



Comparative Efficacy of Unilateral vs. Bilateral Approaches in Percutaneous Kyphoplasty and Vertebroplasty for Osteoporotic Vertebral Compression Fractures

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Abstract

Background Osteoporotic vertebral compression fractures (OVCFs) significantly affect the quality of life of elderly patients by causing severe pain and functional loss. Percutaneous kyphoplasty (PKP) and percutaneous vertebroplasty (PVP) are minimally invasive surgical techniques for the treatment of OVCFs. It can be performed unilaterally or bilaterally for prevention of kyphosis without morbidity. This study aims to compare the radiological and clinical outcomes of unilateral versus bilateral approaches in PKP/PVP procedures.

Methods This retrospective observational study included 230 unilateral ($n = 110$) and bilateral ($n = 120$) patients from three spinal centers who underwent PCP or PVP for OVCF treatment between 2018 and 2024. During the operation, operative time, cement volume, and frequency of fluoroscopy were recorded. The duration of hospital stay was recorded. Visual Analog Scale (VAS) scores and Oswestry Disability Index (ODI) scores were used for clinical evaluation at preoperative, postoperative day 1, and final follow-up. Vertebral height and kyphotic angle were used for radiological evaluation.

Results The unilateral approach had significantly shorter operative times (43.4 ± 9.01 minutes, $p < 0.001$) compared to the bilateral approach (59.9 ± 11.5 minutes), required less cement (4.44 ± 1.01 mL vs. 7.53 ± 0.911 mL, $p < 0.001$), and had fewer fluoroscopy (26.2 ± 6.58 vs. 55.6 ± 9.98 , $p < 0.001$). There were no significant differences between the two groups in VAS scores ($p = 0.663$), ODI scores ($p = 0.650$), vertebral height restoration ($p = 0.720$), or kyphotic angle correction ($p = 0.129$). However, the bilateral group had a higher rate of cement leakage (35 vs. 12%, $p = 0.035$).

Conclusion These findings suggest that the unilateral approach offers procedural advantages without compromising clinical efficacy, making it a preferable option for elderly patients with OVCFs.

Keywords

- bilateral approach
- osteoporotic vertebral compression fractures
- percutaneous kyphoplasty
- vertebroplasty
- unilateral approach

Introduction

Osteoporotic vertebral compression fractures (OVCFs), which can occur with aging spines, can cause severe pain and functional losses that significantly affect patients' quality of life. Globally, approximately 1.4 million OVCF cases are reported annually, affecting a large patient population.^{1,2} Percutaneous kyphoplasty (PKP) and percutaneous vertebroplasty (PVP) are widely used in the treatment of OVCFs, yielding favorable clinical outcomes.

Treating OVCFs primarily involves addressing pain. Additionally, these procedures can correct kyphosis or prevent its development in the long term. Being minimally invasive surgical techniques, they avoid the morbidity associated with major surgeries, which is particularly important for the elderly osteoporotic patient population.³ Moreover, these procedures rapidly alleviate pain, thus preventing complications arising from pain-induced immobilization.

PKP and PVP surgeries can be performed unilaterally or bilaterally. Several authors have suggested unilateral PKP for OVCFs, noting that the outcomes and patient satisfaction were comparable to those of bilateral treatment. Unilateral kyphoplasty was found to be as effective as bilateral kyphoplasty in reducing the degree of pain, the duration of surgery was less, and the complication rate was similar.^{4,5} However, there are also studies showing that bilateral intervention is more effective in correcting the kyphosis angle and that there is no difference in surgical time.^{6,7}

As seen in many studies, both approaches have their own advantages, but there is no clear consensus on their superiority. In the literature, there are few studies with a small number of patients and there are not many studies on the long-term follow-up results of these patients. Therefore, this study aims to compare the radiologic and clinical outcomes of unilateral and bilateral approaches in patients undergoing PKP or PVP in a large patient population.

Materials and Methods

Study Design and Patient Population

The study protocol received approval from the Istanbul Medipol University ethical board numbered 445/2024. This retrospective study was performed by screening all patients who underwent PKP or PVP for the treatment of OVCFs between 2018 and 2024 at three spine centers where the authors are located, totaling 230 patients. The patients were divided into two groups: the unilateral group ($n=110$) and the bilateral group ($n=120$). All cases performed for this purpose were retrospectively reviewed and divided according to whether they were unilateral or bilateral. In the unilateral group, 52 patients underwent kyphoplasty and 58 underwent vertebroplasty, while in the bilateral group, 57 patients underwent kyphoplasty and 63 underwent vertebroplasty. The inclusion criteria were as follows: patients aged ≥ 50 years with local tenderness, low back pain, and lumbar dysfunction; T -score for bone mineral density (BMD) ≤ -2.5 (central dual energy X-ray

absorptiometry [DEXA] was used for BMD measurement), consistent with the diagnostic criteria of osteoporosis, magnetic resonance imaging (MRI) showing a single-level vertebral body with a fresh vertebral compression fracture; and complete data availability during preoperative, intraoperative, and postoperative periods. Patients with pathological fractures due to tuberculosis or tumors, mental illness, coronary heart disease, long-term use of glucocorticoids for rheumatic disease, or abnormal coagulation were excluded. During the follow-up of the study, 42 patients who had missing films or could not be contacted during follow-up were excluded from the study.

Surgical Procedure

All procedures were performed by experienced spine surgeons using standard techniques. Patients were placed on the operating table in the prone position. In the unilateral group, a single incision was made and the puncture site was selected based on clear pedicle shadow visibility under C-arm fluoroscopy. The same procedure was performed bilaterally in the bilateral group. After a working cannula was inserted from the pedicle into the vertebral body, a balloon was inflated for PKP, and a cement injection was performed for PVP without using a balloon. Bone cement consisting of a powder phase (poly(methyl acrylate, methyl methacrylate), zirconium dioxide, benzoyl peroxide) and a liquid phase (methyl methacrylate [MMA], N,N-dimethyl-p-toluidine, hydroquinone) was used (BONEGRAFT, Turkey).

Data Collection and Outcome Measures

A comprehensive data set was compiled, encompassing preoperative, intraoperative, and postoperative variables. These included operative time, volume of cement injected, frequency of intraoperative fluoroscopy, length of hospital stay, and clinical outcomes as measured by the Visual Analog Scale (VAS) and Oswestry Disability Index (ODI). Radiographic outcomes included average vertebral height and kyphotic angle (KA) measurements. Complications such as bone cement leakage and adjacent vertebral fractures were also recorded.

Average Vertebral Height

The average vertebral height refers to the mean height of a vertebra, typically calculated by averaging the measurements of its anterior, middle, and posterior heights.

Kyphotic Angle

It is measured by drawing lines parallel to the superior endplate of the vertebra above the fracture and the inferior endplate of the vertebra below the fracture, and then measuring the angle between these lines.

Statistical Analysis

Statistical analysis was performed using SPSS (version 25.0; IBM Corp.). Independent sample Student's t -test was used to compare continuous variables such as age, BMD T -score, operation time, injected cement volume, intraoperative fluoroscopy frequency, and hospital stay duration between

Table 1 General demographic data of patients

Variable	Unilateral PKP/PVP (n = 110)	Bilateral PKP/PVP (n = 120)	p-value
Age (y)	72.5 ± 8.97	70.8 ± 8.28	0.146
Gender (male/female)	34/76	46/74	0.548
BMD T-score	-2.76 ± 0.429	-3.03 ± 0.450	0.045
Fracture location (thoracic/lumbar)	40/70	34/86	0.575

Abbreviations: BMD, bone mineral density; PKP, percutaneous kyphoplasty; PVP, percutaneous vertebroplasty.

the two groups. The Mann–Whitney *U* test was used for nonparametric variables like VAS and ODI scores. Fisher’s exact test and chi-squared test were employed for categorical variables, including sex, fracture location, scoliosis direction, and complication rates. Parametric data were presented as mean ± standard deviation, nonparametric data as median (interquartile range), and count data as *n* (%). A *p*-value less than 0.05 was considered statistically significant.

Results

A total of 230 patients were included in the study, with 110 undergoing unilateral intervention and 120 undergoing bilateral intervention. The general demographic data of the unilateral and bilateral PKP/PVP groups were compared. The mean age of the unilateral group was 72.5 ± 8.97 years, while that of the bilateral group was 70.8 ± 8.28 years. This difference was not statistically significant (*p* = 0.146). In terms of the BMD *T*-score, the unilateral group exhibited a mean BMD *T*-score of -2.76 ± 0.429, while the bilateral group demonstrated a mean BMD *T*-score of -3.03 ± 0.450. This difference was statistically significant (*p* = 0.045). The gender distribution in the unilateral group was 34 males and 76 females, while in the bilateral group, it was 46 males and 74 females. This difference was not statistically significant (*p* = 0.548). With regard to the localization of fractures, the thoracic/lumbar fractures were 40/70 in the unilateral group and 34/86 in the bilateral group. This difference was not statistically significant (*p* = 0.575). These findings indicate that there were no significant demographic differences between the two groups (► **Table 1**).

The clinical outcomes of unilateral and bilateral PKP/PVP procedures were compared. The operation time was found to be significantly shorter in the unilateral group (43.4 ± 9.01 minutes) compared to the bilateral group (59.9 ± 11.5 minutes; *p* < 0.001). The injected cement volume was also significantly less in the unilateral group (4.44 ± 1.01 mL) compared to the bilateral group (7.53 ± 0.911 mL; *p* < 0.001). Similarly, the frequency of intraoperative fluoroscopy was significantly lower in the unilateral group (26.2 ± 6.58) compared to the bilateral group (55.6 ± 9.98; *p* < 0.001).

The duration of hospital stay did not demonstrate a statistically significant difference between the two groups, with the unilateral group averaging 4.71 ± 1.41 days and the bilateral group averaging 5.28 ± 1.51 days (*p* = 0.052). The VAS scores for preoperative, 1-day postoperative, and final follow-up periods did not demonstrate significant differences between the groups. Similarly, the ODI scores for preoperative, 1-day postoperative, and final follow-up

did not demonstrate significant differences. The mean vertebral height, both preoperatively and at follow-up, did not differ significantly between the groups. The KA measurements, taken preoperatively, at 1 day postoperatively, and at final follow-up, also demonstrated no significant differences between the groups. However, the cement leakage rate was significantly higher in the bilateral group (35%) compared to the unilateral group (12%; *p* = 0.035). There was no significant difference in the incidence of adjacent vertebral fractures between the groups (► **Table 2**). These findings indicate that unilateral PKP/PVP procedures offer advantages in terms of shorter operation times, less cement volume, and lower intraoperative fluoroscopy frequency, with comparable clinical outcomes to bilateral PKP/PVP procedures (► **Figs. 1** and **2**).

Discussion

The results of this study provide valuable insights into the comparative efficacy of unilateral versus bilateral PKP/PVP in the treatment of OVCFs. The primary findings indicate that unilateral procedures offer significant advantages in terms of operative time, cement volume, and intraoperative fluoroscopy frequency. These advantages are particularly relevant for the elderly osteoporotic patient population, for whom shorter and less invasive procedures can reduce the overall surgical burden and associated risks.⁸ The comparative effectiveness of unilateral versus bilateral PKP and PVP in treating OVCF has been explored in various studies. These studies generally indicate that unilateral procedures offer significant advantages over bilateral procedures in terms of operative time, cement volume, and intraoperative fluoroscopy frequency. Unilateral procedures tend to require shorter operative times and use less cement, which is particularly beneficial for elderly patients. This reduction in procedural time and invasiveness can lead to fewer complications and a quicker recovery process.⁹ In our study, the markedly shorter operative time for unilateral procedures (43.4 ± 9.01 minutes) in comparison to bilateral procedures (59.9 ± 11.5 minutes) serves to illustrate the efficacy of the unilateral approach. This finding is consistent with previous studies that have also reported reduced surgical times for unilateral procedures, which can minimize anesthesia exposure and potential complications in elderly patients.

The reduced volume of cement injected in the unilateral group (4.44 ± 1.01 vs. 7.53 ± 0.911 mL) not only suggests a more conservative approach but also correlates with a lower

Table 2 Comparison of the clinical and radiographic parameters between unilateral and bilateral PKP groups

Variable	Unilateral PKP (n = 55)	Bilateral PKP (n = 60)	p-value
Operation time (min)	43.4 ± 9.01	59.9 ± 11.5	< 0.001
Injected cement volume (mL)	4.44 ± 1.01	7.53 ± 0.911	< 0.001
Intraoperative fluoroscopy frequency	26.2 ± 6.58	55.6 ± 9.98	< 0.001
Hospital stay (d)	4.71 ± 1.41	5.28 ± 1.51	0.052
Pre-op VAS score, median (IQR)	7 (6–8)	6.95 (6–9)	0.291
VAS score at 1 d post-op (median)	3.35 (3–4)	3.30 (3–4)	0.663
VAS score at final follow-up (median)	1.96 (1–2)	1.95 (1–2)	0.648
Pre-op ODI score (%)	59.9 ± 4.59	60.8 ± 3.99	0.993
ODI score at 1 day post-op (%)	29.1 ± 2.01	28.8 ± 2.07	0.971
ODI score at final follow-up (%)	20.0 ± 2.00	20.1 ± 2.20	0.650
Pre-op average vertebral height (mm)	18 ± 3	22 ± 3	0.981
Average vertebral height at 1 d post-op (mm)	23 ± 4	28 ± 3	0.113
Average vertebral height at final follow-up (mm)	22 ± 4	33 ± 3	0.720
Pre-op kyphotic angle (degrees)	16 ± 6	14 ± 4	0.229
Kyphotic angle at 1 d post-op (degrees)	8 ± 4	7 ± 3	0.146
Kyphotic angle at final follow-up (degrees)	9 ± 4	7 ± 3	0.129
Cement leakage rate (%)	12	35	0.035
Adjacent vertebral fracture rate (%)	12	8	1.000

Abbreviations: IQR, interquartile range; ODI, Oswestry Disability Index; PKP, percutaneous kyphoplasty; PVP, percutaneous vertebroplasty; VAS, Visual Analog Scale.

risk of cement leakage, a notable complication that was significantly higher in the bilateral group (35 vs. 12%). The cement leakage rate observed in previous studies and in the present study is similar.¹⁰ Unilateral PKP/PVP is technically simpler and has a lower risk of cement leakage, a common complication associated with these procedures. The studies indicate that cement leakage rates are significantly lower in unilateral approaches due to the controlled and lower volume of cement used.¹¹

Despite the aforementioned procedural advantages, the clinical outcomes as measured by the VAS and ODI did not differ significantly between the two groups. Both approaches yielded comparable pain relief and functional improvement, indicating that the unilateral approach does not compromise the clinical efficacy of the treatment. This finding is of significant importance, as it provides evidence to support the use of the less invasive unilateral approach without compromising patient outcomes. Both unilateral and bilateral approaches effectively reduce pain and improve function in patients with OVCFs. However, the unilateral approach has shown to be sufficient in most cases, providing comparable pain relief and functional recovery without the additional risks associated with the bilateral approach.¹² Furthermore, numerous studies have examined the impact of cement quantity on clinical VAS and ODI scores.¹³ These studies have demonstrated that excessive cement use is not more effective in relieving pain, while adequate cement application provides pain control in a relatively short time. These findings are also consistent with the results of our study. Despite the use of a

smaller quantity of cement in the unilateral procedure, satisfactory pain control was achieved.

The absence of notable discrepancies in radiographic outcomes, including mean vertebral height and KA, serves to reinforce the efficacy of unilateral procedures. Both approaches were equally effective in restoring vertebral height and correcting kyphosis, which are essential factors in the long-term management of OVCFs. Furthermore, the incidence of adjacent vertebral fractures was comparable between the two groups, suggesting that the unilateral approach does not elevate the risk of subsequent fractures. A systematic review and meta-analysis revealed that unilateral PKP utilizes less cement and reduces radiation exposure without compromising the restoration of vertebral height or KA. This makes unilateral PKP a suitable alternative to bilateral PKP for the treatment of OVCFs.¹⁴

In a limited number of studies, the bilateral group demonstrated superior clinical and radiological outcomes, underscoring the necessity of bilateral intervention.¹⁵ Nevertheless, the most recent studies still indicate that unilateral access is associated with a lower incidence of complications and satisfactory clinical and radiological outcomes.^{16–20}

Our study's findings align with several previous studies in the literature. For instance, Chung et al compared the efficacy of unilateral and bilateral balloon kyphoplasty in OVCFs and found that bilateral intervention was more effective in correcting the KA, although it did not differ in surgical time compared to unilateral intervention.⁶ Similarly, Chen et al also reported that the bipedicular approach in

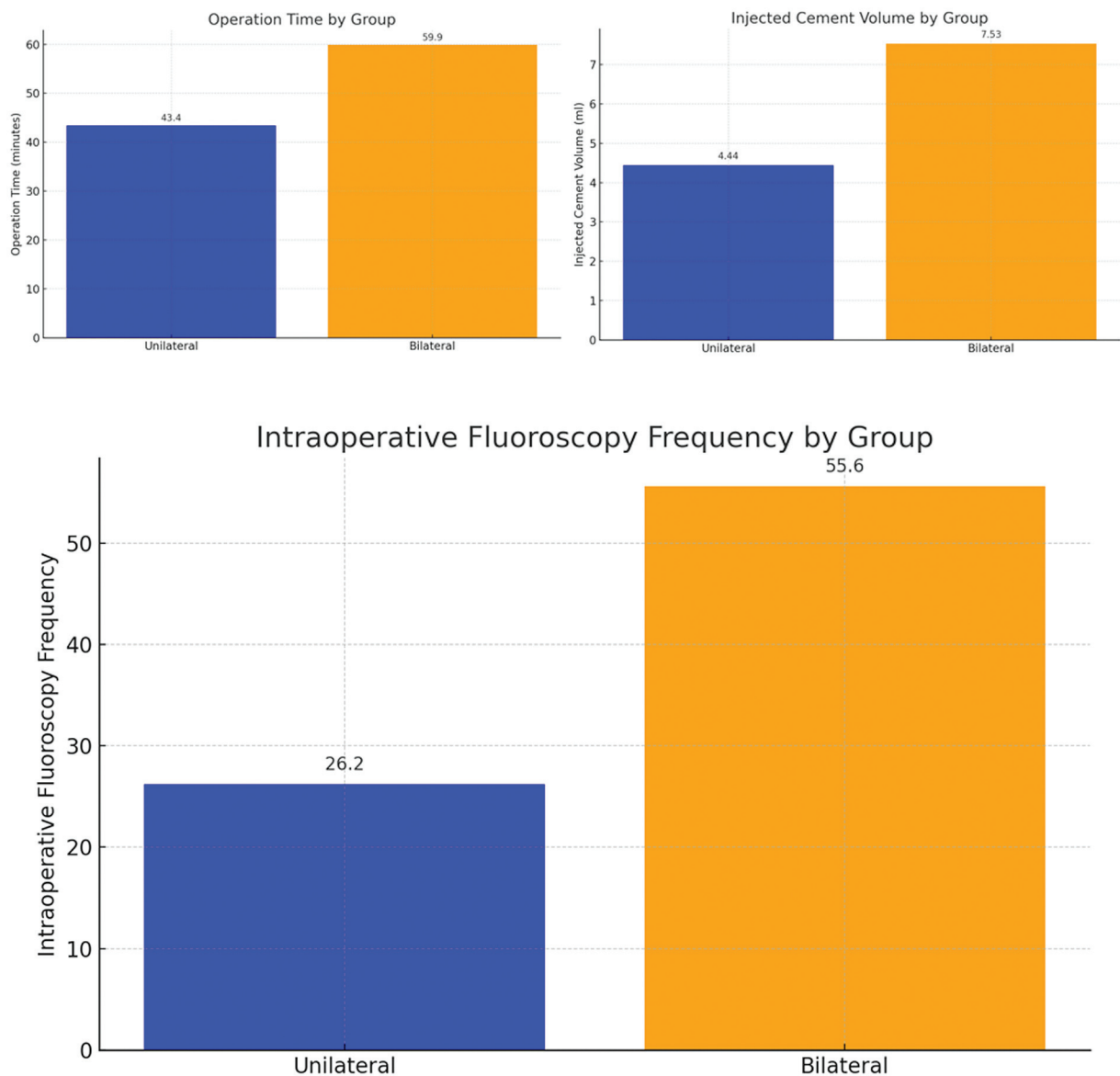


Fig. 1 Comparison of clinical and radiographic parameters between unilateral and bilateral percutaneous kyphoplasty/percutaneous vertebroplasty groups.

kyphoplasty yielded better outcomes in terms of kyphosis correction but noted a higher complication rate due to cement leakage.⁷ Chen et al conducted a prospective study comparing unilateral versus bilateral balloon kyphoplasty for multilevel OVCFs and found that unilateral kyphoplasty was as effective as bilateral in reducing pain and improving function, but with shorter surgical time and lower cement usage. These results are consistent with our findings that unilateral PKP/PVP procedures offer significant procedural advantages without compromising clinical efficacy.⁴ Wang et al also compared unilateral versus bilateral balloon kyphoplasty and found similar results, indicating that unilateral kyphoplasty had shorter operative times and lower cement volume, which aligns with our study's findings.⁵

Rebolledo et al highlighted the importance of cement quantity and its impact on clinical outcomes, noting that excessive cement does not necessarily improve pain relief but increases the risk of complications such as cement

leakage.²⁰ Our study supports this by showing that unilateral procedures, which use less cement, resulted in comparable pain relief and functional improvement to bilateral procedures.

The significant procedural advantages of unilateral PKP/PVP, including shorter operative times and lower cement usage, suggest that this approach is particularly beneficial for elderly patients who may not tolerate longer and more invasive procedures well. The lower rate of cement leakage observed in our study further supports the preference for the unilateral approach, as it minimizes the risk of complications. Despite the procedural differences, both unilateral and bilateral approaches were equally effective in restoring vertebral height and correcting kyphosis, which are critical for the long-term management of OVCFs. This reinforces the idea that the less invasive unilateral approach does not compromise the clinical outcomes, making it a preferable option for many patients.



Fig. 2 Postoperative computed tomography images of patients who underwent (A, B) unilateral and (C–E) bilateral percutaneous kyphoplasty/percutaneous vertebroplasty procedures.

Limitations

This study has several limitations that should be acknowledged. First, as a retrospective observational study, it is subject to inherent biases related to patient selection and data collection. The study relied on the accuracy and completeness of medical records, which may introduce reporting bias. Second, the sample size, while adequate for initial comparisons, may limit the generalizability of the findings to broader populations. Larger, multicenter prospective studies are needed to validate these results. Third, the study did not account for potential confounding factors such as variations in surgical technique, the experience of the surgeons, or differences in postoperative rehabilitation protocols, which could influence the outcomes. Finally, the follow-up period, although sufficient to observe initial clinical and radiological outcomes, may not capture long-term complications or the durability of the benefits observed. Future research should aim to address these limitations by incorporating larger sample sizes, prospective designs, and longer follow-up periods to provide more robust and generalizable conclusions.

Conclusion

This study demonstrates that unilateral PKP/PVP procedures offer significant procedural benefits, including shorter operative times and reduced cement usage, without compromising clinical and radiographic outcomes. These findings support the preferential use of unilateral approaches in the treatment of OVCFs, particularly in elderly patients who may benefit from less invasive procedures.

Data Availability Statement

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

Ethical Approval Statement

Ethical approval was obtained from the Istanbul Medipol University ethical board.

Authors' Contribution

E.U., H.S.C., E.H., and M.A. conceived the study. E.U., H.S.C., N.K., and M.A. developed the methodology. H.S.C., M.E.G., and M.A. performed formal analysis and investigation. E.U., E.H., and H.D. prepared the original draft of the manuscript. E.U., H.S.C., and N.K. reviewed and edited the manuscript.

Conflict of Interest

None declared.

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