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ORIGINAL RESEARCH

Unilateral Percutaneous Curved Kyphoplasty versus Bilateral Percutaneous Kyphoplasty for the Treatment of Single-Level Osteoporotic Vertebral Compression Fractures: A Retrospective Comparative Study

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Objective: This study compared unilateral percutaneous curved kyphoplasty (PCK) and bilateral percutaneous kyphoplasty (PKP) for treating single-level osteoporotic vertebral compression fractures (OVCFs).

Methods: A retrospective analysis was conducted on patients with single-level OVCF treated with either unilateral PCK or bilateral PKP between September 2023 and December 2024. Clinical and radiographic evaluations were performed preoperatively and postoperatively at 1 day, 1, 3, 6 months, and at the latest available follow-up. The final data analysis was conducted in July 2025. Given the study period, the latest follow-up time varied among patients, ranging from 6 to 12 months. The median follow-up time for the entire cohort was 12 months. Parameters assessed included operative time, blood loss, fluoroscopy frequency, cement volume, cement leakage, visual analogue scale (VAS) scores, Oswestry Disability Index (ODI), vertebral height restoration, Cobb angle correction, and complication rates.

Results: The PCK group showed superior intraoperative outcomes, including shorter operative time (37.44 ± 6.52 min vs 44.56 ± 7.74 min), reduced blood loss (8.78 ± 2.91 mL vs 12.81 ± 2.51 mL), fewer fluoroscopic exposures (15.37 ± 2.09 vs 21.79 ± 2.46), and lower cement volume (4.62 ± 0.60 mL vs 5.14 ± 0.69 mL). Cement leakage was significantly less frequent with PCK (4.9% vs 18.8%). Both techniques achieved equivalent long-term clinical results, with no significant differences in VAS scores, ODI scores, vertebral height maintenance, Cobb angle correction, or refracture rates at final follow-up. No major complications occurred in either group.

Conclusion: In this retrospective cohort, with a median follow-up of 12 months, unilateral PCK achieved clinical outcomes comparable to those of bilateral PKP. Furthermore, PCK was associated with superior intraoperative efficiency and reduced radiation exposure. These results suggest that PCK may be a viable and advantageous surgical alternative; however, these findings warrant validation in future randomised controlled trials.

Keywords: unilateral percutaneous curved kyphoplasty, bilateral percutaneous kyphoplasty, osteoporotic vertebral compression fracture

Introduction

Osteoporotic vertebral compression fractures (OVCF) constitute one of the most severe complications of osteoporosis and are a leading cause of disability and mortality among elderly patients.[1] Clinically, early OVCF typically manifests as thoracolumbar back pain, often overlooked initially by patients. As pain intensifies, prolonged bed rest reduces mobility and subsequently accelerates further bone loss.[2] Epidemiological studies have reported a mortality rate approaching 50% within four years among patients receiving conservative treatment for OVCF, highlighting the severity of the condition.[3,4] Currently, percutaneous kyphoplasty (PKP) is regarded as the preferred treatment for osteoporotic vertebral

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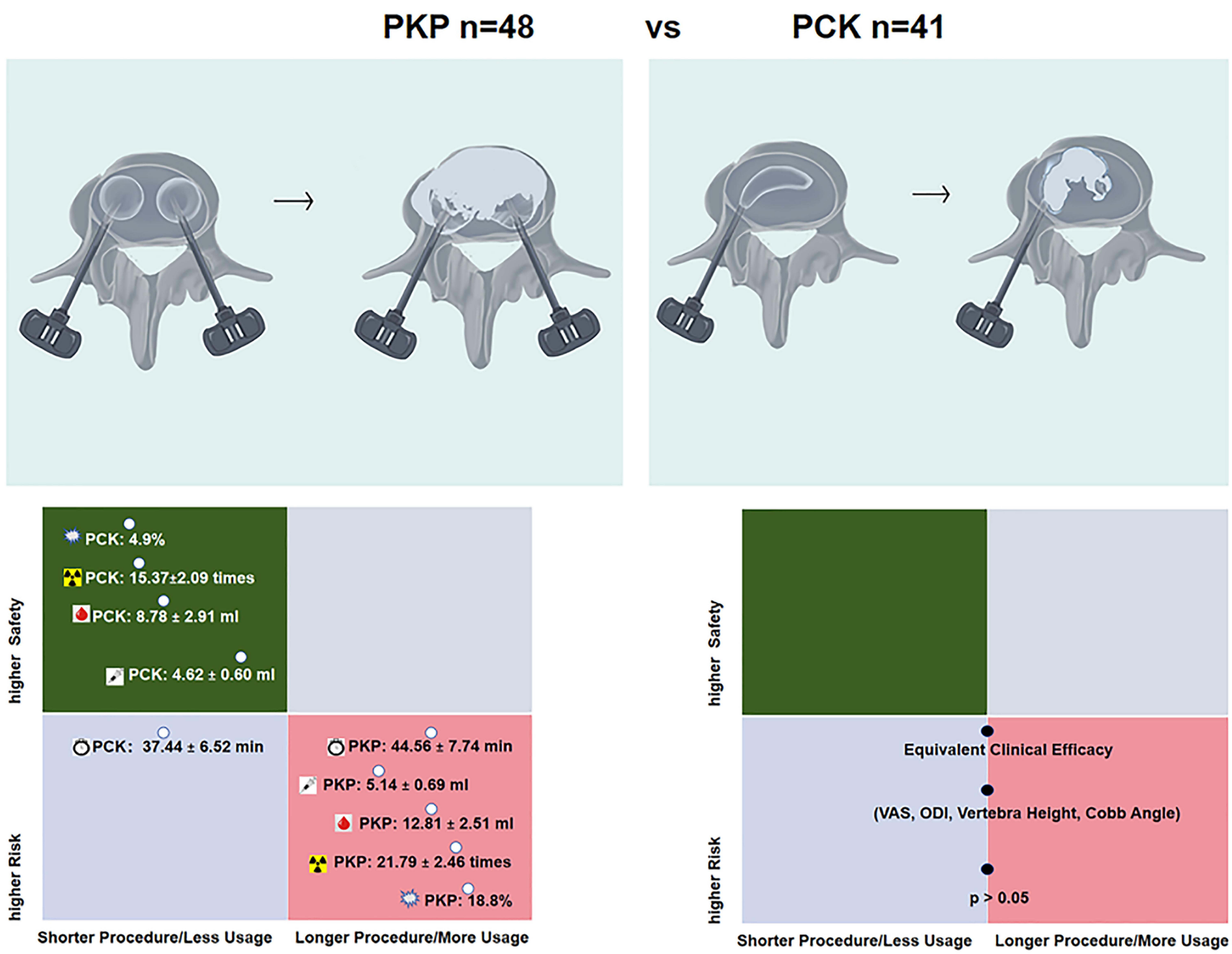
Graphical Abstract



compression fractures (OVCF).[5,6] However, controversy persists regarding the choice of unilateral versus bilateral surgical approaches in clinical practice. Some studies suggest that unilateral PKP reduces the risk of cement leakage, shortens operative time, and decreases intraoperative radiation exposure compared to bilateral PKP, thus facilitating its clinical application.[7–9] Nevertheless, unilateral PKP requires a higher puncture angle precision, increasing the risk of spinal cord and nerve root injuries.[10,11] To address these concerns, recent studies have proposed unilateral percutaneous curved kyphoplasty (PCK) as an alternative. Compared to bilateral PKP, unilateral PCK reportedly demonstrates shorter operative times, reduced incidence of cement leakage, and improved bilateral cement distribution, thus achieving satisfactory clinical efficacy and safety.[11–14] However, studies comparing these techniques remain limited. Therefore, this retrospective study aimed to compare clinical outcomes between unilateral PCK and bilateral PKP to determine which technique offers greater advantages for treating single-level OVCF.

Materials and Methods

General Information

A total of 119 patients with osteoporotic thoracolumbar compression fractures admitted to our hospital between September 2023 and December 2024 were initially selected. Based on the surgical approach chosen by patients

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preoperatively and after applying the exclusion criteria, 89 patients with single-level OVCF were ultimately included. Among them, 41 patients were assigned to the PCK group and 48 to the PKP group. The final data analysis was conducted in July 2025. Given the study period, the latest follow-up time varied among patients, ranging from 6 to 12 months. The median follow-up time for the entire cohort was 12 month (Figure 1). Baseline characteristics, including

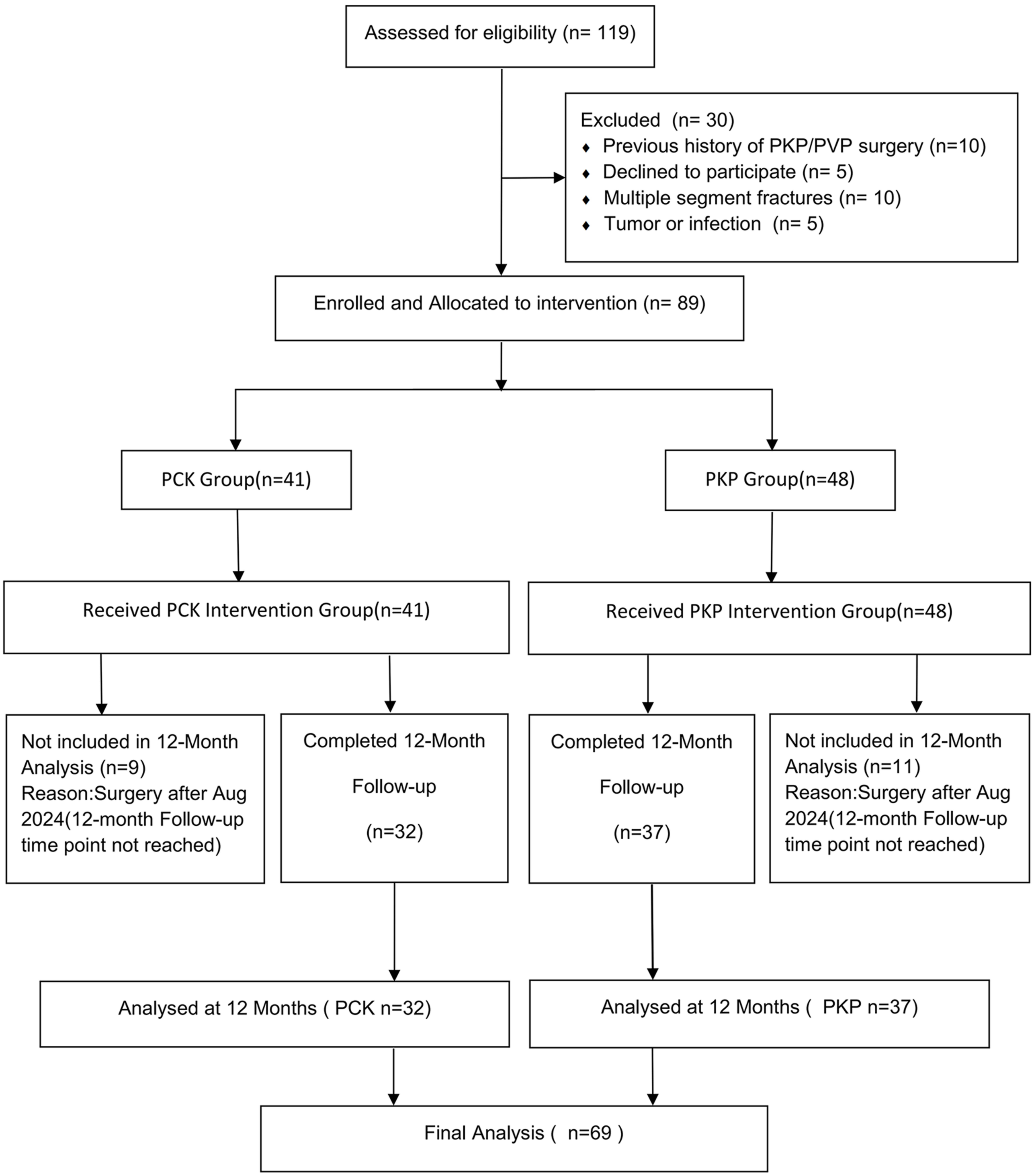

Figure 1 Flowchart of patient selection. A total of 20 patients who underwent surgery after August 2024 were excluded from the final 12-month analysis because their 12-month postoperative time point had not been reached by the data collection cutoff date (December 2024). The final analysis cohort consisted of 69 patients who completed the 12-month follow-up.

gender, age, duration since fracture occurrence, hospitalization time, bone mineral density, body mass index (BMI), vertebral fracture location, and cause of fracture, showed no statistically significant differences between groups (P > 0.05), indicating comparability (Table 1).

Inclusion and Exclusion Criteria

Inclusion Criteria

1. Patients of either gender, aged 60 years or older. 2. A confirmed diagnosis of a single vertebral compression fracture, as evidenced by X-ray, CT, or MRI imaging. 3. A BMD T-score of less than −2.5 SD, indicating the presence of osteoporosis. 4. Absence of spinal cord or nerve compression symptoms. 5. Time interval from onset of symptoms to surgery not exceeding one week. 6. Provision of informed consent by the patient.

Exclusion Criteria

1. Presence of multiple vertebral fractures. 2. Previous history of PKP or PVP procedures. 3. Fractures involving other regions of the body. 4. Coagulation disorders. 5. Diagnosis of malignant or metastatic spinal tumors. 6. Spinal infections, or any systemic or local soft tissue infections. 7. Presence of spinal cord or nerve compression symptoms. 8. Severe spinal deformities, psychiatric conditions, or other circumstances that contraindicate prone positioning during surgery. 9. The follow-up period was less than 12 months.

Surgical Method

Bilateral PKP Group

Patients were placed in a prone position, and the fractured vertebra was localized using a C-arm X-ray machine. Local infiltration anesthesia was performed with 1% lidocaine. Under fluoroscopic guidance, bilateral transpedicular puncture was conducted. Puncture needles were advanced along the pedicle trajectory, with the needle tips reaching the anterior third of the vertebral body in lateral view, and positioned between the inner margin of the pedicle projection and the spinous process in the anteroposterior view. The needle cores were then removed, guide wires inserted, and puncture needle cannulas withdrawn. Dilator cannulas were subsequently inserted, and bone drills advanced into the vertebra through the working cannulas, stopping at 3 mm from the anterior vertebral margin. After verifying satisfactory positioning under fluoroscopy, the bone drills were removed. Balloon dilators were then inserted, and contrast agents slowly injected under fluoroscopic monitoring to inflate balloons to the intended vertebral height or endplate position. Once achieved, contrast agents were slowly withdrawn, decompressing the balloons, which were subsequently removed.

Table 1 Comparison of General Characteristics

Particulars	PCK (n=41)	PKP (n=48)	$\chi 2/t$ value	*P*-value
Gender (n)				
Male	10	10	0.161	0.689
Female	31	38		
Age (years)	73.33 ± 8.67	73.50 ± 8.87	−0.033	0.974
BMI (kg/m^2)	24.79 ± 1.85	24.26 ± 2.11	1.252	0.214
BMD (T-score)	−3.57 ± 0.67	−3.58 ± 0.70	0.091	0.928
Time of injury(day)	3.71 ± 1.05	3.25 ± 1.16	0.260	0.795
Hospitalization time	5.90 ± 1.09	6.04 ± 1.03	−0.618	0.538
Vertebra				
Thoracic vertebra	12	22	2.570	0.109
Lumbar vertebra	29	26		
Cause of fracture				
Falls on the level	31	33	0.62	0.734
Bend down to pick up things	6	8		
No reason	4	7		

Abbreviations: BMI, Body mass index; BMD, Bone mineral density.

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Bone cement was prepared, and upon reaching the dough-like stage, simultaneously injected bilaterally under fluoroscopic control. Injection was ceased once the cement volume reached 24% of vertebral body volume, extended posteriorly to one-fifth to one-quarter of the vertebral body, or when potential leakage was observed.[15] After cement solidification, working cannulas were withdrawn, and the puncture sites were compressed and bandaged for hemostasis. Postoperatively, patients were confined to bed rest for 24 hours, after which they wore waist braces and commenced mobilization, along with routine anti-osteoporotic therapy (Figures 2 and 3).

PCK Group

Patients were placed in a prone position. The fractured vertebra was localized using a C-arm X-ray machine, and local infiltration anesthesia was administered using 1% lidocaine. A puncture needle was inserted with a 10°–20° inclination into the superolateral quadrant of the pedicle via a unilateral transpedicular approach and advanced to the posterior third of the vertebral body. After withdrawing the needle core, the flexible cement delivery device was attached to the puncture needle handle and carefully advanced through the puncture needle cannula across the vertebral midline toward the contralateral side. Proper positioning of the flexible cement delivery device within the vertebra was confirmed by anteroposterior and lateral fluoroscopic views, after which the device was withdrawn. A curved balloon was inserted into the working channel of the puncture needle up to the second marker line on the balloon catheter. After reconfirmation of balloon positioning via fluoroscopic imaging, the balloon was connected to a pressure pump and carefully inflated by injecting contrast medium to achieve fracture reduction. Upon satisfactory reduction, the contrast medium was withdrawn, and the balloon was removed. The flexible cement delivery device was reinserted, and its inner stylet was removed, leaving the outer cannula in place as a cement injection channel. Bone cement was prepared and slowly injected in its dough-like state while continuously monitoring cement dispersion fluoroscopically, to avoid leakage.

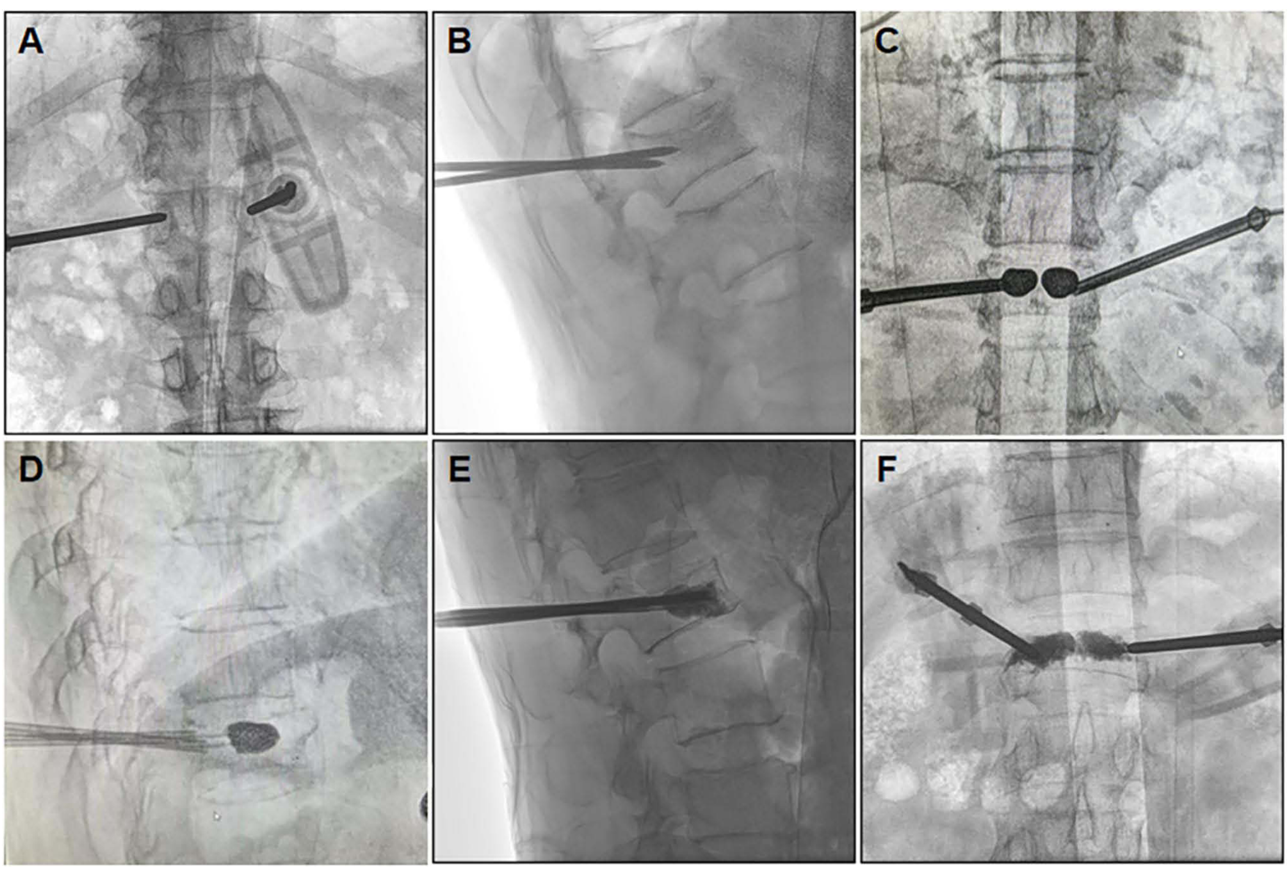

Figure 2 Surgical procedure. (**A**) Anteroposterior fluoroscopic view for puncture localization; (**B**) Lateral view confirming needle position; (**C**) Normal position shows bilateral balloon dilation; (**D**) From the side view, it can be seen that the bilateral balloons have expanded the height of the vertebrae; (**E**) Cement injection under lateral fluoroscopic view; (**F**) Cement injection under anteroposterior fluoroscopic view.

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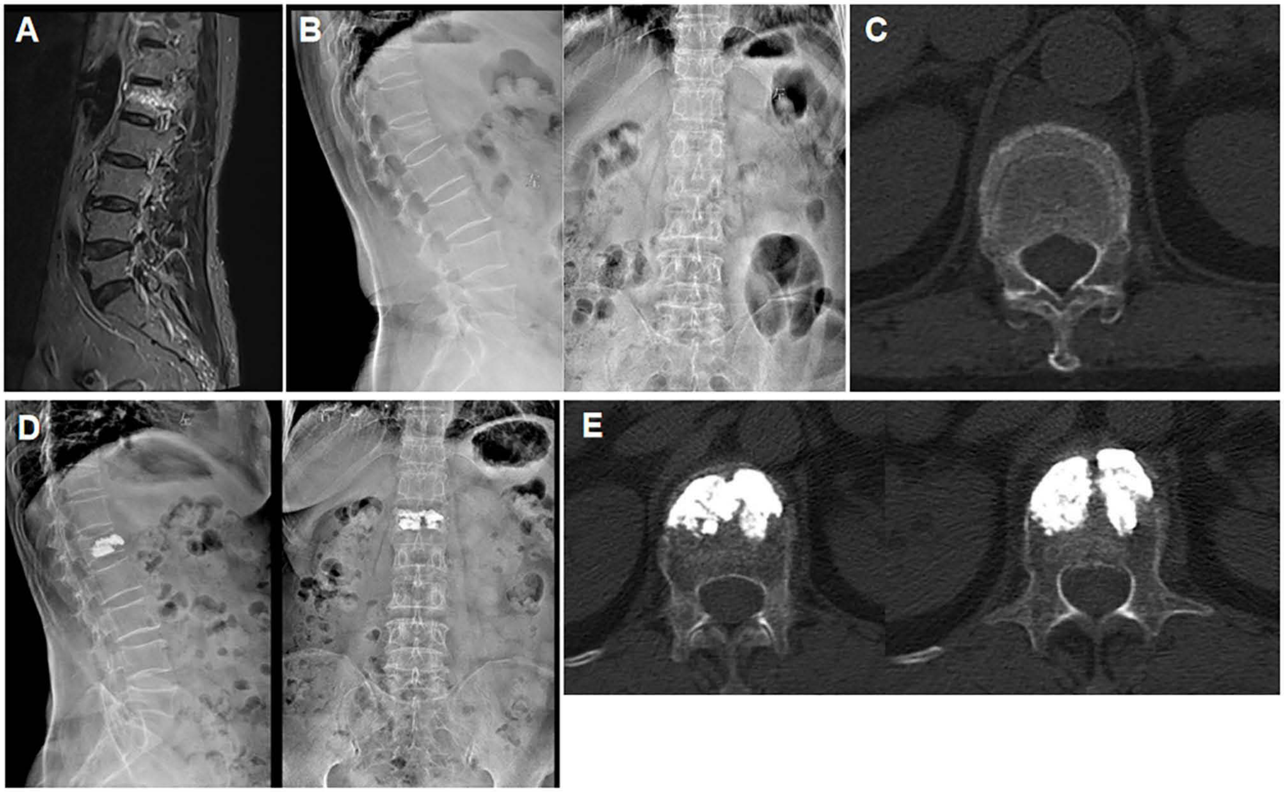

Figure 3 Postoperative images after PKP in a 75-year-old female patient. (**A**) Preoperative sagittal T2-weighted fat-suppressed MRI indicating acute fracture at L1; (**B**) Preoperative lateral and anteroposterior radiographs showing L1 vertebral compression fracture; (**C**) Axial CT scan confirming the L1 vertebral fracture; (**D**) Postoperative lateral and anteroposterior radiographs demonstrating cement distribution and vertebral height restoration; (**E**) Postoperative axial CT scan illustrating cement dispersion.

Cement injection was ceased when the cement approached the posterior vertebral margin or leakage was observed. Finally, the puncture needle was removed, and the puncture site was compressed and dressed for hemostasis (Figures 4 and 5). Postoperatively, patients were confined to bed rest for 24 hours before mobilization with a waist brace and routine anti-osteoporotic treatment.

Evaluation Indicators

The perioperative parameters recorded and compared between the two groups included surgical duration, intraoperative blood loss (The process was as follows:[16]

The dry weight of all gauzes and sponges was recorded before surgery. All used gauzes, sponges, and suction canister contents were collected after surgery. The total blood loss volume was calculated using the formula: Blood Loss (mL) = [Weight of used gauzes and sponges (g) - Dry weight (g)] / 1.055 (where 1.055 g/mL is the approximate density of blood), number of intraoperative C-arm fluoroscopy exposures, cement injection volume, incidence of cement leakage, and cement distribution patterns. Cement distribution was assessed according to the classification method proposed by Chu et al[17] as follows: Excellent, cement cross-filling region ≥75%; Good, cement cross-filling region ≥50% but <75%; Poor, cement cross-filling region <50% (including cases with some cross-filling); Fail, fixed cement with no sign of cross-filling.

Visual analogue scale (VAS) scores for low back pain and Oswestry Disability Index (ODI) scores were recorded preoperatively and at 1, 3, 6, and at the latest available follow-up postoperatively in both groups.

Spinal X-rays were obtained preoperatively and at 1 day, 3 months, 6 months, and at the latest available follow-up postoperatively in both groups to measure anterior vertebral height (AVH) and the kyphotic Cobb angle of the fractured

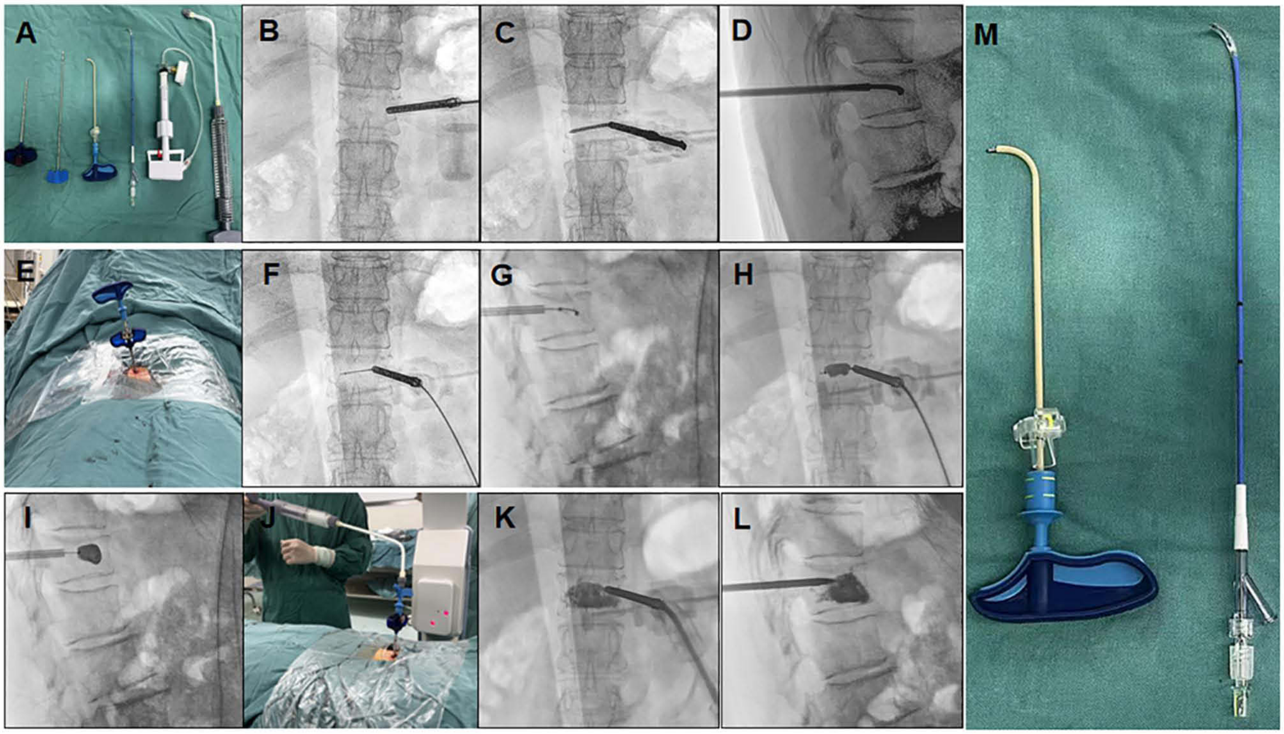

Figure 4 Surgical procedure of PCK. (**A**) Instruments for unilateral PCK (from left to right: puncture needle, bone drill, flexible cement delivery device, curved balloon, rotary pressure pump with volume scale, and rotary cement injection gun with volume scale); (**B**) Puncture localization; (**C** and **D**) Anteroposterior and lateral views showing the curved puncture needle position within the vertebra; (**E**) Puncture needle appearance image; (**F** and **G**) Anteroposterior and lateral views showing the uninflated curved balloon positioned within the vertebra; (**H** and **I**) Anteroposterior and lateral views demonstrating the inflated curved balloon supporting the anterior vertebral body after contrast injection; (**J**) A rotary cement injection gun with capacity scale for injecting bone cement; (**K** and **L**) Anteroposterior and lateral views illustrating bone cement dispersion within the vertebral body; (**M**) flexible cement delivery device, curved balloon.

vertebra (Figure 6). AVH recovery and improvement in the Cobb angle were calculated at 1 day postoperatively. At the final postoperative follow-up, the loss of AVH and Cobb angle correction were assessed.

During the postoperative follow-up period (median, 12 months; range, 6–12 months), the occurrence of refractures and other surgical complications was recorded and compared between the two groups. The final data analysis was conducted in July 2025. Given the study period, the latest follow-up time varied among patients, ranging from 6 to 12 months. The median follow-up time for the entire cohort was 12 months.

Statistical Analysis

Data were collected and analyzed using SPSS version 27.0 statistical software. Continuous data were presented as mean ± standard deviation ($\bar{x} \pm s$). Within-group and between-group comparisons were conducted using paired and independent sample *t*-tests, respectively. Categorical data were expressed as percentages (%) and analyzed using the χ^2-test. Ordinal data were evaluated using the Wilcoxon rank-sum test. For outcome measures obtained at the latest follow-up (which varied in time), the values from the last available visit for each patient were used in the analysis. $P < 0.05$ was considered statistically significant.

Results

Comparison of Perioperative Indicators

The PCK group demonstrated a significantly shorter operative duration, reduced intraoperative blood loss, fewer instances of X-ray fluoroscopy, and a lower volume of bone cement used compared to the PKP group ($P < 0.05$). However, no significant difference was observed in the distribution of bone cement between the two groups ($P > 0.05$) (Table 2).

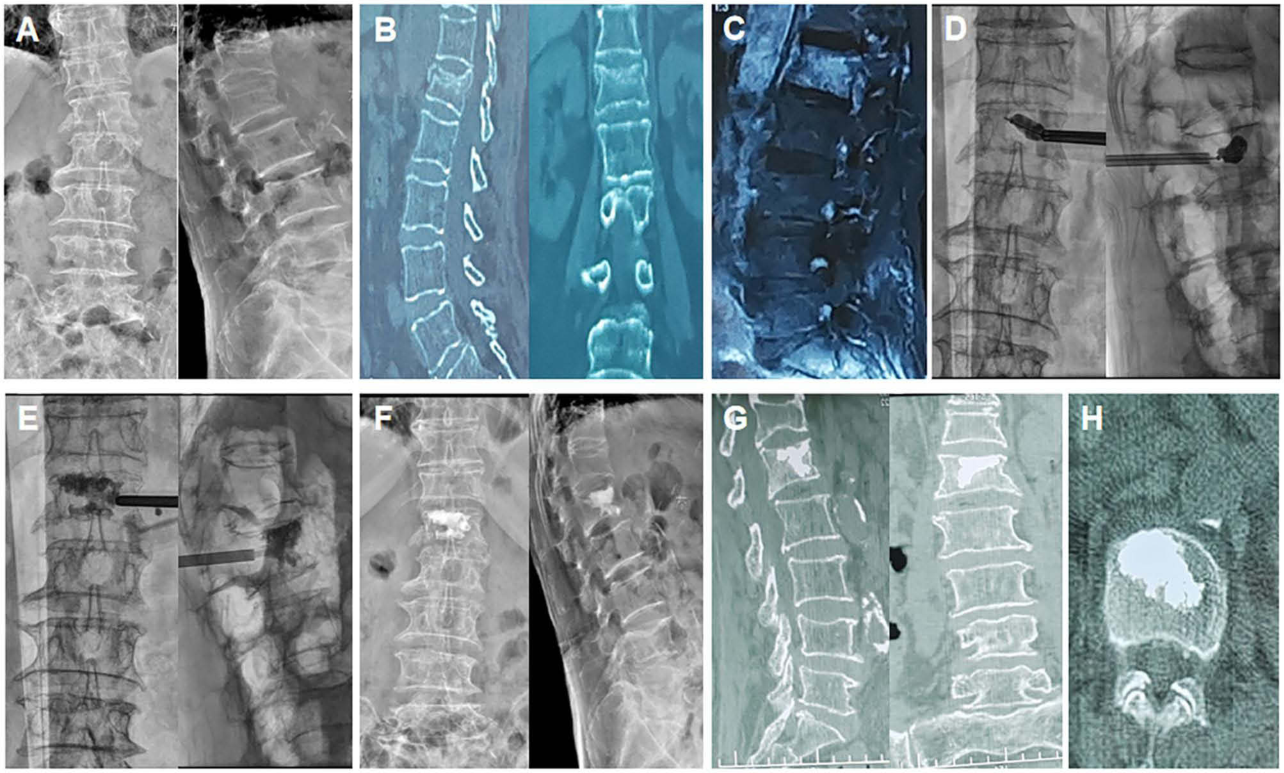

Figure 5 Female patient, 67 years old, undergoing PCK. (**A**) Anteroposterior and lateral X-ray images displaying compression fracture of the L1 vertebra; (**B**) CT reconstruction showing compression fracture of the L1 vertebral endplate; (**C**) MRI indicating an acute recent fracture of the L1 vertebra; (**D**) Intraoperative anteroposterior and lateral fluoroscopy showed the height of the vertebrae after the balloon expansion; (**E**) Intraoperative anteroposterior and lateral fluoroscopy of the distribution of bone cement in the vertebrae; (**F**) Postoperative anteroposterior and lateral X-rays depicting restored vertebral height and cement distribution; (**G**) Postoperative coronal and sagittal CT images demonstrating cement distribution; (**H**) Postoperative axial CT scan illustrating cement dispersion.

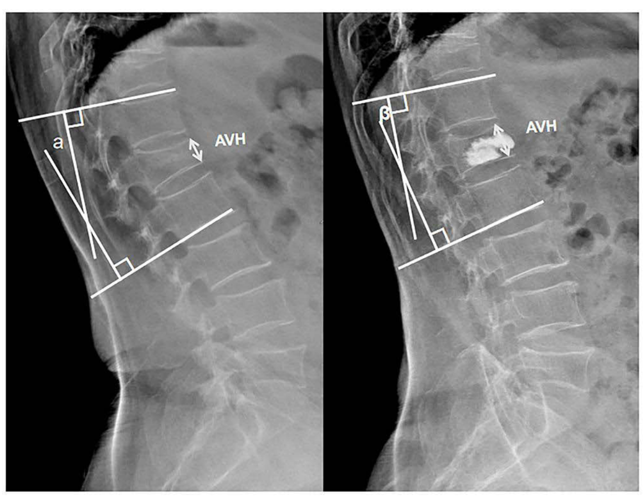

Figure 6 Measurement of Cobb angle. Horizontal lines are drawn along the superior endplate of the vertebra above the fracture and the inferior endplate of the vertebra below the fracture. Perpendicular lines are extended from these horizontal lines, forming an intersection. A larger Cobb angle indicates greater severity of vertebral compression. "a, β" represents the degree of Cobb angle improvement; "AVH" indicates recovery of anterior vertebral height.

Comparison of VAS Pain Scores and ODI Functional Scores Pre- and Post-Surgery

Both groups demonstrated significant reductions in VAS pain scores and ODI functional scores at 1, 3, and 6 months postoperatively compared with preoperative values ($P < 0.05$). At the 12-month assessment, significant reductions were

Table 2 Comparison of Perioperative Indicators

Group	Operation Time (min)	Intraoperative Blood Loss (mL)	Intraoperative Radiation Counts (times)	Bone Cement Injection Amount (mL)	Bone Cement Distribution (cases)			
					Excellent	Good	Poor	Fail
PCK (n=41)	37.44 ± 6.52	8.78 ± 2.91	15.37 ± 2.09	4.62 ± 0.60	35	3	3	0
PKP (n=48)	44.56 ± 7.74	12.81 ± 2.51	21.79 ± 2.46	5.14 ± 0.69	37	5	5	1
T/z value	−4.648	−7.022	−13.149	−3.715	−1.105			
P -value	< 0.001	< 0.001	< 0.001	< 0.001	0.310			

Table 3 Comparison of Pain VAS Scores ODI Functional Score Before and After Surgery

Clusters	PCK (n=41)	PKP (n=48)	*t*-value	*P*-value
VAS scores ($\bar{x} \pm s$, points)				
Before surgery	7.05 ± 0.67	7.02 ± 0.70	0.192	0.848
1 day after surgery	3.39 ± 0.63*	3.46 ± 0.65*	−0.500	0.618
1 months after surgery	2.46 ± 0.55*	2.44 ± 0.50*	0.232	0.817
3 months after surgery	1.54 ± 0.64*	1.50 ± 0.51*	0.302	0.763
6 months after surgery	1.07 ± 0.26*	1.10 ± 0.31*	−0.505	0.615
12 months after surgery$^{\Delta}$	0.88±0.34*	0.92±0.28*	−0.595	0.554
ODI scores ($\bar{x} \pm s$, points)				
Before surgery	75.83 ± 2.19	75.60 ± 2.75	0.422	0.674
1 months after surgery	23.63 ± 1.74*	24.60 ± 2.72*	−1.965	0.053
3 months after surgery	14.15 ± 1.62*	14.46 ± 1.89*	−0.828	0.410
6 months after surgery	6.56 ± 1.03*	6.46 ± 1.07*	0.459	0.647
12 months after surgery$^{\Delta}$	4.19±0.93*	3.89±0.94*	1.311	0.194

Notes: *Indicates significant difference compared to preoperative values (P < 0.05). $^{\Delta}$The sample size for the 12-month analysis was reduced (PCK, n=32; PKP, n=37; total n=69) because the 12-month postoperative time point had not yet been reached for patients who underwent surgery after August 2024 by the data analysis cutoff date (July 2025).
Abbreviations: VAS, visual analogue scale scores; ODI, the Oswestry Disability Index.

also maintained in both groups (P < 0.05). However, no statistically significant differences were observed between the two groups at any of these time points (P > 0.05) (Table 3).

Comparison of AVH and Cobb Angle Pre- and Post-Surgery

The AVH of the fractured vertebra in both groups was significantly greater at 1 day, 3 months, 6 months postoperatively compared with preoperative measurements (P < 0.05). At the 12-month assessment, AVH remained significantly improved compared to preoperative values (P < 0.05). However, no statistically significant differences were observed between the two groups at any postoperative time points (P > 0.05). Additionally, there were no significant differences between groups regarding vertebral height restoration or height loss (P > 0.05). The postoperative Cobb angles were significantly smaller than the preoperative values in both groups (P < 0.05), but no significant differences were detected between the two groups at any follow-up time points (P > 0.05). Moreover, comparisons of Cobb angle improvement and angle loss between groups revealed no significant differences (P > 0.05) (Table 4).

Comparison of Complications Between the Two Groups

Patients were followed postoperatively for a median duration of 12 months (range, 6–12 months). The incidence of bone cement leakage in the PCK group was significantly lower (4.9%, 2/41) than in the PKP group (18.8%, 9/48) (P < 0.05). None of the patients with cement leakage exhibited symptoms of spinal cord or nerve compression. The incidence of

Table 4 Comparison of AVH and Cobb Angle Before and After Surgery

Clusters	PCK (n=41)	PKP (n=48)	*t*-value	*P*-value
Anterior column height of vertebral fracture (mm)				
Before surgery	19.41 ± 3.55	19.57 ± 2.31	−0.250	0.803
1 day after surgery	24.22 ± 3.56*	24.45 ± 3.47*	−0.318	0.751
1 months after surgery	23.70 ± 3.53*	23.77 ± 3.38*	−0.106	0.916
3 months after surgery	23.05 ± 3.50*	23.14 ± 3.36*	−0.121	0.904
6 months after surgery	22.41 ± 3.43*	22.55 ± 3.22*	−0.915	0.846
12months after surgery$^{\Delta}$	22.13±3.69*	22.10±3.50*	0.030	0.977
Anterior column fracture recovery heigh (mm)	4.86 ± 1.71	4.88 ± 1.72	−0.075	0.941
Anterior column fracture loss of height (mm)†	1.85±0.77	1.98±0.69	−0.822	0.413
Cobb Angle				
Before surgery	21.35 ± 8.03	20.34 ± 8.76	0.565	0.573
1 day after surgery	16.55 ± 7.08*	15.38 ± 7.40*	0.757	0.451
1 months after surgery	17.40 ± 7.06*	16.36 ± 7.49*	0.666	0.507
3 months after surgery	18.05 ± 7.06*	17.04 ± 7.48*	0.654	0.515
6 months after surgery	18.85 ± 7.11*	17.61 ± 7.35*	0.809	0.421
12months after surgery$^{\Delta}$	18.31±7.79*	18.22±7.99*	0.049	0.961
The Cobb Angle improves the degree	4.80 ± 1.91	5.12 ± 2.93	−0.608	0.545
The degree of Cobb Angle loss†	2.33±0.60	2.25±0.55	0.671	0.504

Notes: * Indicates significant difference compared to preoperative values ($P < 0.05$); $^{\Delta}$The sample size for the 12-month analysis was reduced (PCK, n=32; PKP, n=37; total n=69) because the 12-month postoperative time point had not yet been reached for patients who underwent surgery after August 2024 by the data analysis cutoff date (July 2025); †The loss of vertebral height and loss of Cobb angle were calculated for eachpatient as the difference between the value on postoperative day 1 and the value at the last available follow-up (ranging from 6 to 12 months).

Table 5 Comparison of Cement Leakage and Vertebral Refracture Rates Between the Two Groups [n (%)]

Group	Bone Cement Leakage Rate	Refracture After Surgery
PCK (n=41)	2 (4.9%)	2 (4.9%)
PKP (n=48)	9 (18.8%)	3 (6.3%)
$\chi 2$ value	3.928	0.078
P-value	0.047	0.779

postoperative vertebral refracture was 4.9% (2/41) in the PCK group and 6.3% (3/48) in the PKP group, with no significant difference between the groups ($P > 0.05$) (Table 5). The occurrence of refractures was associated with inadequate postoperative anti-osteoporotic treatment.

Discussion

With the increasing severity of population aging worldwide, the incidence of OVCF continues to rise annually.[18,19] Given increased life expectancy, especially among individuals aged over 65, there is an urgent need for effective prevention and treatment strategies to address this escalating health concern.[20] OVCF can lead to symptoms such as vertebral and low back pain, spinal kyphotic deformity, and impaired mobility.[21] Treatment options for OVCF include conservative and surgical management. Conservative management primarily involves analgesics, thoracolumbar braces, and strict bed rest. However, prolonged bed rest exacerbates bone loss, worsens osteoporosis, and increases the risk of associated complications such as cardiopulmonary dysfunction, urinary tract infections, deep vein thrombosis, and pressure ulcers,[18] significantly impairing quality of life. Therefore, early and effective intervention is critical. The objectives of surgical treatment for OVCF are rapid and sustained pain relief, early restoration of mobility, spinal stabilization, and reduction of complications.[22] PKP effectively alleviates pain and prevents further vertebral collapse.[5,18,23,24]

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Safe puncture is crucial for successful vertebral augmentation procedures. Multiple meta-analyses have demonstrated that unilateral PKP is associated with reduced intraoperative radiation exposure, shorter operation times, lower bone cement volumes, and a lower incidence of cement leakage compared with bilateral PKP.[7–9,25–27] However, unilateral PKP may increase the risk of adjacent vertebral fractures and cement leakage as the injected cement volume increases.[28,29] Moreover, achieving optimal cement distribution via unilateral PKP often requires a steeper puncture angle, increasing the risk of cement leakage through the vertebral cortex, potentially injuring the spinal cord and nerve roots.[10,11,30] Unilateral PCK combines the advantages of both unilateral and bilateral approaches. Compared with bilateral PKP, PCK employs a unilateral transpedicular approach, thereby reducing operative time and radiation exposure. Compared with unilateral PKP, PCK establishes a curved channel through the vertebral midline, creating a bilateral augmentation cavity and enabling precise control over cement injection location and angle. Consequently, cement is evenly dispersed, overcoming the uneven cement distribution commonly associated with unilateral PKP.[10] Therefore, performing PCK requires mastery of basic transpedicular puncture techniques without emphasizing the puncture angle.[31]

The incidence of refracture following OVCF surgery is associated with bone cement distribution,[10,32–34] as cement dispersion influences postoperative vertebral strength and biomechanical stability.[34] The ideal cement distribution is central within the vertebral body; however, fracture morphology, surgical technique, and puncture trajectory may lead to asymmetric cement distribution.[10] Such uneven distribution may result in asymmetric stress transmission to adjacent vertebral bodies and intervertebral discs, thereby causing adjacent-level fractures or refracture of the treated vertebra.[34] Unilateral PKP typically does not cross the vertebral midline, preventing bilateral cement distribution and consequently leading to uneven vertebral strength, postoperative vertebral collapse, residual low back pain, and increased risk of refracture.[35,36] Conversely, bilateral PKP is associated with prolonged operative duration, increased puncture frequency, and higher radiation exposure. Additionally, bilateral injections may result in incomplete fusion of cement from each side, causing the “double-eyes” phenomenon and suboptimal postoperative outcomes[33] Thus, achieving biomechanical equilibrium requires cement injection crossing. The vertebral midline, ensuring symmetrical vertebral strength.[10,34] The PCK technique achieves bilateral augmentation through a curved pathway across the vertebral midline, utilizing a curved balloon to form a central cavity within the anterior-middle vertebral column. This allows uniform cement dispersion bilaterally, ensuring continuity across the midline region and providing stronger sagittal plane biomechanical support for spinal injuries,[31] which differs significantly from bilateral PKP procedures. In the present study, bone cement distribution was classified as Grade I in 35 cases, Grade II in 3 cases, and Grade III in 3 cases among 41 patients in the PCK group, compared with Grade I in 37 cases, Grade II in 5 cases, Grade III in 5 cases, and Grade IV in 1 case among patients in the bilateral PKP group. No significant difference was found between the two groups, suggesting that PCK achieves bone cement distribution comparable to bilateral PKP.

Cement leakage is one of the major postoperative complications associated with OVCF,[18] predominantly occurring at the anterior-middle vertebral column and collapsed endplates.[22] The incidence of cement leakage ranges from 3.0% to 74.0%.[37,38] Severe cement leakage can cause paralysis, pulmonary embolism, or even death. Risk factors for cement leakage include cement volume, cement viscosity, injection pressure, fracture etiology, degree of vertebral compression, vertebral cortical disruption, repeated puncture attempts, and puncture direction.[38–40] In the present study, the cement leakage rate in the PCK group (4.9%) was significantly lower than in the bilateral PKP group (18.8%), likely because the cement volume injected was significantly lower in the PCK group, consistent with previous reports suggesting increased cement volume as a risk factor for leakage.[28,29] All cement leakages observed in this study were classified as type C,[41] involving leakage through cortical defects into paravertebral soft tissues, without pulmonary embolism or neurological complications. The lower cement leakage rate in the PCK group compared to the PKP group may result from the curved balloon used in PCK, which supports the anterior-middle vertebral column, forming a curved cavity within the vertebral body and permitting low-pressure cement injection (<200 psi). Additionally, balloon dilation compresses adjacent trabecular bone, enhancing vertebral stability and reducing stress concentrations, thereby decreasing cement leakage incidence.[11]

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Study Limitations

This study has several limitations. First and foremost, the major limitation is its retrospective, non-randomized design. The fact that the surgical approach was chosen by patients preoperatively rather than being randomly assigned introduces the potential for selection bias. Although our baseline characteristics were well-balanced (Table 1), we cannot rule out unmeasured confounding by factors such as surgeon preference, specific fracture morphology, patient anatomy, or socio-economic status. While propensity-score matching or multivariable adjustment would be ideal, our sample size was underpowered for such robust analyses. Future prospective, randomized controlled trials are necessary to confirm our findings.

Conclusion

This study, with a median follow-up of 12 months, indicates that the therapeutic outcomes of the PCK technique are comparable to those of the bilateral PKP technique in treating elderly patients with OVCFs. PCK offered significant intraoperative advantages, including greater efficiency and reduced radiation exposure. Although the follow-up was incomplete for a minority of patients due to the study timeline, the median follow-up duration supports the robustness of the medium-term outcomes observed. These findings suggest that PCK is a viable and efficient surgical alternative. Further studies are encouraged to confirm its long-term non-inferiority.

Ethical Approval

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Chongqing Nanan District People's Hospital [approval number: (2025) Nanrenyilunshen No. (07)], and written informed consent was obtained from all participants.

Author Contributions

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.

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Disclosure

The authors reports no conflicts of interest in this work.

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