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Analysis of the Effect of Bone Cement Distribution Patterns on Surgical Outcomes of Percutaneous Vertebroplasty for Osteoporotic Vertebral Compression Fractures

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Abstract: *Objective:* To evaluate the impact of bone cement distribution patterns on the surgical outcomes of percutaneous vertebroplasty (PVP) for osteoporotic vertebral compression fractures (OVCF). *Methods:* Sixty-four patients with OVCF treated at our hospital from January 2022 to December 2023 were included and divided into two groups based on bone cement distribution patterns: the clustered group and the diffuse group. Both groups underwent PVP. We compared the incidence of bone cement leakage, operative time, blood loss, changes in Visual Analog Scale (VAS) pain scores, and Oswestry Disability Index (ODI) scores before and after treatment between the two groups. *Results:* The number of cases with bone cement leakage was significantly higher in the diffuse group compared to the clustered group ($P < 0.05$). There were no significant differences between the two groups in terms of volume of bone cement injected, intraoperative blood loss, or surgical time ($P > 0.05$). Post-treatment, both VAS and ODI scores were lower than pre-treatment scores in both groups, with the diffuse group showing significantly lower scores than the clustered group ($P < 0.05$). No postoperative adverse complications were observed in either group. *Conclusion:* PVP is highly effective for treating OVCF. A more uniform distribution of bone cement is associated with a greater reduction in postoperative pain and improved functional outcomes. However, careful attention is needed to prevent bone cement leakage.

Keywords: Percutaneous vertebroplasty; Bone cement; Osteoporotic vertebral compression fractures

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1. Introduction

Thoracolumbar vertebral fractures are common and prevalent conditions in spinal surgery, typically resulting from traumatic injury or osteoporosis [1]. With advancements in societal productivity and improvements in healthcare, life expectancy has increased, leading to more pronounced aging issues. Particularly in elderly

patients, exacerbated calcium loss and severe bone tissue calcification make the spine highly susceptible to fractures from minor trauma, thus increasing the incidence of osteoporotic vertebral compression fractures (OVCF) [2,3]. The unique nature of spinal fractures significantly impacts patients' daily lives, especially affecting the physical and psychological health of elderly individuals [4,5]. Consequently, percutaneous vertebroplasty (PVP) has become widely used in clinical practice for treating vertebral fractures due to its simplicity and speed [6,7]. During the procedure, bone cement commonly exhibits two distribution patterns within the vertebral body: clustered and diffuse [8]. The effect of these two bone cement distribution patterns on surgical outcomes remains controversial. Therefore, this study aims to analyze the impact of different bone cement distribution patterns on postoperative symptom improvement to provide clinical guidance.

2. Materials and methods

2.1. General information

We selected 64 patients who underwent PVP for OVCF at our hospital between January 2022 to December 2023. The cohort included 16 males and 48 females, with 25 cases of thoracic fractures and 39 cases of lumbar fractures. The patients' ages ranged from 64 to 93 years, with a mean age of 75.81 ± 7.83 years. Based on the distribution patterns of bone cement within the vertebral body, patients were divided into two groups: the clustered group and the diffuse group. The comparison showed that the baseline characteristics of patients in both groups were comparable before treatment ($P > 0.05$), with no significant differences (**Table 1**).

Inclusion criteria: (1) Diagnosed with thoracolumbar vertebral fractures by digital radiography or other imaging modalities. (2) Age ≥ 65 years. (3) Clear indications for surgery with informed consent obtained from the patient and their family. (4) Single vertebral body compression fracture. Exclusion criteria: (1) Presence of significant comorbidities such as cardiopulmonary diseases unsuitable for surgery. (2) Multisegmental fractures. (3) Pathological fractures. (4) Pre-existing old fractures.

Table 1. The baseline characteristics of the two groups

Group	Clustered group	Diffuse group	*P*
Age	76.38 ± 7.67	75.04 ± 8.11	0.49
Gender (M/F)	8/29	8/19	0.47
Hypertension (*n*)	26	13	0.07
Diabetes (*n*)	21	12	0.33
Fracture location (Thoracic/Lumbar)	14/23	11/15	0.81

Note: Data are presented as mean ± standard deviation or number of patients. *P* values are from comparisons between the two groups.

2.2. Methods

Upon admission, patients were given absolute bed rest and symptomatic treatment, including pain management. Comprehensive imaging with X-ray, computed tomography, and magnetic resonance imaging was performed to confirm the fracture location and type and to exclude absolute surgical contraindications. PVP was then carried out. Patients were positioned prone on the operating table with routine electrocardiogram monitoring and supplemental oxygen. Using a C-arm fluoroscope, the pedicle projection points on either side of the

affected vertebra were marked. The surgical area was disinfected with iodine tincture, and sterile drapes were applied. Local anesthesia was administered with 1% lidocaine at the marked points, progressively deepened until reaching the periosteum. A puncture needle was inserted bilaterally into the pedicles. After breaching the bone, the position, angle, and depth of the needle were confirmed with C-arm fluoroscopy. Adjustments were made until the needle tip reached the anterior third of the vertebral body. The needle core was removed, and a guidewire was inserted, followed by a cannula. Bone cement was prepared and injected bilaterally into the vertebral body in a stringy, viscous state. Under fluoroscopic guidance in both anteroposterior and lateral views, the cement was gradually injected while closely monitoring its distribution and filling. Injection was stopped when the cement approached the posterior wall of the vertebral body. After allowing the cement to solidify, the cannula was removed, and the puncture sites were disinfected and bandaged. Postoperatively, patients were advised to rest in bed for 12 hours, after which they could begin walking with lumbar support.

2.3. Observation indicators

The surgical parameters included: (1) Operation time. (2) Intraoperative blood loss. (3) Volume of bone cement injected. (4) Type of bone cement distribution. (5) Presence or absence of bone cement leakage.

Pain and functional impairment were evaluated using the Visual Analog Scale (VAS) and the Oswestry Disability Index (ODI) preoperatively and 8 hours postoperatively. The VAS scores range from 0 to 10, where 0 indicates no pain, ≤ 3 represents mild pain, 4–6 signifies pain affecting sleep, and 7–10 denotes severe pain. The ODI questionnaire consists of 10 items addressing standing, sitting, walking, traveling, lifting, sexual activity, social life, personal care, and pain intensity. Each item is scored from 0 to 5, with higher scores indicating greater functional impairment.

2.4. Statistical methods

Data analysis was performed using SPSS29.0 statistical software. Measurement data were expressed as mean ± standard deviation (SD). Normality and homogeneity of variance were first tested; if the data were normally distributed and variances were equal, comparisons between two independent groups were made using the independent samples *t*-test. For categorical data, chi-square tests were used. If data did not meet these assumptions, the Mann–Whitney U test was applied. A P value of < 0.05 was considered statistically significant.

3. Results

Based on the distribution patterns of bone cement within the vertebral body, patients were categorized into two groups: the clustered group (37 cases) and the diffuse group (27 cases). No postoperative complications were observed in either group. There were no significant differences between the two groups in terms of volume of bone cement injected, intraoperative blood loss, or surgical time ($P > 0.05$). The number of cases with bone cement leakage was significantly higher in the diffuse group compared to the clustered group ($P < 0.05$). The preoperative VAS and ODI scores showed no significant differences between the two groups ($P > 0.05$); postoperative VAS and ODI scores significantly decreased in both groups ($P < 0.05$), with the diffuse group showing lower scores compared to the clustered group ($P < 0.05$). The results are presented in **Tables 2** and **3**.

Table 2. Perioperative indicator comparison

Indicator	Clustered group	Diffuse group	*t*	*P*
Number of cases	37	27	-	-
Operation time (minutes)	33.19 ± 4.86	32.96 ± 5.58	-0.17	0.86
Volume of bone cement (ml)	6.68 ± 0.77	6.83 ± 0.94	-0.95	0.34
Number of leaks	7	19	17.13	< 0.05
Blood loss (ml)	7.85 ± 1.48	7.76 ± 1.33	-0.26	0.79

Table 3. Comparison of VAS and ODI scores

Group		Clustered group	Diffuse group	*t*	*P*
VAS score	Preoperative	6.59 ± 1.19	6.19 ± 1.15	-1.43	0.15
	Postoperative	2.81 ± 0.94	1.59 ± 0.80	-4.60	< 0.05
ODI score	Preoperative	40.42 ± 4.16	40.30 ± 4.24	-0.13	0.89
	Postoperative	16.95 ± 4.83	11.93 ± 3.76	-4.41	< 0.05

4. Discussion

Osteoporotic vertebral compression fractures are a prevalent issue among the elderly due to age-related bone density loss and calcium metabolism disorders [9,10]. The risk of fractures in this population is further exacerbated by reduced balance and coordination, leading to frequent falls [11]. PVP, initially developed by Galibert and Deramond in 1987, has evolved from treating vertebral hemangiomas [12] to effectively managing vertebral fractures by injecting bone cement to stabilize the vertebral structure and restore height [13].

Traditionally, conservative treatments for thoracolumbar fractures, such as strict bed rest and medication, have long recovery periods and are associated with complications like pneumonia and deep vein thrombosis [14,15]. PVP offers a minimally invasive alternative with benefits such as reduced operative time and quicker mobilization [16,17]. However, with the widespread use of PVP, several issues have emerged, including severe neurological damage from bone cement leakage [18], inappropriate cement volume, inadequate cement dispersion, and insufficient pain relief postoperatively [19]. The relationship between the distribution of bone cement within the vertebra and its leakage, as well as the degree of pain relief experienced by patients, remains controversial and lacks standardized evaluation criteria [20]. Some studies suggest that slower injection speeds, more viscous cement, and lower injection pressures tend to produce a clustered distribution of cement, while faster speeds and higher pressures are associated with a more diffuse distribution. Other factors, such as the total volume of cement injected and the timing of injection, also influence the distribution pattern.

In this study, there were no significant differences between the two groups in terms of volume of bone cement injected, duration of surgery, and intraoperative blood loss ($P > 0.05$). However, the amount of cement leakage was significantly higher in the diffuse group compared to the clustered group (19 vs. 7), with this difference being statistically significant ($P < 0.05$). This discrepancy may be due to the nature of the clustered cement, which tends to bond and concentrate, thus reducing the likelihood of leakage. Conversely, the diffuse cement is more dispersed and does not interconnect as tightly, making it more prone to leakage. Additionally, based on previous surgical experience, the timing of cement injection during the procedure significantly affects

leakage. Injecting cement when it has reached a stringy consistency can reduce the likelihood of leakage. Research also indicates that diffuse cement distribution tends to form a tighter mechanical connection with the vertebral bone, and the broader thermal effect of the cement can deactivate local nerves more effectively, leading to more significant pain relief in patients with a diffuse cement pattern.

In this study, the VAS scores significantly decreased postoperatively in both the clustered group and the diffuse group compared to preoperatively, with the reductions being statistically significant ($P < 0.05$). This indicates that, regardless of the bone cement distribution pattern, patients experienced notable pain relief. However, pain relief was more pronounced in the diffuse group (1.59 ± 0.80) compared to the clustered group (2.81 ± 0.94). Similarly, ODI scores showed significant improvement postoperatively in both groups, with the differences being statistically significant.

5. Conclusion

In summary, PVP significantly alleviates patient symptoms postoperatively. The distribution pattern of bone cement within the vertebrae has a substantial impact on the degree of symptom relief and functional impairment [20]. Although the risk of bone cement leakage is higher with a diffuse distribution compared to a clustered one, its symptom improvement is more pronounced. Surgeons should adjust their technique based on intraoperative fluoroscopic findings, tailoring the volume and rate of bone cement injection according to the patient's pain levels and fracture line location to balance the amount and distribution of bone cement with symptom improvement. This study has limitations, including a relatively small sample size, which may affect the robustness of observed differences. Long-term follow-up data is also lacking. Larger sample sizes and extended follow-up are needed to make the conclusions more reliable.

Disclosure statement

The authors declare no conflict of interest.

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