 5), and 26 cases had short-segment fixation combined with PKP (Group 6). The clinical records were reviewed and no significant differences were found regarding demographic data, body mass index (BMI), BMD, the level of fractured vertebrae, fractured vertebral body height (FVBH), and the compression ratio of the injured vertebral height (VHCR). Preoperative clinical assessments such as the visual analogue scale (VAS), the American Spinal Injury Association (ASIA) impairment scale, Oswestry Disability Index (ODI), and Cobb's angle (Cobb) were also not statistically different. (Table 1).

Surgical Procedures

Anesthesia and Position

Following general anesthesia with tracheal intubation, patients were carefully prepared in the prone position, pillows padded under the upper chest and pelvis to reach the hyperextension of the thoracolumbar spine.

Approach and Exposure

The standard open posterior approach to the thoracolumbar spine was utilized for all patients. After locating the fractured vertebra and incision site with C-arm assistance, a longitudinal skin incision was made over the fractured vertebra and lengthened one or two levels above and below, for the short- or long-segment fixation technique respectively. Exposing the spinous process, lamina, and facet joints, reconfirmed the injured vertebra with fluoroscopy, then locating pin was inserted into each fractured and adjacent vertebrae pedicle.

Pedicle Screw Insertion

Following C-arm confirmation, poly-axial pedicle screws of adequate size were inserted into the adjacent upper and lower vertebrae of the fractured vertebrae through pedicles. For bone cement screw implantation, after tapping, positioning, and catheterization at the appropriate location in the vertebral body of the spine, cement was injected into the vertebral body through the catheter, and then the pedicle screw was inserted.

Decompression

A pre-bent rod was provisionally placed to maintain spinal stability, then spinous process, supraspinous ligament, interspinous ligaments, partial lamina, and ligamentum flavum were successively removed and the lamina was trimmed to expose and release the nerve roots.

PKP procedure

If necessary to combine with PKP, the working channel was inserted into the injured vertebral body through a cannula system, followed by the placement of a balloon into the cavity of the vertebral body and inflation, then cement was carefully injected into the vertebra using a bone cement injector.

Vertebral Restoration

Again C-arm fluoroscopy was performed to confirm the spinal sagittal alignment, and two rods were contoured accordingly and fixed with pedicle screws. Restoration of compressed vertebrae and reconstruction of the spinal sequence were conducted utilizing postural reduction and internal fixation systems. However, it should be noted that, due to the poor holding power of screws in the osteoporotic bone environment, the reconstructed method by the pedicle screw system was usually used to deal with those who profited little from postural reduction.

Fixation, Fusion, and Closure

The facet joints of the surgical segment were disrupted and decorticated for fusion in all patients. The implantation of the screw-rod system and fully tightened all screws, completed the posterolateral spinal fusion, the wound was washed and closed layer by layer. (Fig. 1).

Rehabilitation

The postoperative management was the same in each group. Under the guidance of the rehabilitation physician, patients were required to master the rehabilitation strategies before surgery, and rehabilitation videos are also provided to consolidate knowledge. Rehabilitation was performed according to a standard rehabilitation protocol formulated by the hospital, including leg raising, active quadriceps contractions, ankle pump exercises, and lumbar dorsal muscle strengthening. Patients were allowed to walk and resume their daily activities 2 days after surgery, immobilized and supported by a hard back brace. Low-back strengthening exercises should be intensified 2 weeks after surgery. All patients were strictly treated with anti-osteoporosis drugs such as zoledronic sodium and supplemented with calcium and vitamin D3 after surgery.

TABLE 1 Comparison of demographic characteristics and perioperative general data of each group

Variables		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Statistic value	*P* value
Age (years)[a]		69.7 (67.7–71.7)	68.8 (66.9–70.8)	69.9 (68.3–71.5)	69.9 (68.6–71.3)	68.7 (67.3–70.1)	69.8 (68.5–71.1)	0.562	0.729
Gender (female/male)[b]		32/13	26/13	21/9	21/11	21/8	16/10	1.129	0.951
BMI (kg/m^2)[a]		22.8 (22.2–23.5)	23.2 (22.7–23.8)	23.2 (22.7–23.6)	23.3 (23.0–23.7)	23.3 (23.0–23.5)	23.4 (23.1–23.6)	0.666	0.649
BMD (T-score)[a]		−3.43 (−3.58 ~ −3.28)	−3.35 (−3.46 ~ −3.23)	−3.41 (−3.52 ~ −3.31)	−3.37 (−3.45 ~ −3.29)	−3.37 (−3.44 ~ −3.30)	−3.47 (−3.54 ~ −3.40)	1.150	0.333
Course of disease (days)[a]		29.9 (26.5–33.4)	30.5 (28.2–32.9)	30.8 (28.2–33.4)	28.7 (27.0–30.4)	28.4 (26.7–30.1)	28.2 (26.2–30.3)	1.059	0.382
DGOU classification (n)[b]	OF3	39	35	23	28	27	24	4.829	0.437
	OF4	6	4	7	4	2	2		
ASIA scale (n)[b]	C	3	2	1	2	1	1	1.984	0.996
	D	31	25	20	21	22	18		
	E	11	12	9	9	6	7		
FVBH (mm)[a]		6.24 (6.03–6.45)	6.37 (6.18–6.55)	6.34 (6.18–6.50)	6.15 (6.01–6.28)	6.16 (6.01–6.31)	6.32 (6.17–6.48)	1.388	0.227
VHCR (%)[a]		72.7 (71.7–73.7)	72.1(71.3–72.9)	71.8 (71.1–72.5)	72.3 (71.6–72.9)	72.7 (72.0–73.4)	71.8 (71.1–72.6)	1.026	0.401
Fractured vertebrae (n)[b]	T10	1	2	1	1	1	1	10.460	0.995
	T11	4	3	3	3	3	4		
	T12	16	11	9	14	14	12		
	L1	17	15	12	9	10	5		
	L2	5	6	4	3	2	1		
	L3	2	2	1	2	1	1		
Operation time (min)[a]		81.4 (76.8–85.9)	66.6 (63.8–69.4)	129.3 (125.2–133.4)	100.0 (97.8–102.2)	110.9 (107.7–114.1)	83.9 (82.0–85.8)	194.019	0.000
Blood loss (ml)[a]		73.9 (64.2–83.6)	56.2 (50.5–61.8)	177.5 (165.6–189.5)	105.6 (102.0–109.1)	93.1(89.2–96.9)	73.2 (70.6–75.7)	192.209	0.000
No. of screws (n)[a]		9.9 (9.6–10.3)	5.4 (5.2–5.6)	9.8 (9.5–10.0)	5.5 (5.3–5.6)	8.7 (8.6–8.9)	4.5 (4.4–4.6)	765.854	0.000
Complications (n)[b]	Incision inflammation	2	1	4	0	3	2	7.048	0.217
	Thrombosis	1	1	2	1	2	0	3.171	0.674
	Cardiopulmonary events	2	0	6	0	1	1	18.282	0.003
	Mental disorder	1	0	2	1	2	0	5.029	0.412
	Total	6 (13.3%)	2 (5.1%)	14 (46.7%)	2 (6.3%)	8 (27.6%)	3 (11.5%)	27.950	0.000
Hospital stay (days)[a]		9.2 (8.4–10.0)	8.1(7.5–8.6)	10.8 (10.1–11.5)	8.6 (8.2–9.0)	9.8 (9.3–10.3)	9.0 (8.6–9.4)	12.067	0.000
Follow-up (months)[a]		37.3 (34.9–39.6)	37.4 (35.4–39.4)	36.8 (35.5–38.1)	35.8 (34.7–36.8)	35.9 (34.8–37.0)	36.8 (35.9–37.7)	1.061	0.381
VAS score[a]		7.13 (6.82–7.44)	7.15 (6.87–7.43)	7.27 (7.05–7.48)	7.16 (6.96–7.35)	7.07 (6.87–7.27)	7.04 (6.83–7.25)	0.507	0.771
ODI score (%)[a]		75.20 (73.41–76.98)	74.38 (72.96–75.81)	75.47 (74.41–76.52)	74.25 (73.18–75.32)	74.10 (73.19–75.01)	74.76 (74.09–75.44)	0.970	0.435
Cobb (°)[a]		25.73 (24.15–27.32)	25.56 (24.02–27.11)	26.20 (25.02–27.38)	25.44 (24.43–26.44)	25.10 (24.22–25.99)	24.92 (23.99–25.86)	0.668	0.648

Abbreviations: AO Spine-DGOU Osteoporotic Fracture Classification (DGOU), Bone mineral density (BMD), body mass index (BMI), visual analogue scale (VAS), ASIA impairment scale (ASIA), Oswestry Disability Index (ODI), Cobb' angle (Cobb), fractured vertebral body height (FVBH), the compression ratio of the injured vertebral height (VHCR), surgical blood loss (blood loss), number of screws implanted during surgery (No. of screws), surgery-related and perioperative complications (complications), deep vein thrombosis of lower extremity (thrombosis).; [a]Values were expressed as mean ± SD and evaluated by the student's t-test.; [b]Values were expressed as numbers and compared using the chi-square test.

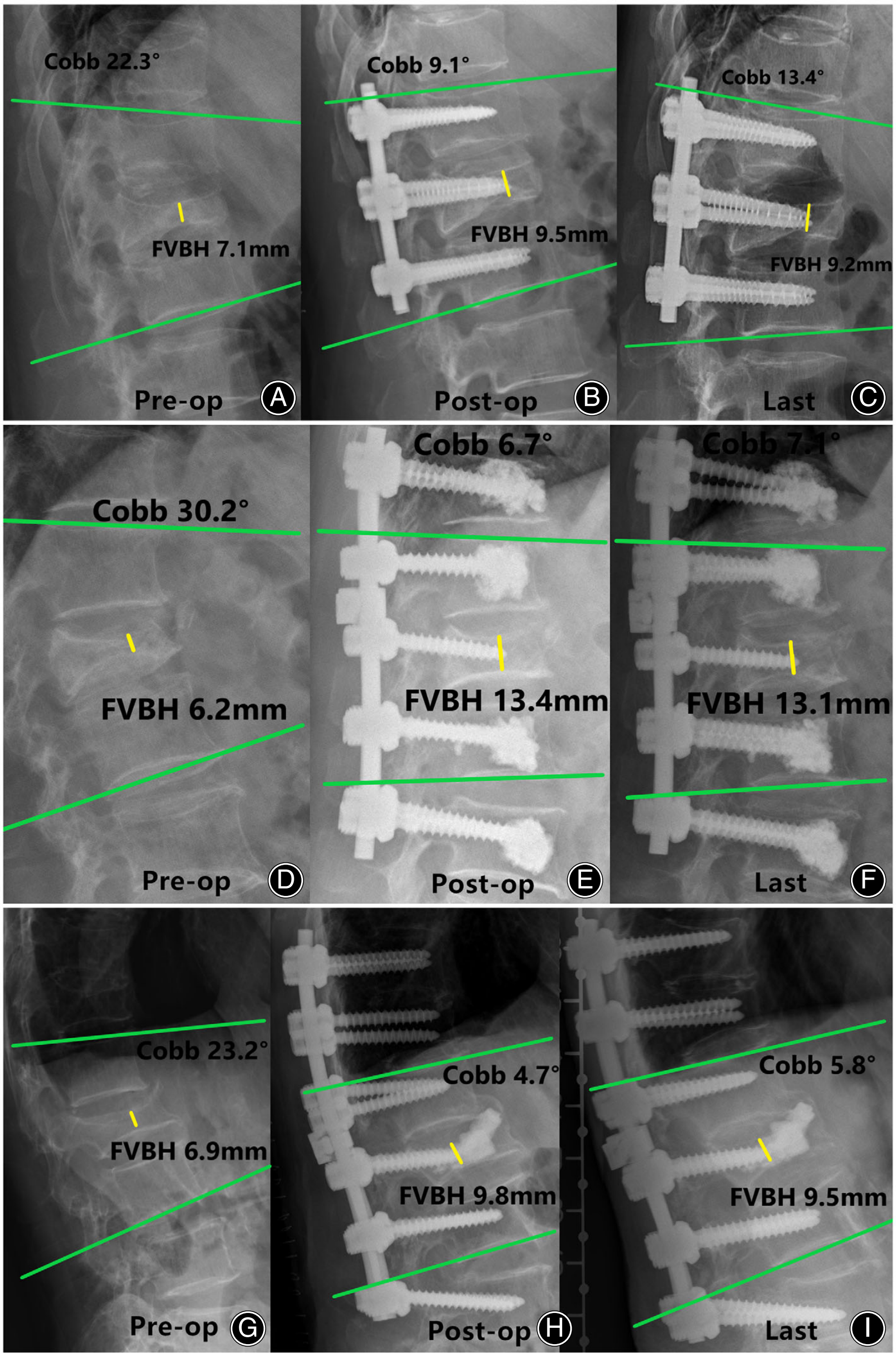

Fig. 1 The Fig. shows the preoperative (Pre-op), postoperative (Post-op), and last follow-up (Last) plain films of three representative patients and shows the measurement of Cobb's angle (Cobb) and the measurement of the fractured vertebral body height (FVBH). (A–C) Are from a patient who underwent short-segment fixation (Group 2); (D–F) are from a patient who underwent long-segment fixation with cement-reinforced screws (Group 3); (G–I) are from a patient underwent long-segment fixation with cement-reinforced screws (Group 3). The green lines show how the method of measuring Cobb's angle, which is formed by the superior endplate of the upper vertebra and the inferior endplate of the vertebra. FVBH is measured at the point of maximal collapse

Clinical Evaluations

Clinical records were reviewed for operative time, surgical blood loss, and surgery-related and perioperative complications such as incision inflammation, cardiopulmonary events, and deep vein thrombosis. Clinical assessments were performed before and after surgery, regarding subjective symptoms, back pain, and leg pain were assessed using VAS, and functional impairment was assessed by ODI score. Residual back pain referred to the presence of moderate to severe pain after surgery (VAS score ≥4). The severity of spinal cord injury was graded using the ASIA impairment scale, which was divided into five levels: A, B, C, D, and E according to sensation and muscle strength.

X-ray examinations were routinely performed on all patients before surgery and at postoperative follow-ups. Radiological images were used for evaluating the vertebral height (VH), the compression ratio of the injured vertebra (VHCR), and loss of correction in the sagittal plane. VH was measured at the point of maximal collapse or the middle of a normal vertebra. VHCR was calculated by the formula: ([upper VH + lower VH]/2 – injured VH) / ([upper VH + lower VH]/2) *100%. The local kyphotic angle was calculated by the segmental Cobb's angle (Cobb), formed by the superior endplate of the upper vertebra and the inferior endplate of the vertebra on lateral X-ray plain films. Radiologic images were also observed to determine the presence of complications or not, such as new vertebral fractures, loosening of pedicle screws, and breakage of internal fixation. In addition, an evaluation of cement leakage was conducted for both cement-augmented screws and the PKP procedure. Radiological measurements were conducted by two different researchers, and the mean value was taken for analysis.

Statistical Analysis

Statistical analysis was performed using the SPSS software version 24.0 (IBM, Armonk, NY, USA). Student's *t*-tests and one-way ANOVA among groups were conducted to analyze the continuous variables such as the VAS score, ODI score, VH, and Cobb if the data were confirmed to meet the normal distribution and homogeneity of variance assumptions. Chi-squared test was used to compare the dichotomous or categorical variables such as gender, fractured level, and complications. The difference was considered statistically significant when the *P*-value was less than 0.05, and "n.s." meant no significant difference. The sample size calculation was performed using G-Power software 3.1 (effect size 0.5, α-error 0.05, power 0.95, number of groups 6), and a minimum of 107 total sample size was recommended. The qualitative results were presented in the form of numbers or percentages, and quantitative data were reported as mean and 95% confidence interval (CI).

In addition, this study selected the VAS score, the ODI score, Cobb's angle, and FVBH at the last follow-up as the outcome indicators, and used the method of network meta-analyses to analyze the impact of various surgical options on the outcome indicators. Pooled data were assessed by standardized mean difference with a 95% confidence interval. To rank the treatment effect, the surface under the cumulative ranking curve (SURCA) value of each intervention was estimated. The SURCA value ranges between 0 and 1, and a greater value indicates a greater probability of becoming the best intervention.

Results

Baseline Characteristics of Participants

The six groups had similar distributions in age, gender, course of the disease, follow-up period, and injured level (P = n.s.), and the characteristics of the patients were summarized in Table 1. The most time-saving procedure was in Group 2, with an average operation time of 66.6 (63.8–69.4) minutes, while the most time-consuming procedure was in Group 3, with an average operation time of 129.3 (125.2–133.4) minutes ($P < 0.001$). Patients in Group 3 had the highest mean surgical blood loss at 177.5 (165.6–189.5) ml, while patients in Group 2 had the least mean blood loss at 56.2 (50.5–61.8) ml ($P < 0.001$). Bone cement leakage occurred in six patients in Group 3, four in Group 4, five in Group 5, and four in Group 6, however, there was no need of additional therapy to deal with an asymptomatic leakage. Compared with other groups, patients in Group 3 were more prone to perioperative complications such as incision inflammation, thrombosis, cardiovascular events, and mental disorders ($P < 0.001$), but all these complications were relieved after drug therapy. (Table 1). However, in terms of postoperative recovery of the height of the injured vertebral body, in Group 3, the height of the injured vertebral body could be restored to an average of 16.71 (16.43–16.99) mm, which was significantly higher than that of the other groups ($P < 0.001$); in addition, the mean Cobb's angle of Group 3 was 5.73 (5.36–6.11) °, which was significantly smaller than the other groups ($P < 0.001$). (Fig. 2).

Clinical Assessment Results

Compared with preoperative data, subjective symptoms of all patients improved postoperatively. The mean preoperative VAS score in Group 1 was 7.13 (6.82–7.44), which decreased to 4.58 (4.31–4.85) postoperatively, 2.02 (1.77–2.27) at the 1-year postoperative follow-up, and 1.91 (1.69–2.13) at the last follow-up; the average of VAS score in Group 2 was 7.15 (6.88–7.43), 4.31 (4.11–4.51), 2.31 (2.13–2.49), and 2.62 (2.34–2.9) at the preoperative, postoperative, 1-year, and final follow-up, respectively; the corresponding VAS scores in Group 3 were 7.27 (7.05–7.48), 4.53 (4.33–4.73), 2.03 (1.87–2.19), and 2.07 (1.86–2.27); respective 7.16 (6.96–7.35), 4.06 (3.90–4.23), 1.97 (1.85–2.09), and 1.72 (1.58–1.86) in Group 4; 7.07 (6.87–7.27), 4.52 (4.36–4.67), 2.00 (1.89–2.11), and 1.90 (1.76–2.04) in Group 5, respectively; and the corresponding VAS scores in Group 6 were 7.04 (6.83–7.25), 4.23 (4.08–4.39), 2.04 (1.93–2.15), and 2.23 (2.05–2.41) ($P < 0.001$). One patient in Group 1, nine in Group 2, three in Group 3, one in Group 4, one in Group 5, and five in Group 6 suffered from residual low back pain at the follow-ups after surgery ($P = 0.007$). The functional disability scores of all groups improved significantly after surgery compared to the preoperative period, with the most significant improvement in Group 2, where the mean ODI score (%) decreased from 74.25 (73.18–75.32) preoperatively to 32.38 (31.07–33.68) at the last follow-up, followed by Group 1, where the average of ODI score was 33.04 (31.15–34.93) at the last follow-up, and then followed by Groups 3, 5, 6, and 2, the mean ODI scores of which were 36.97 (35.46–38.47), 37.28 (36.00–38.56), 39.08 (37.71–40.44), and 41.38 (39.47–43.3), respectively ($P < 0.001$). After surgical treatment, the neurological function of each group was improved to a certain extent, and there was no statistical difference in ASIA scores among the groups at the last follow-up. Seven patients in Group 1, 12 in Group 2, six in Group 3, four in Group 4, seven in Group 5, and six in Group 6 were graded D; 38 in Group 1, 27 in Group 2, 24 in Group 3, 28 in Group

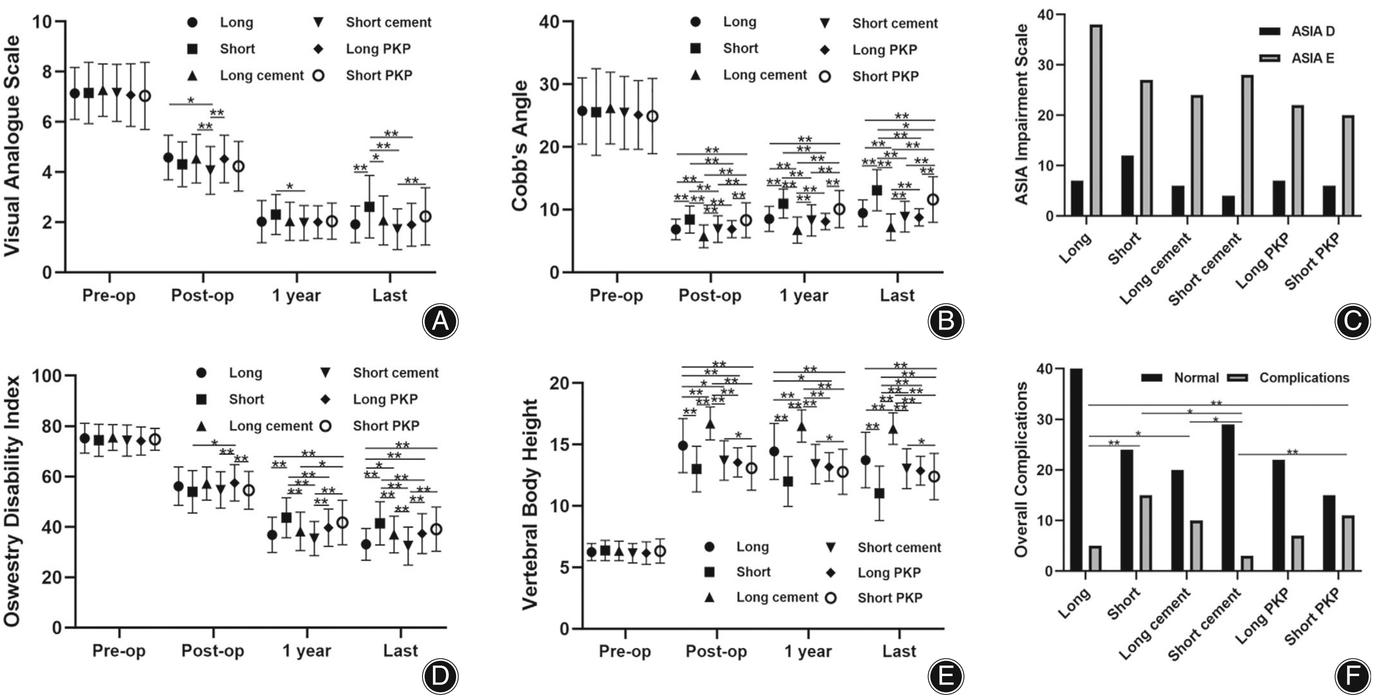

Fig. 2 Comparison of the VAS, the ODI score, Cobb's angle, and injured vertebral body height among groups preoperative (Pre-op), postoperative (Post-op), at 1-year follow-up, and last follow-up (Last). (C and F) were the ASIA grading of each group at the last follow-up and the comparison of overall complications among the groups, respectively. Abbreviating long-segment fixation (Group 1) to Long, short-segment fixation (Group 2) to Short, long-segment fixation with cement-reinforced screws (Group 3) to Long cement, short-segment fixation with cement-reinforced screws (Group 4) to Short cement, long-segment fixation combined with PKP (Group 5) to Long PKP, and short-segment fixation combined with PKP (Group 6) to Short PKP. $p < 0.05$ (*), and $p < 0.01$(**).

4, 22 in Group 5, and 20 in Group 6 were graded E ($P = 0.452$). (Table 2 and Fig. 2).

Radiographic Measurement Results

Compared with the postoperative values, there was a certain downward trend in FVBH and Cobb's angle in each group at 1 year and the last follow-up. In addition, there were statistically significant differences in FVBH and Cobb's angle among the groups at 1 year and the last follow-up. The mean FVBH at postoperative 1 year and the last follow-up in Group 1 were 14.44 (13.75–15.12) mm and 13.73 (13.05–14.41) mm, respectively; in Group 2, the corresponding mean FVBH value was 11.99 (11.54–12.45) mm and 11.02 (10.53–11.52) mm, in Group 3 the mean FVBH values were 16.51 (16.23–16.78) mm and 16.30 (16.03–16.56) mm, and 13.40 (13.13–13.40) mm and 13.03 (12.75–13.32) mm in Group 4, 13.18 (12.99–13.36) mm and 12.87 (12.68–13.06) mm in Group 5, and Group 6 the mean FVBH values were 12.77 (12.48–13.05) mm and 12.39 (12.10–12.68) mm, respectively ($P < 0.001$). The averages of Cobb's angle (°) in Groups 1 to 6 at one-year follow-up were 8.51 (7.91–9.11), 10.96 (10.44–11.48), 6.73 (6.31–7.16), 8.28 (7.85–8.71), 8.10 (7.89–8.32), and 10.08 (9.61–10.54) °, respectively, and at the last follow-up, the mean values of Cobb's angle in each group were 9.44 (8.81–10.08), 13.09 (12.35–13.83), 7.20 (6.76–7.64), 8.86 (8.43–9.28), 8.76 (8.54–8.98), and 11.62 (11.05–12.18), respectively, with statistically significant differences among the groups ($P < 0.001$). (Table 2 and Fig. 2).

Internal Fixation-Related Complications

Two patients in Group 1, nine patients in Group 2, four in Group 5, and seven in Group 6 experienced asymptomatic screw loosening without progressive kyphosis, and revision surgery was not required ($P < 0.001$); because of back pain, one patient in Group 2 removed the internal fixation and relieved it after the surgery; three patients in Group 1, four in Group 2, seven in Group 3, two in Group 4, three in Group 5, and two patients in Group 6 developed new vertebral fractures during the follow-up period, and were treated with percutaneous kyphoplasty ($P = 0.234$). Two patients in Group 2 and one patient in Group 6 were confronted with re-collapse of the injured vertebrae ($P = 0.257$).

Overall complication rates were defined as cases with any one of residual back pain, screw loosening, reoperation, vertebral re-collapse, and new vertebral fracture during follow-up, and the difference in complication rate was statistically significant ($P = 0.003$). The highest overall complication rate was in Group 6 with an incidence of 42.3% (11/26),

TABLE 2 Comparison of end-point clinical outcome indicators and internal fixation-related complications

Variables		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Statistic value	*P* value
VAS score[a]		1.91 (1.69–2.13)	2.62 (2.34–2.9)	2.07 (1.86–2.27)	1.72 (1.58–1.86)	1.90 (1.76–2.04)	2.23 (2.05–2.41)	10.141	0.000
ODI score (%)[a]		33.04 (31.15–34.93)	41.38 (39.47–43.3)	36.97 (35.46–38.47)	32.38 (31.07–33.68)	37.28 (36.00–38.56)	39.08 (37.71–40.44)	18.221	0.000
Cobb (°)[a]		9.44 (8.81–10.08)	13.09 (12.35–13.83)	7.20 (6.76–7.64)	8.86 (8.43–9.28)	8.76 (8.54–8.98)	11.62 (11.05–12.18)	64.760	0.000
FVBH (mm)[a]		13.73 (13.05–14.41)	11.02 (10.53–11.52)	16.30 (16.03–16.56)	13.03 (12.75–13.32)	12.87 (12.68–13.06)	12.39 (12.10–12.68)	96.559	0.000
Residual back pain (n)[b]		1 (2.2%)	9 (23.1%)	3 (10.0%)	1 (3.1%)	1 (3.4%)	5 (19.2%)	16.031	0.007
Vertebral body recollapse (n)[b]		0 (0%)	2 (5.1%)	0 (0%)	0 (0%)	0 (0%)	1 (3.8%)	6.546	0.257
New vertebral fracture(n)[b]		3 (6.7%)	4 (10.3%)	7 (23.3%)	2 (6.3%)	3 (10.3%)	2 (7.7%)	6.827	0.234
Screw loosening (n)[b]		2 (4.4%)	9 (23.1%)	0 (0%)	0 (0%)	4 (13.8%)	7 (26.9%)	22.511	0.000
Overall complication (n)[b]		5 (11.1%)	15 (38.5%)	10 (33.3%)	3 (9.4%)	7 (24.1%)	11 (42.3%)	17.653	0.003
ASIA scale (n)[b]	D	7 (15.6%)	12 (30.8%)	6 (20.0%)	4 (12.5%)	7 (24.1%)	6 (23.1%)	4.715	0.452
	E	38 (84.4%)	27 (69.2%)	24 (80.0%)	28 (87.5%)	22 (75.9%)	20 (76.9%)		

Abbreviations: Visual analogue scale (VAS), ASIA impairment scale (ASIA), Oswestry Disability Index (ODI), Cobb' angle (Cobb), and fractured vertebral body height (FVBH). Overall complication rate refers to cases with residual back pain, screw loosening, and new vertebral fractures by the last follow-up.; [a]Values were expressed as mean ± SD and evaluated by the student's t-test.; [b]Values were expressed as numbers and compared using the chi-square test.

followed by Group 2 with an incidence of 38.5% (15/39), followed by Group 3 with an incidence of 33.3% (10/30), and complication rate in Group 5 and Group 1 was 24.1% (7/29) and 11.1% (5/45), respectively, while the lowest overall complication rate was 9.4% (3/32) in Group 4. (Table 2 and Fig. 2).

Ranking of Surgical Methods According to Clinical and Radiological Outcome Indicators

This study selected the outcome indicators for the VAS score, the ODI score, Cobb's angle, and FVBH at the last follow-up. The surface under the cumulative ranking curve (SURCA) value of each internal fixation method was estimated to rank the treatment effect, and a greater value indicates a greater probability of becoming the best intervention.

According to the VAS pain score, the surgical intervention most likely to rank first in terms of pain relief was the short-segment fixation with cement-reinforced screws (Group 4), followed by long-segment fixation combined with PKP (Group 5) and long-segment fixation (Group 1), then long-segment fixation with cement-reinforced screws (Group 3) and short-segment fixation combined with PKP (Group 6), and finally the short-segment fixation (Group 2). (Fig. 3A).

According to the ODI score, the surgical intervention that is most likely to rank first in terms of improving patient dysfunction was a short-segment fixation with cement-reinforced screws (Group 4), followed by long-segment fixation (Group 1), long-segment fixation with cement-reinforced screws (Group 3), long-segment fixation combined with PKP (Group 5) short-segment fixation combined with PKP (Group 6), and finally short-segment fixation (Group 2). (Fig. 3B).

The most likely first-ranked surgical intervention for the maintenance of Cobb's angle was a long-segment fixation with cement-reinforced screws (Group 3), followed by short-segment fixation with cement-reinforced screws (Group 4) and long-segment fixation combined with PKP (Group 5), then the long-segment fixation (Group 1), and then short-segment fixation combined with PKP (Group 6), and finally short-segment fixation (Group 2). (Fig. 3C).

The most likely top-ranked surgical intervention for reconstructing fractured vertebral height and maintaining vertebral height was a long-segment fixation with cement-reinforced screws (Group 3), followed by long-segment fixation (Group 1), then the short-segment fixation with cement-reinforced screws (Group 4), and then long-segment fixation combined with PKP (Group 5) and short-segment fixation combined with PKP (Group 6), and finally the short-segment fixation (Group 2). (Fig. 3D).

Discussion

Main Findings

In the present study, patients of VSOVCF acquired satisfactory therapeutic effects through pedicle screw fixation; the main finding was that, in terms of pain relief, reduction of

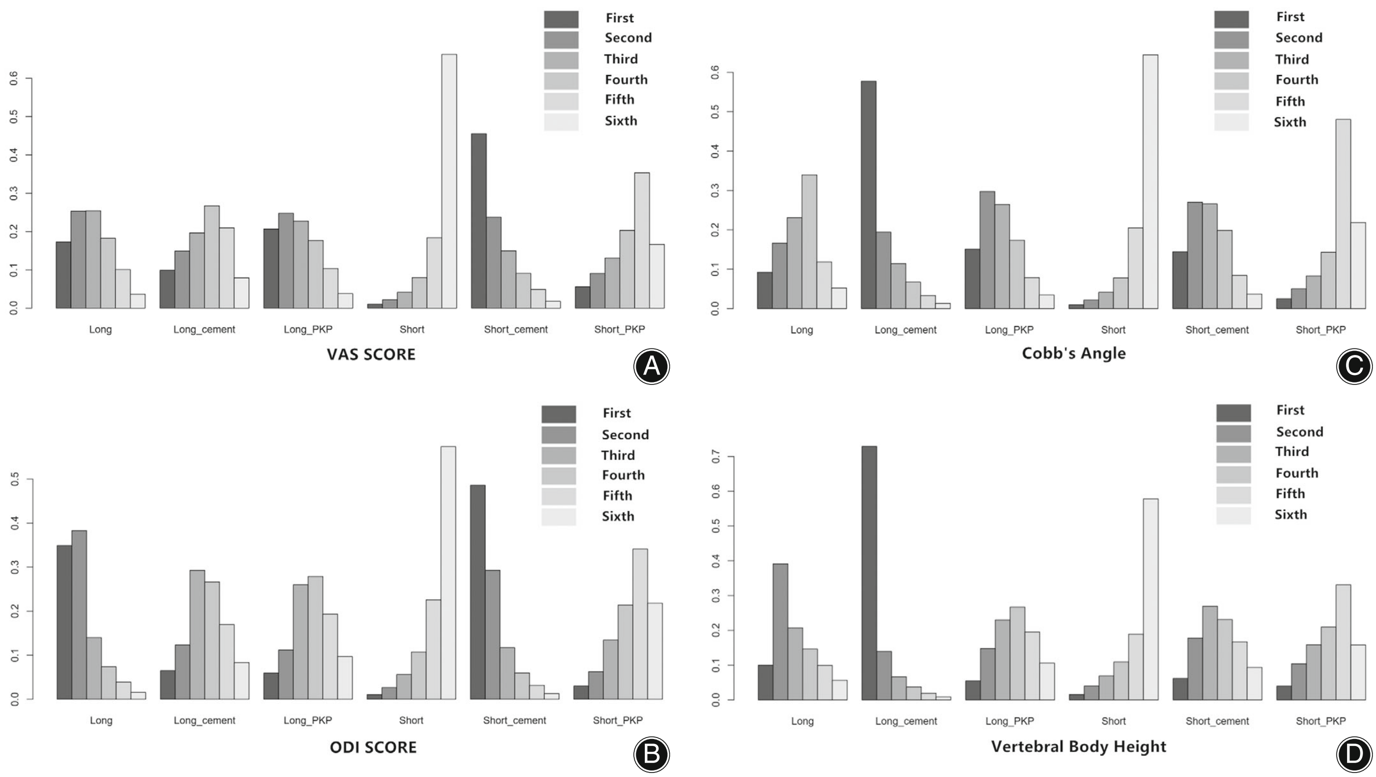

Fig. 3 Ranking of surgical methods according to the VAS score, the ODI score, Cobb's angle, and vertebral body height, and a greater value indicates a greater probability of becoming the best intervention. Abbreviations: the possibility of ranking first (First), the possibility of ranking second (Second), the possibility of ranking third (Third), the possibility of ranking fourth (Fourth), the possibility of ranking fifth (Fifth), and the possibility of ranking sixth (Sixth)

complications, improvement of function, maintenance of vertebral body height and normal spinal sequence, the short-segment fixation with cement-reinforced screws is the most satisfying procedure in treating severe osteoporotic vertebral compression fractures, while the long-segment fixation is also a well-performed surgical method. However, it is difficult to achieve ideal surgical results with short-segment fixation alone, and complications associated with internal fixation are more likely to occur; while long-segment fixation with cement-reinforced screws can maintain spinal sequence well, the therapeutic benefit is less than ideal because this surgical method is a little aggressive for elderly patients. The results of this study do not appear to find a helpful effect of cement kyphoplasty on the pedicle screw fixation procedure. In other words, kyphoplasty does not reduce the higher complication rates associated with short-segment fixation; meanwhile, cement kyphoplasty could not increase the efficacy of long-segment fixation, but increases the operative time and intraoperative blood loss. Therefore, considering all, if spine surgeons are proficient in using cemented screws, short-segment fixation with cement-reinforced screws should be used as the preferred surgery for the treatment of VSOVCF, otherwise, surgeons can directly and unquestionably use long-segment fixation to achieve satisfactory clinical results.

Necessity and Objective of Surgery

Despite controversial opinions on the choice of surgical treatment, it is generally accepted that when vertebral compression fractures lead to spinal instability and neurological disorders, surgery is necessary to achieve spinal stability and improve neurological disorders.[16,19] The thoracolumbar spine lacks support from the rib cage, and osteoporotic vertebral fractures are easily aggravated, which would result in significantly progressive kyphotic deformity and neurological deterioration. Surgical treatment is usually required in these cases as a nonoperative therapeutic regimen is generally ineffective.[20] The surgical goals of VSOVCF paralleled those of unstable spine injury, including correction of kyphotic deformity, stabilization of the spine by arthrodesis, and nerve decompression when necessary. However, the reduced bone stock and inadequate reduced osseous mass in a fragile bone environment severely reduced the grip strength of the screw and increased the risk of screw loosening, difficult fixation, junctional kyphosis, and consequentially surgical failures. Osteoporotic vertebral compressive fractures in thoracolumbar segments, a transition from thoracic kyphosis to lumbar lordosis, had a high risk and possibility of progression if the anterior part of the vertebral body collapsed. If the increased bending moment was combined with anterior vertebral body insufficiency, the kyphotic deformity increased, and then the bending moment increased, even more, producing a vicious cycle.[21] But fortunately, suitable pedicle screws will achieve satisfactory results with correct insertion techniques by experienced spine surgeons. The previous literature has shown that many techniques could improve pedicle screw strength to pullout, which included, but are not limited to long-segment fixation, cement-augmented screws, or the combination with PKP.[22–25]

Comparison of Long-Segment versus Short-segment Fixation

It can be inferred from the results of the study, that the superiority of long-segment over short-segment fixation tended to be more of a radiographic advantage, which may have little impact on pain relief or functional improvement, but long-segment fixation possessed an apparent advantage in reducing both implant-related and overall complications compared with short-segment technique. These complications largely reflected the fact that the short-segment fixation was less reliable than the long-segment technique in stabilizing the spinal sequence and correcting spinal deformity in the treatment of VSOVCF. The findings of the present study once again verified the correctness of Alpantaki *et al.*'s theory of treating osteoporotic vertebral fractures that to prevent screw loosening and correct kyphosis at the thoracolumbar junction, long-segment instrumentation should be utilized.[5] For the internal fixation itself in the osteoporotic bone environment, the efficacy of the long segment is indeed better than that of the short segment and does not increase the incidence of surgery-related complications.[26] With a mean follow-up of 3 years, this study observed only two asymptomatic loosening cases in the long-segment group while nine cases in the short-segment group, perhaps because long-segment fixation achieved good mechanical stability and could better disperse screw stress. And some surgical tips need to be used such as the technique of no pretapping or tapping only the outer cortex of the pedicle, to increase the pullout strength of pedicle screws in osteoporotic bone. Postural reduction played an important role in the correction of kyphotic deformity, and rods were contoured according to the spinal sagittal alignment to reduce pullout force and shear force.

Benefits and Precautions from Cement-augmented Screws

Cement-augmented screws are mostly used methods to secure and improve screw purchase in osteoporotic vertebrae of poor bone quality and are biomechanically more stable than conventional pedicle screw fixation.[27] Technical solutions for osteoporotic poor bone have been developed to minimize negative impacts, in addition, the capabilities and drawbacks of these techniques should essentially be known and mastered. Based on the results of a previous study, the optimal cement filling volume was 75% of the trajectory volume, and excessive cement increased the risk of leakage.[28] The cement augmented screws method had the risk of cement leakage and may result in disastrous consequences. As a previous study reported, cement leakage was found in 165 (73.3%) augmented vertebrae, and pulmonary embolism was observed in four (4.1%) patients.[29] The cement-augmented technique was proven to increase the pullout strength of the internal fixation by improving the implant-bone interface. However, once the screw was cemented within a vertebral body, revision of the screw would be difficult or even impossible.[15] Adjacent vertebral body fractures are also a tough clinical problem, as reported by Toyone *et al.* that patients who underwent internal fixation were susceptible to the development of subsequent vertebral fractures within 2 years after surgery. As the mechanism, changes in postoperative immobilization and altered biomechanics, and initial low bone density were assumed.[30] In addition, the surgical method, which involves posterior decompression, cement-augmented screws insertion, and rigid posterior fixation in one procedure, is technically common but a little aggressive, as patients with VSOVCF are usually elderly and often accompanied by impaired cardiopulmonary function, chronic inflammation, multiple organ functional decline, or multiple organ dysfunction, the risk of postoperative morbidity and mortality cannot be ignored using the cemented screw technique and less invasive technique should be utilized.[31] Therefore, based on the results of the current study, short-segment fixation is recommended rather than the long-segment technique when cement-reinforced screws are used.

Role of Kyphoplasty in the Posterior Pedicle Screw Fixation

Although percutaneous kyphoplasty performed well in the treatment of severe OVCF,[32] the combination of it with long-segment or short-segment fixation could not significantly improve the effectiveness of surgical treatment. Compared with other internal fixation procedures, the surgical effect of short-segment fixation combined with cement kyphoplasty is obviously inferior in both subjective symptom relief and postoperative imaging evaluation. Even if the method of long-segment fixation combined with cement kyphoplasty is used, the surgical effect will not be improved compared with the conventional long-segment fixation, but it will increase the operation time, intraoperative bleeding, and other related risks. Controversy also exists on this point, a previous study found that for OVCF with severe compression and kyphosis, short-segment fixation combined with cement vertebroplasty can achieve good clinical and radiographical results,[33] but the study did not compare it to other internal fixation methods. A recent review focused on the topics of the efficacy of vertebroplasty in short-segment pedicle screw fixation of vertebral fractures and concluded that internal fixation combined with vertebroplasty can help restore the anatomy and stabilize the fractures.[34] However, few studies have studied the efficacy of this surgical method for very severe vertebral compressive fractures.

Strengths and Limitations

So far, this is the first study to comprehensively compared the clinical and radiological effects of different internal fixation methods in the treatment of VSOVCF, demonstrating the superiority of the short-segment fixation with cement-reinforced screws and the conventional long-segment fixation technique, and either one qualified as the optimal surgical scheme in treating VSOVCF. It was inevitable that several limitations existed in this study. First, the number of patients who underwent internal fixation for treating VSOVCF was relatively small and the average follow-ups of 3 years were relatively too short for the study of the survival of internal fixation. To a large extent, this is due to the lack of long-term follow-up data, such as 5-year or 10-year follow-ups, which is not enough to study the long-term complications related to internal fixation. Also, a CT scan was not routinely performed at follow-ups, and screw loosening rate or other implant-related failures might be underestimated by plain films. Moreover, for this study, the nature of the retrospective study was a limitation and the inclusion criteria for patients who underwent different operations cannot be completely consistent. For example, some spine surgeons, just do not like to use bone cement because of its danger. However, comparing the preoperative demographic and preoperative pain and function scores shows no significant difference among the groups. Therefore, a comparative study of surgical treatment effects can be conducted. Of course, in order to better evaluate, the best way is to carry out prospective randomized controlled clinical research to improve its credibility. The current study, though regrettable, achieved its original aim of comparing different techniques for the treatment of VSOVCF.

Conclusions

Based on the findings of this study, in terms of pain relief, reduction of complications, improvement of function, maintenance of vertebral body height and normal spinal sequence, the short-segment fixation with cement-reinforced screws is the most satisfying procedure in treating severe osteoporotic vertebral compression fractures, while the long-segment fixation is also a well-performed surgical method. Therefore, considering all, if spine surgeons are proficient in using cemented screws, short-segment fixation with cement-reinforced screws should be used as the preferred surgery for the treatment of VSOVCF, otherwise, surgeons can directly and unquestionably use long-segment fixation to achieve satisfactory clinical results.

Ethics Approval and Consent to Participate

This study was approved by the ethics committee of The First Affiliated Hospital, Sun Yat-sen University (No [2021]020), and all methods were performed in accordance with the Declaration of Helsinki and its later amendments or comparable ethical standards. Since the study was retrospective, the informed consent was exempt according to relevant regulations by the Institutional Review Board of The First Affiliated Hospital, Sun Yat-sen University.

Availability of Data and Materials

Research-related data generated and/or analyzed during the current study are not publicly available due to the limitations of data sharing in the clinical research center of The First Affiliated Hospital, Sun Yat-sen University, but are available from the corresponding author on reasonable request.

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Competing Interests

Zhenxing Wen, Xiaoyi Mo, Hangzhan Ma, Haonan Li, Changhe Liao, Dan Fu, Wing Hoi Cheung, Zhichao Qi, Shengli Zhao, and Bailing Chen declare that they have no conflicts of interest or financial interests.

Authors' Contributions

Zhenxing Wen: conception, design, acquisition of data, analysis and interpretation of data, drafting, and final approval. Xiaoyi Mo: acquisition of data, analysis and interpretation of data, drafting, critical revision, and final approval. Hangzhan Ma: conception, design, analysis, and interpretation of data, drafting, and final approval. Haonan Li: software, imaging measurements, and final approval. Changhe Liao: software, analysis and interpretation of data, and final approval. Dan Fu: critical revision, and final approval. Wing Hoi Cheung: software, critical revision, and final approval. Zhichao Qi: conceptualization, acquisition of data, interpretation of data, drafting, and final approval. Shengli Zhao: conceptualization, interpretation of data, software, critical revision, and final approval. Bailing Chen: conceptualization, methodology, project administration, drafting, validation, supervision, and final approval. All authors read and approved the final manuscript.

Disclosure Statement

We have no conflicts of interest or financial interests to disclose.

References

1. Kutsal FY, Ergin Ergani GO. Vertebral compression fractures: still an unpredictable aspect of osteoporosis. Turk J Med Sci. 2021;51(2):393–9.

2. Peh WC, Gilula LA, Peck DD. Percutaneous vertebroplasty for severe osteoporotic vertebral body compression fractures. Radiology. 2002;223(1):121–6.

3. Wang H, Zhang Z, Liu Y, Jiang W. Percutaneous kyphoplasty for the treatment of very severe osteoporotic vertebral compression fractures with spinal canal compromise. J Orthop Surg Res. 2018;13(1):13.
4. Che H, Breuil V, Cortet B, et al. Vertebral fractures cascade: potential causes and risk factors. Osteoporosis Int. 2019;30(3):555–63.
5. Alpantaki K, Dohm M, Korovessis P, Hadjipavlou AG. Surgical options for osteoporotic vertebral compression fractures complicated with spinal deformity and neurologic deficit. Injury. 2018;49(2):261–71.
6. Girardo M, Rava A, Fusini F, Gargiulo G, Coniglio A, Cinnella P. Different pedicle osteosynthesis for thoracolumbar vertebral fractures in elderly patients. Eur Spine J. 2018;27(Suppl 2):198–205.
7. Weiser L, Huber G, Sellenschloh K, et al. Insufficient stability of pedicle screws in osteoporotic vertebrae: biomechanical correlation of bone mineral density and pedicle screw fixation strength. Eur Spine J. 2017;26(11):2891–7.
8. Galbusera F, Volkheimer D, Reitmaier S, Berger-Roscher N, Kienle A, Wilke HJ. Pedicle screw loosening: a clinically relevant complication? Eur Spine J. 2015;24(5):1005–16.
9. Kim JH, Ahn DK, Shin WS, Kim MJ, Lee HY, Go YR. Clinical effects and complications of pedicle screw augmentation with bone cement: comparison of fenestrated screw augmentation and vertebroplasty augmentation. Clin Orthop Surg. 2020;12(2):194–9.
10. Rometsch E, Spruit M, Zigler JE, et al. Screw-related complications after instrumentation of the osteoporotic spine: a systematic literature review with meta-analysis. Global Spine J. 2020;10(1):69–88.
11. Wen Z, Mo X, Zhao S, et al. Comparison of percutaneous kyphoplasty and pedicle screw fixation for treatment of thoracolumbar severe osteoporotic vertebral compression fracture with kyphosis. World Neurosurg. 2021;152:e589–96.
12. Moon MS, Choi WT, Moon YW, Kim YS, Moon JL. Stabilisation of fractured thoracic and lumbar spine with Cotrel-Dubousset instrument. J Orthop Surg. 2003;11(1):59–66.
13. Huang YS, Hao DJ, Wang XD, et al. Long-segment or bone cement-augmented short-segment fixation for Kummell disease with neurologic deficits? A comparative cohort study. World Neurosurg. 2018;116:e1079–86.
14. Frankel BM, Jones T, Wang C. Segmental polymethylmethacrylate-augmented pedicle screw fixation in patients with bone softening caused by osteoporosis and metastatic tumor involvement: a clinical evaluation. Neurosurgery. 2007;61(3):531–7.
15. El Saman A, Meier S, Sander A, Kelm A, Marzi I, Laurer H. Reduced loosening rate and loss of correction following posterior stabilization with or without PMMA augmentation of pedicle screws in vertebral fractures in the elderly. Eur J Trauma Emerg Surg. 2013;39(5):455–60.
16. Yasuda T, Kawaguchi Y, Suzuki K, et al. Five-year follow up results of posterior decompression and fixation surgery for delayed neural disorder associated with osteoporotic vertebral fracture. Medicine. 2017;96(51):e9395.
17. Liu H, Xu JW, Sun GR, Shi WF, Xiang LM, Chen S. Minimally invasive pedicle screw fixation, including the fractured vertebra, combined with percutaneous vertebroplasty for treatment of acute thoracolumbar osteoporotic compression fracture in middle-age and elderly individuals: a prospective clinical study. Medicine. 2022;101(10):e29011.
18. Schnake KJ, Blattert TR, Hahn P, et al. Classification of osteoporotic thoracolumbar spine fractures: recommendations of the spine section of the German Society for Orthopaedics and Trauma (DGOU). Global Spine J. 2018;8(2):46 s–9 s.
19. Uchida K, Kobayashi S, Matsuzaki M, et al. Anterior versus posterior surgery for osteoporotic vertebral collapse with neurological deficit in the thoracolumbar spine. Eur Spine J. 2006;15(12):1759–67.
20. Chmielnicki M, Prokop A, Kandziora F, Pingel A. Surgical and non-surgical treatment of vertebral fractures in elderly. Z Orthop Unfall. 2019;157(6):654–67.
21. 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. 2003;28(18):2170–5.
22. Lehman RA Jr, Kang DG, Wagner SC. Management of osteoporosis in spine surgery. J Am Acad Orthop Surg. 2015;23(4):253–63.
23. Kiner DW, Wybo CD, Sterba W, Yeni YN, Bartol SW, Vaidya R. Biomechanical analysis of different techniques in revision spinal instrumentation: larger diameter screws versus cement augmentation. Spine. 2008;33(24):2618–22.
24. Gazzeri R, Roperto R, Fiore C. Surgical treatment of degenerative and traumatic spinal diseases with expandable screws in patients with osteoporosis: 2-year follow-up clinical study. J Neurosurg Spine. 2016;25(5):610–9.
25. Zhou Q, Zhang J, Liu H, et al. Comparison of percutaneous Kyphoplasty with or without posterior pedicle screw fixation on spinal sagittal balance in elderly patients with severe osteoporotic vertebral compression fracture: a retrospective study. Front Surg. 2022;9:800664.
26. Girardo M, Massè A, Risitano S, Fusini F. Long versus short segment instrumentation in osteoporotic thoracolumbar vertebral fracture. Asian Spine J. 2021;15(4):424–30.
27. Rong Z, Zhang F, Xiao J, et al. Application of cement-injectable cannulated pedicle screw in treatment of osteoporotic thoracolumbar vertebral compression fracture (AO type a): a retrospective study of 28 cases. World Neurosurg. 2018;120:e247–58.
28. Fan HT, Zhang RJ, Shen CL, et al. The biomechanical properties of pedicle screw fixation combined with trajectory bone cement augmentation in osteoporotic vertebrae. Clin Spine Surg. 2016;29(2):78–85.
29. Mueller JU, Baldauf J, Marx S, et al. Cement leakage in pedicle screw augmentation: a prospective analysis of 98 patients and 474 augmented pedicle screws. J Neurosurg Spine. 2016;25(1):103–9.
30. Toyone T, Ozawa T, Kamikawa K, et al. Subsequent vertebral fractures following spinal fusion surgery for degenerative lumbar disease: a mean ten-year follow-up. Spine. 2010;35(21):1915–8.
31. Lin HH, Chang MC, Wang ST, Liu CL, Chou PH. The fates of pedicle screws and functional outcomes in a geriatric population following polymethylmethacrylate augmentation fixation for the osteoporotic thoracolumbar and lumbar burst fractures with mean ninety five month follow-up. Int Orthop. 2018;42(6):1313–20.
32. Lee JK, Jeong HW, Joo IH, Ko YI, Kang CN. Percutaneous balloon kyphoplasty for the treatment of very severe osteoporotic vertebral compression fractures: a case-control study. Spine J. 2018;18(6):962–9.
33. Li Z, Wang Y, Xu Y, Xu W, Zhu X, Chen C. Efficacy analysis of percutaneous pedicle screw fixation combined with percutaneous vertebroplasty in the treatment of osteoporotic vertebral compression fractures with kyphosis. J Orthop Surg Res. 2020;15(1):53.
34. Zhang GA, Zhang WP, Chen YC, Hou Y, Qu W, Ding LX. Efficacy of vertebroplasty in short-segment pedicle screw fixation of thoracolumbar fractures: a meta-analysis. Med Sci Monit. 2019;25:9483–9.