


The Impact of Bone Cement Distribution in Unilateral PVP on Therapeutic Outcomes of Vertebral Compression Fracture Repair

Alimujiang Yusufu^{1,2,*}, Parhat Yasin^{1,2,*}, Abuduwupuer Haibier¹, Yuan Ma^{1,2}

¹Spine Surgery Department, Sixth Affiliated Hospital of Xinjiang Medical University, Urumqi, People's Republic of China; ²Xinjiang Spine Surgery Institute, Urumqi, People's Republic of China

*These authors contributed equally to this work

Correspondence: Yuan Ma, Email traumatica@qq.com

Background: Osteoporotic vertebral compression fractures (OVCFs) are common in the elderly, severely impacting health and quality of life. Percutaneous vertebroplasty (PVP) is a primary treatment, with bone cement distribution being a key factor influencing its efficacy.

Objective: This study aimed to evaluate the impact of bone cement distribution patterns on clinical outcomes in unilateral PVP for OVCFs.

Methods: A total of 145 patients undergoing first-time unilateral PVP were retrospectively analyzed. Based on postoperative anteroposterior X-rays, patients were divided into three groups according to cement coverage: Group A (uniform distribution across three vertebral regions, n=57), Group B (covering >1/2 to ≤2/3, n=51), and Group C (covering >1/3 to ≤1/2, n=37). Primary outcomes (VAS, ODI, vertebral height recovery, refracture rate) and secondary outcomes were compared.

Results: At one-year follow-up, VAS scores were significantly lower in Groups A (2.12±0.54) and B (2.16±0.54) than in Group C (2.43±0.50, P<0.05). Vertebral height recovery was superior in Groups A and B compared to Group C (P<0.05). The overall refracture rate was significantly lower in Group A (3.6%) than in Group C (18.9%, P<0.05), with no significant difference from Group B (3.9%). Group A received a higher cement volume (4.95±0.43 mL) than Groups B and C (P<0.05).

Conclusion: Bone cement distribution crossing the vertebral midline is associated with better pain relief, improved vertebral height restoration, and a lower refracture rate after unilateral PVP. However, exceeding two-thirds vertebral coverage does not appear to be a critical factor for surgical efficacy.

Keywords: osteoporotic vertebral compression fractures, thoracolumbar vertebrae, percutaneous vertebroplasty, bone cement

Introduction

Osteoporotic vertebral compression fractures (OVCFs) are clinical manifestations secondary to osteoporosis.¹ As one of the most severe fracture types, OVCFs account for approximately 50% of all osteoporotic fractures and has become the third most common fragile fracture in the world.^{2,3} This type of fracture is more common in the elderly, and may lead to chronic pain, motor dysfunction, spinal deformities, decreased quality of life and increased mortality. It not only seriously affects human health and quality of life, but also brings a heavy burden to families and society.^{4,5} While conservative management remains an option, it is often associated with prolonged pain, functional limitation, and risks of fracture progression or non-union, underscoring the need for effective surgical alternatives like percutaneous vertebroplasty (PVP).⁶

Percutaneous vertebroplasty (PVP) can instantly relieve pain and stabilize fractured vertebrae. It has high safety and reliable short-term efficacy. It has become the most commonly used treatment method for OVCFs in recent years.^{7,8} Polymethyl methacrylate bone cement is one of the most commonly used bone cements in clinical practice. It has good

injection properties and mechanical properties. The safety and clinical effect of treating OVCFs have been widely recognized.⁹ Studies have proved that balanced filling of bone cement can effectively reduce vertebral fractures after PVP and improve recovery effect. However, how to ensure good bone cement distribution in PVP is still the focus of doctors.¹⁰

This study analyzed the clinical data of OVCFs patients diagnosed and treated at the Sixth Affiliated Hospital of Xinjiang Medical University from January 2022 to January 2024, and discussed the impact of bone cement distribution on the efficacy of unilateral PVP, so as to provide effective prevention and treatment measures to prevent postoperative vertebral fractures and improve surgical efficacy. To this end, we conducted a single-center retrospective cohort study of 145 patients who underwent unilateral PVP between January 2022 and June 2024, evaluating the association between cement distribution patterns (Group A, B, C) and key outcomes including pain relief (VAS at 12 months), vertebral height restoration, and refracture rates.

Materials and Methods

Case Selection

Inclusion criteria: ① Patients who underwent unilateral approach percutaneous vertebroplasty for the first time; ② Bone density examination confirmed osteoporosis, defined as a bone mineral density (BMD) T-score ≤ -2.5 standard deviations (SD) at the lumbar spine or hip, and MRI confirmed a fresh fracture consistent with osteoporotic changes; ③ Patients with BMD T-score > -2.5 SD (indicating normal bone mass or osteopenia); ④ Fresh compression fractures located in the thoracic or lumbar spine (T1-L5), with the number of fractured vertebrae ≤ 2 .

Exclusion criteria: ① Patients with burst fractures (including thoracolumbar and other levels) or fractures caused by high-energy trauma. ② Patients with fractures associated with spinal canal compromise, spinal cord, or cauda equina nerve root injury. (This explicitly excludes cervical, sacral, and any other fracture types not meeting the inclusion criteria). ③ Patients with bone density showing normal or low bone mass. ④ Patients who cannot tolerate surgery such as coagulation abnormalities, mental history, liver and kidney dysfunction, etc. ⑤ Patients with metastatic tumors or other pathological fractures; ⑥ Patients allergic to bone cement.

This trial was conducted in the Department of Spinal Surgery, the Sixth Affiliated Hospital of Xinjiang Medical University from January 2022 to June 2024. There were 145 patients who chose to be admitted to the Sixth Affiliated Hospital of Xinjiang Medical University from January 2022 to January 2024 and received unilateral approach PVP for the first time, including 49 males and 96 females. The test complies with the Declaration of Helsinki. The test plan was reviewed by the Ethics Committee of the Sixth Affiliated Hospital of Xinjiang Medical University. Batch number: LFYLLSC20250710-01. All the trial subjects signed an informed consent form (see [Figure 1](#) for case screening flow chart).

Surgical Methods

Preoperative Preparation

All patients completed X-rays, CT and MRI examinations after admission to evaluate vertebral compression; routine blood C-reactive protein, liver and kidney function, and serum bone metabolism examinations were performed to evaluate the patient's basic condition; bone density examinations were performed to evaluate the patient's bone quality.

PVP Surgery Plan

The patient was prone to the position, with the chest and back and lower limbs raised, so that the chest and abdomen were suspended in the air. After the vertebrae was positioned in the vertebrae, he first gently pressed the vertebrae and used manual method to reduce the partial compression fracture. Conventional towel laying, local anesthesia, unilateral pedicle puncture, the entry point was selected at the lateral and superior aspect (the "10 o'clock" position on the left pedicle or the "2 o'clock" position on the right pedicle, conceptually) of the pedicle's outer margin, after the puncture needle reaches the inner edge of the spinal canal root. In the lateral position of the fluoroscopic lateral position, it can be seen that the puncture needle reaches the posterior edge of the vertebrae and continues to enter the needle to reach 1/3 of the front of the vertebrae. Again, the correct position of the puncture needle is confirmed to be on the midline of the

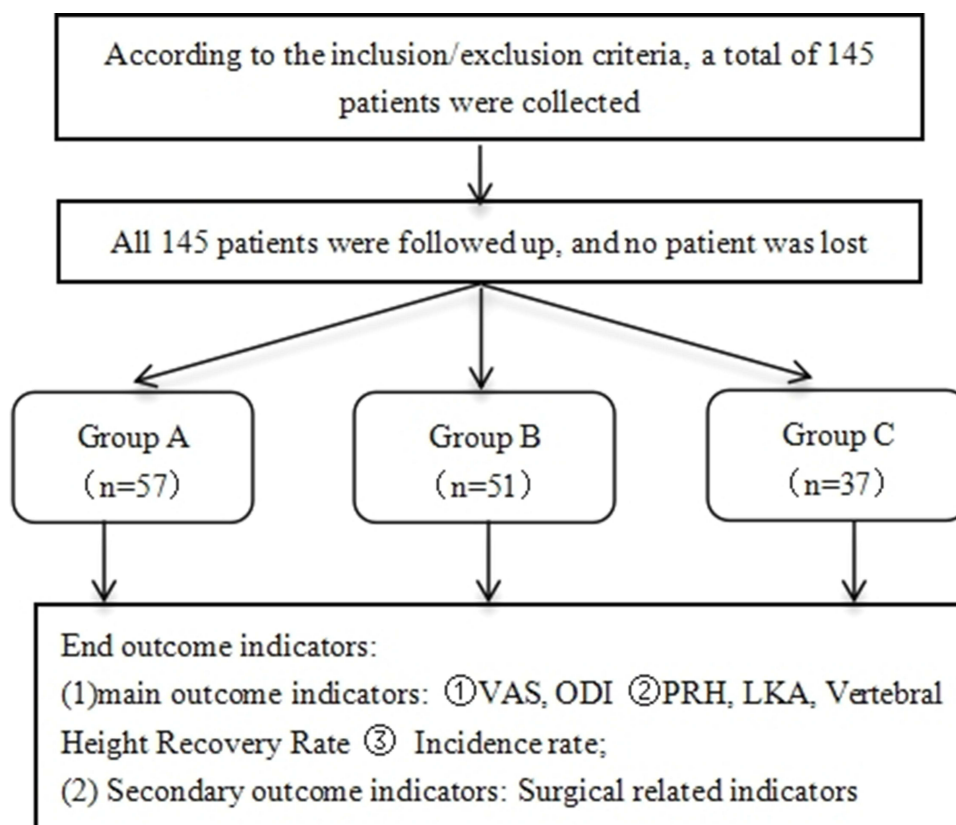


Figure 1 Flow chart of patient assignment.

Notes: The vertebral body was divided into three regions A, B and C. Group I: the bone cement was evenly distributed in ABC region; Group II: the bone cement was distributed more than half but not more than two thirds of the vertebral body; Group III: the bone cement was distributed more than one third but not more than one half of the vertebral body (The yellow line divides the entire vertebral body into three equal parts, while the red line divides it into two equal parts.).

vertebra or just passed the midline of the vertebra. Pull out the puncture needle core and place the bone cement push rod to inject the bone cement that is in the “wire drawing stage” into the vertebra. The entire operation is monitored through the whole process to prevent the bone cement from leaking. At the end, first rotate the puncture needle and then pull it out to prevent the bone cement from being dragged. No suture incision is required, sterile dressing is bandaged, the patient’s vital signs are monitored to be smooth and then sent back to the ward.

Postoperative Treatment

After 8 hours of bed rest, you can wear a waist circumference and get out of bed to move, continue to treat anti-osteoporosis, take oral calcium carbonate D3 tablets, 600 mg each time, once a day; α -calciferol capsules, 0.25 μ g each, 1 to 2 times a day. Use 100mL of zoledronic acid injection once a year for 3 to 5 consecutive years. You can also intravenously inject salmon calcitonin 50IU each time, once a day for 1 consecutive month. The patient underwent X-ray and CT reexamination after surgery to clarify the distribution of bone cement and the recovery of the surgical vertebral body height.

Type of Bone Cement Distribution

Observe the distribution of bone cement based on the front X-ray film of the vertebral body, divide the vertebral body into three areas, type I (the bone cement is evenly distributed in the three areas), type II (the distribution range of bone cement exceeds one-half of the vertebral body, but not more than two-thirds), and type III (the bone cement only exceeds one-third of the vertebral body, but not more than one-half of the vertebral body), see [Figure 2](#).

Refracture Evaluation

After percutaneous vertebroplasty, the patient developed lumbar back pain and discomfort again. Physical examination showed positive percussion pain of spinal or spinous process. Through medical history, clinical manifestations and

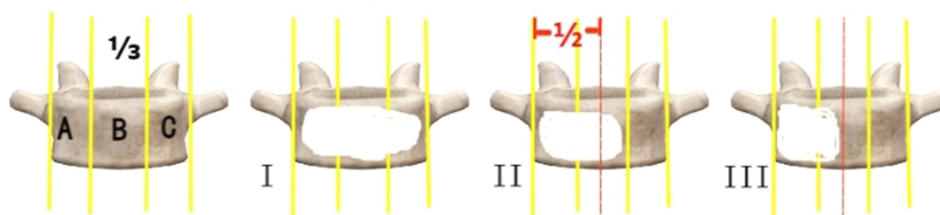


Figure 2 Type of bone cement distribution.

Notes: A1 is the preoperative posterior edge of the vertebra; A2 is the preoperative height of the fractured vertebra; A3 is the preoperative anterior edge of the vertebra. B1 is the postoperative posterior edge of the vertebra; B2 is the postoperative restored height of the vertebra; B3 is the postoperative anterior edge of the vertebra.

lumbar X-ray examination, it was suggested that the percussion plane vertebra had a compressive fracture, and the MRI examination showed that the fracture occurred again.

Observation Indicators

Collect basic information about patients before surgery, including gender, age, body mass index, time from injury to surgery, underlying diseases, VAS, ODI, PFH and LKA, etc.

The main outcome indicators include: postoperative VAS, ODI, PRH, LKA, vertebral height recovery rate, refracture occurrence and cement leakage rate. Among them, the measurement method of the local posterior kyphosis angle is: Line A is the parallel line of the upper end plate of the first vertebra above the fractured vertebra, Line B is the parallel line of the lower end plate of the first vertebra below the fractured vertebra, and LKA is the angle between A and B (see Figure 3). Recovery rate of vertebral height = (postoperative vertebral height - preoperative vertebral height)/primitive vertebral height.⁸ Secondary outcome indicators include: operation time, number of intraoperative fluoroscopy, Length of stays, amount of cement injection and total hospitalization cost.

Statistical Analysis

SPSS26.0 software was used to conduct statistical analysis of the research data. The measurement data is expressed in $\bar{x} \pm s$, and the count data is expressed in rate (%). According to the results of the normality test, if the normality distribution is met, the variance analysis is used for comparison between the three groups; if the normality distribution is not met, the Kruskal-wallisH test is used for comparison between the three groups. For post-hoc pairwise comparisons among the three groups following a significant ANOVA result, the Student-Newman-Keuls (SNK) q test was employed, as it is well-suited for identifying which specific group means differ after a significant omnibus test.

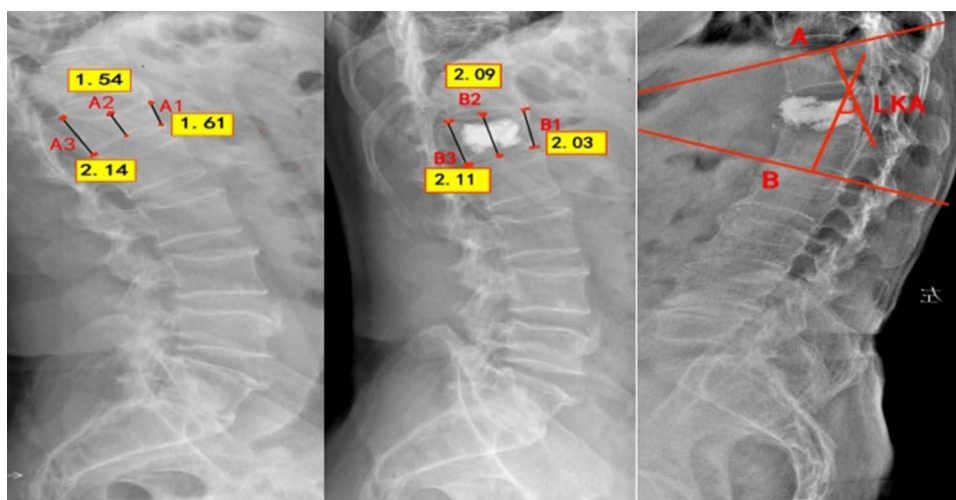


Figure 3 Measurement of imaging parameters after vertebroplasty.

Results

General Information

There was no statistically significant difference in the general information of the two groups ($P>0.05$), suggesting that the two groups are comparable (Table 1). The follow-up time of the two groups was 12–20 months, and the average follow-up time was (14.145 ± 1.863) months.

Comparison of Main Outcome Indicators

Comparison Between Postoperative VAS and ODI

In terms of VAS scores of low back pain in 1 week after surgery, there was no difference between the three groups of patients ($P>0.05$); in terms of VAS scores of low back pain in 6 months after surgery, there was a significant difference between patients in group A compared with those in the other two groups ($P<0.05$), and group A had a smaller pain score. At the first anniversary of the operation, there was no significant difference between VAS scores of low back pain in group A and group B ($P>0.05$). However, groups A and B had smaller VAS scores compared with group C, and the difference was statistically significant ($P<0.05$). There was no significant difference in ODI scores of the three groups of patients after surgery ($P>0.05$). The specific situation is shown in Table 2 and Figure 4.

Comparison of Postoperative Imaging Indicators, Refractory Incidence and Bone Cement Leakage

By comparing the postoperative imaging data of patients after follow-up, it was found that patients in Group A and Group B had better vertebral height and vertebral height response rates ($P=0.014$) and lower overall fracture event rates ($P=0.020$), with statistically significant differences; there was no significant difference in the remaining indicators of the three groups of patients ($P > 0.05$), see Table 3.

Table 1 Comparison of the Baseline Data

Index	Group A (n=57)	Group B (n=51)	Group C (n=37)	F/ χ^2	P
Age ($\bar{x} \pm s$, years)	72.00 \pm 7.409	69.14 \pm 7.422	71.49 \pm 5.762	2.426	0.092
Gender (male/female)	20/37	13/38	16/21	3.091	0.213
BMI ($\bar{x} \pm s$, kg/m ²)	22.572 \pm 4.015	22.308 \pm 3.126	22.797 \pm 3.690	0.198	0.821
Follow up time ($\bar{x} \pm s$, months)	14.035 \pm 1.581	14.451 \pm 2.138	13.892 \pm 1.853	1.130	0.326
The time between fracture and surgery ($\bar{x} \pm s$, days)	4.26 \pm 0.897	4.25 \pm 0.744	4.19 \pm 0.776	0.103	0.902
Diabetes (n/%)	5/8.8	4/7.8	3/8.1	0.032	0.984
Cardiovascular system (n/%)	8/14.0	4/7.8	3/8.1	1.348	0.510
Respiratory system (n/%)	5/8.8	1/2.0	1/2.7	3.165	0.205
Neurological diseases (n/%)	5/8.8	5/9.8	1/2.7	2.083	0.353
PVP segment				0.443	0.801
Thoracic (n/%)	25/43.9	20/39.2	17/45.9		
Lumbar (n/%)	32/56.1	31/62.8	20/54.1		
Causes of injury				2.375	0.667
Fall injuries (n/%)	25/43.9	26/51.0	21/56.8		
Car crash injuries (n/%)	17/29.8	16/31.4	10/27.0		
Sprain injuries (n/%)	15/26.3	9/17.6	6/16.2		
History of long-term smoking (n/%)	10/17.5	9/17.6	6/16.2	0.037	0.982
History of long-term alcohol (n/%)	10/17.5	7/13.7	6/16.2	0.299	0.861
Preoperative VAS ($\bar{x} \pm s$, score)	6.82 \pm 0.984	6.84 \pm 1.007	6.81 \pm 1.198	0.011	0.990
Preoperative ODI ($\bar{x} \pm s$, %)	71.68 \pm 3.169	70.45 \pm 3.449	71.03 \pm 3.564	1.632	0.199
PFH ($\bar{x} \pm s$, cm)	1.382 \pm 0.066	1.388 \pm 0.051	1.380 \pm 0.044	0.272	0.762
LKA ($\bar{x} \pm s$, °)	14.65 \pm 1.529	14.71 \pm 1.082	15.03 \pm 1.343	0.972	0.381

Abbreviations: BMI, Body Mass Index; VAS, Visual analogue scale; ODI, Oswestry Disability Index; PFH, Preoperative fractured vertebral body height; LKA, Local kyphosis angle.

Table 2 Comparison of Postoperative VAS and ODI Scores in the Three Groups

Index	Follow-up Time	Group A (n=57)	Group B (n=51)	Group C (n=37)	F	P
VAS (score)	1 week	4.88±1.087	4.90±1.044	4.65±1.230	0.652	0.523
	6 months	2.95±0.718	3.45±0.901 [#]	3.51±0.651*	8.212	<0.001
	1 year	2.12±0.537	2.16±0.543**	2.43±0.502*	4.274	0.016
ODI (%)	1 week	27.49±3.670	28.76±3.750	28.11±4.326	1.455	0.237
	6 months	23.37±3.315	23.22±3.951	22.46±3.753	0.743	0.477
	1 year	21.18±1.824	21.53±2.641	20.73±2.524	1.275	0.283

Notes: “#”: Group B compared with group A, p <0.05; “*”: Group C compared with group A, P <0.05; “**”: Group B compared with group C, P<0.05.

Abbreviations: VAS, Visual analogue scale; ODI, Oswestry Disability Index.

Comparison of Secondary Outcome Indicators

The amount of bone cement injection intraoperative in patients in Group A was significantly extraordinarily unnecessary for the other two groups, and the difference was statistically significant (P<0.001); the differences in the operation time, fluoroscopy, hospitalization days and hospitalization costs of the three groups were not statistically significant (P>0.05), see Table 4.

Discussion

As population aging intensifies, the incidence of OVCFs continues to rise.¹¹ At present, the treatment of OVCFs is mainly surgical treatment. PVP can treat low-trauma OVCFs due to its high reliability and safety, and has now become one of the main surgical methods for this disease.^{12–14} PVP is a minimally invasive surgery in spinal surgery that minimizes surgical trauma, shorter surgery time, and can quickly relieve pain and recover quickly after surgery. This technology has been widely used since 1987 to treat vertebral compression fractures and vertebral bone destruction caused by osteoporosis, bone metastasis and invasive hemangioma.^{15,16} Studies have reported that different bone cement distributions may bring different surgical effects.^{17,18} The distribution pattern of bone cement has been studied by many researchers. Some literature reports that whether bone cement distribution exceeds the midline of the vertebral body has nothing to do with vertebral body strength, strengthening vertebral fracture and postoperative effect, but the current views are not consistent.^{19,20} Our study reveals a more nuanced picture. The discrepancy likely stems from how “midline crossing” is defined and evaluated. Previous studies often employed a binary classification (crossing vs not crossing). In contrast, our three-group grading system specifically differentiated between a uniform, bilateral distribution (Group A) and an asymmetric or limited distribution that merely passes the midline (Group B). Our findings indicate that the superior outcomes in Groups A and B are not solely due to crossing the midline per se, but are critically dependent on achieving a balanced and sufficient volumetric filling that restores biomechanical symmetry. A mere “touch” of cement across the midline, without adequate and even dispersion, may be insufficient to confer the biomechanical advantages.

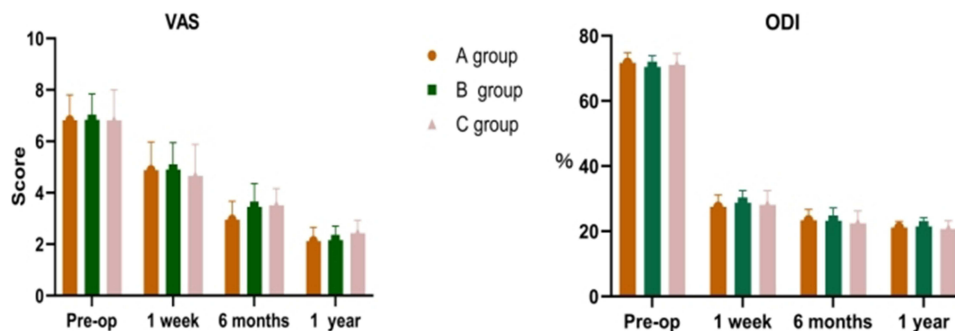


Figure 4 Comparison of VAS and ODI between the three groups.

Table 3 Comparison of Imaging Data and Complications Among the Three Groups

Index	Group A (n=57)	Group B (n=51)	Group C (n=37)	F/X ²	P
PRH (cm)	2.060±0.158	2.044±0.127	1.997±0.132*	2.340	0.100
LKA (°)	6.49±1.104	6.71±1.154	7.00±1.528	1.886	0.155
Vertebral height recovery rate (%)	32.5±6.9	31.4±5.5	28.8±5.6*	4.401	0.014
Refracture of injured vertebrae (n/%)	1/1.8	0/0.0	3/8.1	5.720	0.057
Adjacent vertebral fracture (n/%)	1/1.8	2/3.9	4/10.8	3.796	0.150
Overall fracture incidence rate (n/%)	2/3.6	2/3.9**	7/18.9*	7.781	0.020
Cement leakage (n/%)	8/14.0	10/19.6	7/18.9	0.684	0.710

Notes: “*”: Group C compared with group A, P <0.05; “**”: Group B compared with group C, p <0.05.

Abbreviations: PRH, Postoperative restored vertebral body height; LKA, Local kyphosis angle.

Table 4 Comparison of Secondary Outcome Indicators Between the Two Groups

Index	Group A (n=57)	Group B (n=51)	Group C (n=37)	F	P
Surgery time ($\bar{x} \pm s$, min)	44.56±9.291	43.06±10.329	43.76±8.375	0.341	0.711
Exposures times ($\bar{x} \pm s$, times)	15.86±1.941	15.78±2.625	16.11±1.792	0.251	0.778
Cement injection dosage ($\bar{x} \pm s$, mL)	4.953±0.431	4.837±0.336**	4.562±0.354*	11.976	<0.001
LOS ($\bar{x} \pm s$, days)	7.40±0.799	7.43±0.922	7.62±1.010	0.728	0.485
Hospitalization costs ($\bar{x} \pm s$, RMB)	13,722.333±1793.253	13,079.745±2420.269	13,727.459±2245.369	1.490	0.229

Notes: “*”: Group C compared with group A, P <0.05; “**”: Group B compared with group C, p <0.05.

Abbreviation: LOS, Length of stays.

Therefore, our conclusions do not outright contradict but rather refine the previous understanding by emphasizing the qualitative aspect of cement distribution beyond a simple binary threshold.

At present, the optimal bone cement distribution cannot be determined. Therefore, this study explores the optimal bone cement distribution state for treating OVCFs by comparing three different distributions of bone cement. PVP surgery for elderly OVCFs can help relieve pain immediately after surgery. The reason is that after the cement is injected into the vertebrae, it can spread along the fracture site in a liquid state, playing an adhesion effect, making the fracture stable, and after solidification, it can increase the strength of the vertebrae, so that the vertebrae can withstand axial stress without further compression and deformation. At the same time, bone cement can produce thermal effects at the fracture site, and high temperature destroys the painful nerve endings of the fracture site, thereby achieving a good pain relief effect. Our study shows that patients in Group A were significantly better than patients in Group C at 6 months and 1 year after surgery, indicating that uniform bone cement distribution can reduce postoperative pain, improve patient quality of life, and improve patient satisfaction with surgery. Yu et al²¹ reported that evenly distributed bone cement state may cause less pain. Qi Zhenliang et al²² reported that when the bone cement filling exceeded the midline, the patients' ODI and VAS scores improved significantly compared with preoperatively (P<0.01). In addition, some studies believe that injecting a larger amount of bone cement within a certain range can enable patients to obtain better pain relief and imaging indicators in the short term.²³ There are also reports that when the amount of bone cement is injected is constant, the better the diffusion effect, the larger the volume, the greater the diffusion volume ratio of bone cement, and it is relatively better to relieve pain after surgery.²⁴ In combination with our experimental results, patients in Group A had the largest amount of bone cement dose and uniform distribution of bone cement. Compared with Group C, patients in Group A had lower pain scores, vertebral height and vertebral height recovery rate.

Our results demonstrate a clear positive clinical effect associated with adequate cement distribution. Specifically, Patients in Groups A and B exhibited a statistically significant and clinically meaningful advantage over those in Group C, manifested as superior vertebral height restoration and a markedly lower overall refracture rate. The direction of this effect underscores that achieving cement distribution beyond the midline (as in Groups A & B) is a key determinant of better structural outcomes and long-term durability of the repair. Clinically, this translates to a reduced need for revision surgery, better maintenance of spinal alignment, and potentially a lower risk of chronic pain and disability for the patient.

Previous research on bone cement has found that when the asymmetric distribution of bone cement (such as unilateral and uneven distribution) is found in the vertebral body, it will not only destroy the stress balance in the vertebral body, but also destroy the stress conduction trend of the spinal segment, which will lead to new spinal fractures or scoliosis after surgery.^{25,26} However, since unilateral PVP surgery has the characteristics of uneven distribution of bone cement on both sides of the vertebral body, it is relatively difficult to achieve bone cement exceeding the midline of the vertebral body and evenly distributed during surgery, which may increase the surgical time and increase the patient's trauma; in addition, excessive distribution of bone cement may lead to excessive stability of the vertebral body, thereby affecting the physiological curvature and range of movement of the vertebral body. Additionally, if the cement touches the nerve root or spinal cord of the vertebral body, it may lead to nerve damage or other complications.

There are certain limitations in this trial: ① Due to the diversity of patients, medical conditions, surgical methods, research methods, follow-up time and other variable factors, the reliability of the above conclusions still needs to be confirmed by further prospective studies; ② The grouping method of this study is different from previous studies, which may lead to subjective deviations in the results; ③ This study is a single-center retrospective study. If you want to further study the correlation between the distribution of bone cement and the efficacy of surgery, large sample size and multi-center studies are required.

Conclusions

In this retrospective cohort study, a bone cement distribution that crossed the vertebral midline was associated with significantly lower long-term postoperative pain scores, better vertebral height recovery, and a reduced incidence of refractures compared to a distribution confined largely to the puncture side. However, the extent to which the cement filled the vertebral body (specifically, whether it exceeded two-thirds) did not show a significant association with the key clinical outcomes measured, suggesting that achieving midline crossing is more critical than maximizing the filler volume alone.

Abbreviations

OVCFs, Osteoporotic vertebral compression fracture; PVP, Percutaneous vertebroplasty; BMI, Body mass index; PFH, Preoperative fractured vertebral body height; PRH, Postoperative restored vertebral body height; LKA, Local kyphosis angle; ODI, Oswestry disability index; VAS, Visual analogue scale; LOS, length of stay.

Data Sharing Statement

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

The study protocol was approved by the Ethics Committee of the Sixth Affiliated Hospital of Xinjiang Medical University; All patients gave informed consent.

Acknowledgments

The authors sincerely thank the entire staff of the Department of Spinal Surgery, the Sixth Affiliated Hospital of Xinjiang Medical University, for their assistance throughout the study.

Author Contributions

Alimujiang Yusufu and Paierhati Yasheng contributed equally to this work, as co-first authors. All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

There is no funding to report.

Disclosure

The authors declare that they have no competing interests.

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