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Original Article

Percutaneous kyphoplasty improves surgical outcomes and quality of life in elderly patients with osteoporotic vertebral compression fractures

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Abstract: Objective: To evaluate the effects of percutaneous kyphoplasty (PKP) on surgical outcomes and postoperative well-being in elderly patients with osteoporotic vertebral compression fractures (OVCFs). Methods: A total of 118 geriatric patients with OVCF treated at the Fourth Affiliated Hospital of Harbin Medical University between March 2022 and March 2025 were retrospectively analyzed. Among them, 54 underwent percutaneous vertebroplasty (PVP group), and 64 received PKP (PKP group). Data collected included surgical outcomes (bone cement injection volume, operative duration) and vertebral morphological parameters (kyphotic Cobb angle, mid/anterior vertebral height). Bone mineral density (BMD) and bone metabolism markers, including osteocalcin (BGP), bone-specific alkaline phosphatase (BALP), were assessed. Functional outcomes (Visual Analog Scale [VAS], Oswestry Disability Index [ODI], and Japanese Orthopaedic Association [JOA] Scale) were evaluated. Additionally, complications such as cement leakage, infection, and pressure ulcers were monitored. Quality of life was assessed using the Short Form-36 Health Survey (SF-36). Variables associated with pain relief were identified through univariate screening followed by multivariate analysis. Results: Compared with PVP, PKP involved more bone cement use and longer procedural duration. However, PKP achieved more pronounced reductions in post-treatment Cobb angle, VAS, and ODI scores than PVP, along with more significant increases in mid/anterior vertebral height, BMD, BGP, BALP, JOA, and SF-36 scores. The complication rate was similar between groups. Conclusion: In geriatric OVCF cases, PKP enhances vertebral morphology, BMD, bone metabolism, functional recovery, and patient well-being, while maintaining a safety profile comparable to PVP, despite requiring greater cement volumes and extended surgery time.

Keywords: Percutaneous kyphoplasty, senile osteoporotic vertebral compression fracture, surgical outcomes, quality of life, clinical efficacy

Introduction

Among fragility fractures, osteoporotic vertebral compression fractures (OVCFs) are the most prevalent and are associated with serious risks, including increased disability and mortality risks. They severely impair daily activities, mobility, and overall quality of life in affected individuals [1]. Older adults with reduced bone mineral density (BMD) or compromised bone microarchitecture are particularly susceptible, often suffering from chronic back pain, progressive spinal deformity, and even neurological deficits [2]. Globally, approximately 1.45 million people suffer from OVCFs each year, with a thoracolumbar-to-non-thoracolumbar ratio of nearly 2:1 [3]. In geriatric populations, OVCF can trigger secondary issues such as digestive and respiratory dysfunction, depression, and lower limb weakness, significantly complicating management [4]. Both percutaneous vertebroplasty (PVP) and percutaneous kyphoplasty (PKP) are minimally invasive procedures used to treat OVCFs. Although both procedures provide rapid pain relief and structural stabilization, neither can completely eliminate the risk of cement leakage [5]. Intradiscal cement leakage may predispose patients to adjacent vertebral fractures, while severe leakage into the epidural or foraminal spaces can, in extreme cases, cause paraplegia [6]. Previous studies have shown that both PVP and

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PKP effectively alleviate pain and restore mobility in OVCF patients, with a lower incidence of polymethylmethacrylate (PMMA) extravasation observed in PKP [7]. Therefore, it is essential to systematically compare these two procedures to clarify differences in efficacy, safety, and post-treatment quality of life.

Despite their widespread use, few studies have systematically evaluated how PVP and PKP affect surgical outcomes, functional recovery, and health-related quality of life in elderly OVCF patients. To address this gap, the present study systematically compared the clinical benefits of PKP versus PVP in elderly OVCF patients. Parameters assessed included surgical characteristics (cement volume, operative time), vertebral morphology (kyphotic Cobb angle, anterior and mid-vertebral height), BMD, bone metabolism markers, patient-reported outcomes (pain, function, quality of life), and complications. The results aim to offer evidence-based guidance for optimizing surgical strategies and improving patient outcomes.

Information and methodology

General data

This retrospective study was conducted with approval from the Ethics Committee of the Fourth Affiliated Hospital of Harbin Medical University. A total of 118 geriatric OVCF cases treated between March 2022 and March 2025 were retrospectively analyzed. Among them, 54 patients underwent percutaneous vertebroplasty (PVP) and 64 received percutaneous kyphoplasty (PKP). Baseline demographic and clinical characteristics were comparable between groups (P>0.05), confirming their suitability for comparison.

Inclusion/exclusion criteria

Inclusion criteria: 1) Diagnosis of OVCF confirmed by imaging and clinical assessment [8]; 2) Age ≥60 years; 3) Fracture onset within the past two weeks; 4) Tolerance to anesthesia and surgery; 5) Presentation with typical postural low back pain that worsened with standing and improved in the recumbent position, accompanied by localized tenderness and percussion pain; and 6) Complete medical records available.

Exclusion criteria: 1) Significant neurological compromise; 2) Active infection or joint pathology; 3) Concomitant fractures; 4) Contraindications to PVP or PKP; 5) Restricted mobility from unrelated causes; 6) Non-target vertebral fractures; 7) Cognitive or psychiatric disorders; 8) Severe cardiometabolic, hepatic, or renal disease; 9) Coagulopathies or major systemic illness; and 10) Other types of vertebral fracture.

Treatments

All procedures were performed under local anesthesia with patients in the prone position. Under fluoroscopic guidance, PMMA bone cement was injected unilaterally via a transpedicular approach using a 14G puncture needle.

PVP group: After standard preoperative preparation (local anesthesia, aseptic cleaning, and draping), a cannula was advanced transpedicularly into the fractured vertebral body under biplanar fluoroscopic guidance. The inner stylet was removed, and approximately 4 mL of PMMA was injected slowly under continuous biphasic fluoroscopy [9]. Injection was immediately discontinued upon observation of cement extravasation (e.g., cement dispersion into vertebral margins, intervertebral disc space, or venous plexus). The puncture needle was withdrawn following cement hardening.

PKP group: The puncture route was identical to that of the PVP group. Guided by biphasic fluoroscopy, the needle was advanced through the pedicle to the anterior-middle third of the vertebral body, after which the stylet was withdrawn to establish a working channel. A balloon tamp was then introduced and inflated with contrast medium under C-arm fluoroscopic monitoring until satisfactory vertebral height restoration was achieved. The balloon was deflated and removed, and approximately 4 mL of PMMA was slowly injected into the created cavity under real-time fluoroscopy. Injection was stopped immediately upon signs of leakage. Following confirmation of cement interdigitation and polymerization at the anterior vertebral margin were confirmed, the cannula was withdrawn.

Observation indicators

Surgical outcomes: Data on bone cement injection volume and procedure duration were collected for comparative analysis. The cement volume was directly read from the injector scale, while operative duration was defined as the total time from initial skin puncture to final needle withdrawal.

Vertebral morphological parameters: Radiographic assessments were performed preoperatively and on postoperative day 3. The kyphotic Cobb angle of the injured vertebra was quantified from lateral spinal radiographs (Kunming Huida Sci. & Tech. Co., Ltd.). Briefly, lines were drawn along the superior endplate of the vertebra above the injury and the inferior endplate of the vertebra below it. The Cobb angle was then calculated by measuring the angle formed by perpendiculars to these two lines [10]. Axial computed tomography (CT) images with sagittal multiplanar reconstructions were used to measure mid-vertebral and anterior vertebral heights [11]. The mid-vertebral height was defined as the vertical distance between the anterosuperior and anteroinferior corners of the affected vertebra on a sagittal image, while the anterior height was measured at the pedicle midpoint level as the vertical distance between the superior and inferior endplates.

BMD and bone metabolism indexes: BMD was assessed pre-treatment and three months after intervention using dual-energy X-ray absorptiometry (DXA). For bone metabolism analysis, fasting morning venous blood (5 mL) was collected and centrifuged to obtain serum. These samples were then subjected to enzyme-linked immunosorbent assay (ELISA) to determine serum levels of osteocalcin (BGP) and bone-specific alkaline phosphatase (BALP) before and after treatment.

Functional scales: Pain intensity was evaluated using the Visual Analogue Scale (VAS; 0-10 points), with higher scores indicating greater pain severity [12]. Functional disability was assessed using the Oswestry Disability Index (ODI; 0-50 points), where lower scores indicated better recovery [13]. Lumbar function was further evaluated preoperatively and six months postoperatively using the Japanese Orthopaedic Association (JOA) Back Pain Evaluation Questionnaire (29-point total), with higher scores indicating improved function [14].

Complications: Postoperative complications, including cement leakage, infection, and pressure sores, were recorded, and incidence rates were compared between the two groups.

Quality of life: The 36-Item Short Form Health Survey (SF-36) [15] was used to assess changes in health-related quality of life. The assessment encompassed four domains: Somatic Pain, General Well-being, Physical Performance, and Physical Role Functioning, each scored on a 100-point scale, where higher scores correlates with better life quality.

Statistical methods

Continuous variables were expressed as mean ± standard error of the mean (SEM). Between-group comparisons were performed using independent-sample t-tests, whereas within-group pre-post treatment comparisons employed paired t-tests. Categorical variables were presented as frequencies and percentages (%) and compared using Pearson's chi-squared test. All analyses were performed using SPSS Statistics version 21.0.

To identify predictors of low back pain relief in senior OVCF patients, univariate analysis was first conducted, followed by multivariate binary logistic regression. A $P<0.05$ was considered statistically significant.

Results

Baseline characteristics

As shown in **Table 1**, there were no significant differences between the PVP and PKP groups in baseline characteristics, including sex distribution, age, disease duration, fracture etiology, or affected spinal segments ($P>0.05$).

Surgical outcomes

As shown in **Table 2**, PKP procedures required significantly more bone cement volume and longer operative duration compared with PVP ($P<0.001$).

Vertebral morphological parameters

As shown in **Table 3**, the two groups demonstrated comparable baseline measurements of kyphotic Cobb angle, mid-vertebral height, and

Table 1. Comparison of baseline characteristics between the two groups

Indicators	PVP group (n=54)	PKP group (n=64)	χ^2/t	P
Sex			0.201	0.654
Male	29 (53.70)	37 (57.81)		
Female	25 (46.30)	27 (42.19)		
Age (years)	68.67±5.43	70.22±5.35	1.557	0.122
Disease duration (days)	7.00±3.50	8.23±3.90	1.788	0.076
Fracture causation			0.632	0.729
Falls	22 (40.74)	25 (39.06)		
Fall from heights	22 (40.74)	30 (46.88)		
Car accidents	10 (18.52)	9 (14.06)		
Affected spinal segment			0.497	0.780
L_1	30 (55.56)	38 (59.38)		
L_2	20 (37.04)	20 (31.25)		
L_3	4 (7.41)	6 (9.38)		

Note: PVP, percutaneous vertebroplasty; PKP, percutaneous kyphoplasty.

Table 2. Comparison of surgical parameters between the two groups

Indicators	PVP group (n=54)	PKP group (n=64)	t	P
Bone cement volume (mL)	3.06±0.86	3.87±1.25	4.024	<0.001
Operative duration (min)	39.26±5.48	49.88±8.43	7.946	<0.001

Note: PVP, percutaneous vertebroplasty; PKP, percutaneous kyphoplasty.

Table 3. Comparison of vertebral morphological parameters between the two groups

Indicators	PVP group (n=54)	PKP group (n=64)	t	P
Kyphotic Cobb angle (°)				
Pre-treatment	27.26±9.33	26.28±9.34	0.568	0.571
Post-treatment	21.02±5.37*	13.03±2.88**	10.284	<0.001
Mid-vertebral height (mm)				
Pe-treatment	10.20±2.82	9.73±2.69	0.925	0.357
Post-treatment	15.72±5.94*	18.83±3.90**	3.409	<0.001
Anterior vertebral height (mm)				
Pre-treatment	7.93±2.08	7.30±2.43	1.498	0.137
Post-treatment	14.33±3.14*	19.08±3.53**	7.657	<0.001

Note: PVP, percutaneous vertebroplasty; PKP, percutaneous kyphoplasty. *P<0.05, **P<0.01 (intragroup comparisons versus baseline measurements).

anterior vertebral height (P>0.05). Following treatment, both groups demonstrated significant improvement in vertebral morphology. Additionally, the PKP group achieved a more pronounced reduction in Cobb angle and more pronounced restoration of anterior and mid-vertebral height compared with the PVP group (all P<0.05).

BMD and bone metabolism

The comparative assessment presented in **Figure 1** demonstrates that both groups showed comparable pretreatment levels of BMD, BGP, and BALP (P>0.05). Following treatment, all bone metabolism indicators increased significantly, with the PKP group achieving superior outcomes (P<0.05).

Functional outcomes

Baseline VAS, ODI, and JOA scores did not differ significantly between groups (P>0.05). As shown in **Figure 2**, both groups exhibited marked improvement after treatment, with significantly reduced VAS and ODI scores and ele-

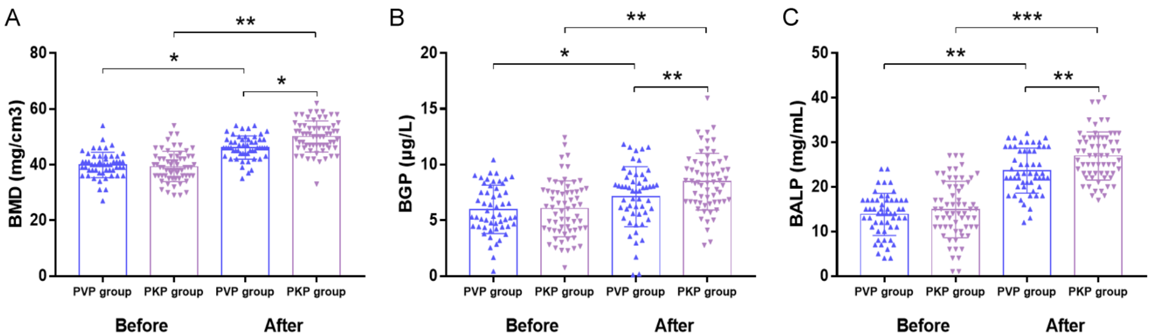

Figure 1. Comparison of BMD and bone metabolism markers between the two groups. A. BMD; B. BGP; C. BALP. Notes: PVP, percutaneous vertebroplasty; PKP, percutaneous kyphoplasty; BMD, bone mineral density; BGP, osteocalcin; BALP, bone alkaline phosphatase. *P<0.05, **P<0.01.

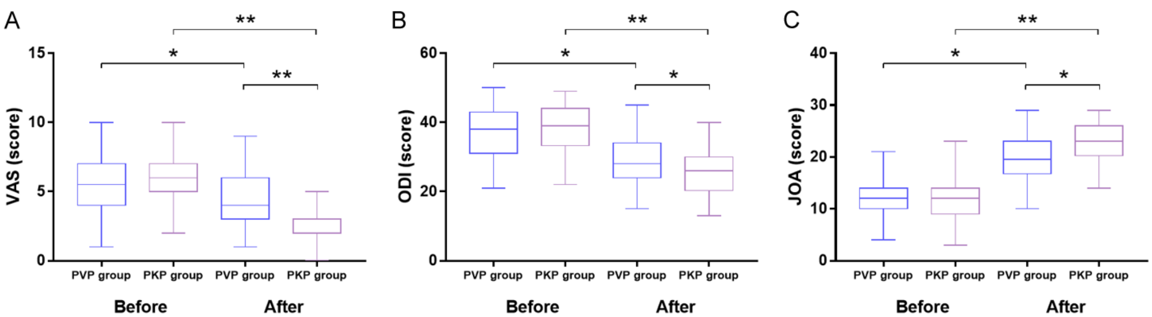

Figure 2. Comparison of functional outcomes between the two groups. A. VAS; B. ODI; C. JOA. Notes: PVP, percutaneous vertebroplasty; PKP, percutaneous kyphoplasty; VAS, Visual Analogue Scale; ODI, Oswestry Disability Index; JOA, Japanese Orthopaedic Association. *P<0.05; **P<0.01.

Table 4. Comparison of the incidence of complications between the two groups

Indicators	PVP group (n=54)	PKP group (n=64)	χ^2	P
Bone cement leakage	3 (5.56)	2 (3.13)		
Infections	1 (1.85)	2 (3.13)		
Pressure sores	5 (9.26)	0 (0.00)		
Total	9 (16.67)	4 (6.25)	3.242	0.072

Note: PVP, percutaneous vertebroplasty; PKP, percutaneous kyphoplasty.

vated JOA scores (P<0.05). Additionally, The PKP group demonstrated superior functional recovery compared with the PVP group, reflected by lower VAS and ODI and higher JOA scores (P<0.05).

Complications

As shown in **Table 4**, the overall incidence of complications did not differ significantly between the PKP and PVP groups (P>0.05). The frequencies of bone cement leakage, infection, and pressure sores were comparable. Importantly, no patient experienced symptomatic cement leakage attributed to the pursuit of a 4 mL injection volume.

Quality of life

As presented in **Table 5**, preoperatively, no intergroup differences were observed between groups in SF-36 scores, including Somatic Pain, General Well-being, Physical Performance, and Physical Role Functioning (P>0.05). After treatment, both groups demonstrated significant improvements across all domains. Notably, patients in the PKP group achieved significantly higher post-treatment scores in each dimension compared with those in the PVP group (P<0.05).

Factors influencing low back pain relief in elderly OVCF patients

Potential predictors of low back pain relief in senior OVCF patients were analyzed using univariate (**Table 6**) and multivariate (**Table 7**)

Table 5. Comparison of quality of life metrics between the two groups

Indicators	PVP group (n=54)	PKP group (n=64)	t	P
Somatic Pain (points)				
Pre-treatment	45.26±5.17	43.86±6.22	1.314	0.191
Post-treatment	70.33±5.49*	74.94±8.76**	3.350	0.001
General Well-being (points)				
Pre-treatment	47.69±4.91	46.38±4.36	1.535	0.128
Post-treatment	69.22±6.14*	73.97±6.35**	4.110	<0.001
Physical Performance (points)				
Pre-treatment	45.63±7.90	46.50±6.51	0.656	0.513
Post-treatment	70.93±6.87*	78.33±7.01**	5.765	<0.001
Physical Role Functioning (points)				
Pre-treatment	48.81±5.56	49.23±5.28	0.420	0.675
Post-treatment	70.57±5.58*	76.70±8.39**	4.580	<0.001

Note: PVP, percutaneous vertebroplasty; PKP, percutaneous kyphoplasty. *P<0.05, **P<0.01 (within-group comparison to pretreatment values).

Table 6. Univariate analysis of factors associated with pain relief in elderly OVCF patients

Indicators	Ineffective group (n=25)	Effective group (n=93)	χ^2/Fisher	P
Age (years)			5.368	0.021
<70 (n=62)	8 (32.00)	54 (58.06)		
≥70 (n=56)	17 (68.00)	39 (41.94)		
Affected vertebral segment			11.403	<0.001
L_1 (n=68)	7 (28.00)	61 (65.59)		
L_{2-3} (n=50)	18 (72.00)	32 (34.41)		
Bone cement leakage			-	0.063
No (n=113)	22 (88.00)	91 (97.85)		
Yes (n=5)	3 (12.00)	2 (2.15)		
Baseline ODI (points)			5.832	0.016
<40 (n=63)	8 (32.00)	55 (59.14)		
≥40 (n=55)	17 (68.00)	38 (40.86)		
Cobb angle (°)			0.040	0.842
<27 (n=54)	11 (44.00)	43 (46.24)		
≥27 (n=64)	14 (56.00)	50 (53.76)		
Treatment protocol			6.320	0.012
PVP (n=54)	17 (68.00)	37 (39.78)		
PKP (n=64)	8 (32.00)	56 (60.22)		

Note: PVP, percutaneous vertebroplasty; PKP, percutaneous kyphoplasty; ODI, Oswestry Disability Index.

Table 7. Multivariate analysis of independent predictor for pain relief in geriatric OVCF cases

Indicators	B	SE	WALD	P	OR (95% CI: Lower limit-upper limit)
Age (years)	0.667	0.523	1.626	0.202	1.949 (0.699-5.435)
Affected vertebral segment	1.388	0.528	6.903	0.009	4.008 (1.423-11.289)
Baseline ODI (points)	1.053	0.520	4.109	0.043	2.866 (1.035-7.935)
Treatment protocol	-1.082	0.517	4.378	0.036	0.339 (0.123-0.934)

Note: PVP, percutaneous vertebroplasty; PKP, percutaneous kyphoplasty; ODI, Oswestry Disability Index.

logistic regression models. Therapeutic efficacy was defined as a ≥30% improvement in JOA score, yielding 93 effective and 25 ineffective cases. Six variables met the event-per-variable threshold (EPV≥4) for model inclusion: patient age, affected spinal segment, cement leakage, baseline ODI, Cobb angle, and treatment protocol. Other factors were excluded due to limited statistical power or clinical relevance.

Univariate analysis identified age, affected spinal segment, baseline ODI, and treatment protocol as significant predictors of pain relief (all $P<0.05$), whereas bone cement leakage and Cobb angle changes showed no statistical relevance (both $P>0.05$). In the multivariate logistic regression model, affected vertebral segment, baseline ODI, and treatment protocol remained independent predictors of postoperative pain improvement in elderly OVCF patients (all $P<0.05$).

Discussion

Our findings revealed that PKP in elderly OVCF patients required greater bone cement volume and a longer surgical period compared with PVP. Similar results were reported in a meta-analysis by Wei et al. [16], which demonstrated that PKP, particularly in OVCF patients with intravertebral fissures, involves longer surgical duration and greater bone cement injection than PVP. Importantly, the present study confirmed that PKP achieved superior restoration of vertebral morphology in elderly OVCF patients, with key improvements including a smaller kyphotic Cobb angle of the affected vertebra and greater mid/anterior vertebral height. PKP, an advancement on PVP, utilizes balloon expansion to create an intravertebral cavity, allowing for controlled injection of a larger cement volume. This provides stronger internal support, facilitating better correction of vertebral height and alignment. Consistent with our results, Wang et al. [17] reported that PKP yielded greater pain relief and more significant Cobb angle correction compared with PVP, confirming its biomechanical advantages. Subsequent findings revealed that PKP enhanced BMD and bone metabolism markers, including BGP and BALP, indicating improved bone remodeling capacity. Functional assessments based on VAS, ODI, and JOA scales further confirmed PKP's superiority in pain relief and functional recovery, corroborating existing literature [18]. The reason may lie in the minimal invasiveness of PKP: under fluoroscopic guidance, balloon-assisted injection stabilizes the fractured vertebra, restores structural integrity, and reduces micromotion, thereby relieving pain while minimizing infection and pressure ulcer risk. This results in enhanced postoperative spinal stability and rehabilitation outcomes. Consistent with these findings, Zuo et al. [19] reported in a meta-analysis that PKP provided more durable pain reduction in both acute and subacute OVCF cases, making it particularly advantageous for chronic OVCF management. Conversely, PVP was found to deliver more immediate, but shorter-lasting, benefits in acute and subacute OVCF cases.

Additionally, safety evaluations revealed that PKP was associated with a lower incidence of bone cement leakage and overall complications (including cement leakage, infections, and pressure ulcers); however, these differences were not statistically significant compared with PVP. This may be attributed to PKP's intrinsic leakage-preventive mechanisms (creating a compact bony cavity via balloon pre-dilation), controlled cement volume injection, and low-pressure delivery of high-viscosity cement. Dai et al. [20] similarly reported that, despite longer operative time, higher cost, and increased fluoroscopic exposure, PKP provided superior vertebral height restoration and kyphotic correction compared with PVP in patients with osteoporotic Kümmell's disease, without increasing the risk of cement leakage, postoperative fever, or adjacent fractures. These findings are consistent with our results. Emerging evidence further suggests that PKP may offer survival benefits over PVP in OVCF patients [21]. Our investigation established that PKP intervention yielded more pronounced quality-of-life enhancements for geriatric OVCF patients across multiple domains: Somatic Pain, General Well-being, Physical Performance, and Physical Role Functioning. Wang et al. [22] also demonstrated that, in OVCF patients following bilateral oophorectomy for ovarian cancer, PKP outperformed PVP in lumbar stabilization, intervertebral height retention, and kyphosis correction. These benefits translated into improved life quality, corroborating the present study's conclusions.

Multivariate analysis in our study identified three independent predictors of poor postoperative pain relief in elderly OVCF patients: fractures involving the L_{2-3} segments, a baseline ODI score exceeding 40 points, and PVP treatment. Similarly, Zhang et al. [23] reported that persistent low back pain following PVP was independently associated with factors such as advanced age, multiple vertebral fractures, lumbar comorbidities, emotional status, fracture location, and preoperative fascial injury, highlighting multifactorial contributors to pain persistence. Furthermore, Firanescu et al. [24] identified additional predictors of residual pain after PVP, including female sex, baseline VAS score exceeding 8, chronic pain duration, mild/severe Genant grades, and new-onset fractures. Collectively, these findings complement our results and underscore the complexity of pain mechanisms in elderly OVCF patients undergoing vertebral augmentation therapy.

Studies have explored optimized modifications to PKP. Shi et al. [25] proposed a modified technique known as deflectable PKP (DPKP) based on traditional PKP technique. Their prospective analysis demonstrated that this unilateral transpedicular approach could achieve comparable outcomes to bilateral puncture. The key improvement involves a deflectable curved bone expander creating a central cavity, enabling more uniform cement dispersion and enhanced biomechanical stability. Similarly, Tao et al. [26] noted that robotic-assisted PKP allows for the optimal single-entry trajectory, lowering the risk of injury to blood vessels, nerves, and cortical bone, while ensuring favorable bone cement distribution.

The present study has several limitations. First, a fixed amount of bone cement (approximately 4 mL) was used for all patients. Future studies should consider personalized cement dosing based on vertebral volume and fracture severity to optimize biomechanical outcomes. Second, a cost-benefit comparison between the two techniques was not performed, which would be valuable for assessing PKP's clinical and economic feasibility. Lastly, secondary outcomes, such as sleep quality and emotional status, were not evaluated. Including these measures in future investigations may reveal additional quality-of-life benefits of PKP in elderly OVCF patients.

Conclusion

In geriatric OVCF cases, PKP requires greater bone cement volume and takes longer operative time than PVP but provides superior outcomes in vertebral height restoration, BMD and turnover markers, pain reduction, spinal functional recovery, and overall quality of life.

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Disclosure of conflict of interest

None.

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