Joint Diseases and Related Surgery

Jt Dis Relat Surg
2026;37(2):381-389

ORIGINAL ARTICLE

Manual reduction combined with percutaneous vertebroplasty versus percutaneous kyphoplasty for the treatment of osteoporotic vertebral compression fractures

Dong-zhe Li, MD[1], Yu He, MD[1], Zhao-kui Yan, MD[2], Tai-ping Wang, MD[1], Yong Zeng, MD[1]

[1]Department of Orthopedics Surgery, West China School of Medicine, Sichuan University, Sichuan University affiliated Chengdu Second People's Hospital, Chengdu Second People's Hospital, Chengdu, China

[2]Department of Orthopaedics, West China School of Public Health and West China Fourth Hospital, Sichuan University, Chengdu, China

Osteoporotic vertebral compression fractures (OVCFs) represent the most prevalent type of fragility fracture encountered in clinical practice and are and are one of the major clinical consequences of osteoporosis.[1] These fractures can lead to severe back pain and spinal deformity, significantly impairing patients' quality of life and posing a growing challenge to global healthcare systems.[2] In the United States alone, approximately 700,000 new cases of OVCFs are reported annually. The combined economic burden attributed to OVCFs and hip fractures is estimated to range between $10 billion and $15 billion each year, highlighting the substantial financial impact of these conditions.[3,4]

For patients with acute thoracolumbar OVCFs, percutaneous vertebroplasty (PVP) is a safe and

Received: September 21, 2025
Accepted: October 22, 2025
Published online: March 16, 2026

Correspondence: Yong Zeng, MD. Department of Orthopaedics, West China School of Public Health and West China Fourth Hospital, Sichuan University, Chengdu, China.

E-mail: 176143225@qq.com

Citation: Li DZ, He Y, Yan ZK, Wang TP, Zeng Y. Manual reduction combined with percutaneous vertebroplasty versus percutaneous kyphoplasty for the treatment of osteoporotic vertebral compression fractures. Jt Dis Relat Surg 2026;37(2):381-389. doi: 10.52312/jdrs.2026.2652.

© 2026 Joint Diseases and Related Surgery. This is an open access article published under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0), which permits non-commercial use, distribution, reproduction, and adaptation in any medium, provided the original work is properly cited. http://creativecommons.org/licenses/by-nc/4.0/

ABSTRACT

Objectives: This study aims to compare manual reduction combined with percutaneous vertebroplasty (PVP) versus percutaneous kyphoplasty (PKP) for the treatment of fresh (≤ 3 weeks post-injury), single-segment osteoporotic vertebral compression fractures (OVCFs).

Patients and methods: Between January 2021 and January 2024, a total of 136 patients (46 males, 90 females; mean age: 76.8 ± 8.4 years; range, 60 to 94 years) with thoracolumbar OVCFs who underwent vertebral augmentation were retrospectively analyzed. The patients were assigned to either Group 1 (manual reduction + PVP, n = 60) or Group 2 (PKP alone, n = 76). Operative time, fluoroscopy frequency, cement volume, cement leakage, cement distribution, anterior vertebral height (AVH), kyphotic Cobb angle, and Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) scores were compared.

Results: Compared to Group 2, Group 1 showed significantly shorter operative time (29.2 ± 5.1 min *vs*. 32.4 ± 8.2 min, $p < 0.05$), fewer intraoperative fluoroscopy scans (18.9 ± 1.7 *vs*. 21.9 ± 3.0, $p < 0.05$), greater cement volume (4.9 ± 0.8 mL *vs*. 4.0 ± 0.7 mL, $p < 0.05$), and a higher proportion of favorable cement distribution (80.0% *vs*. 56.6%, $p < 0.05$). Cement leakage rates were comparable (21.7% *vs*. 18.4%, $p > 0.05$). Although preoperative parameters were similar between the groups, Group 1 achieved significantly better postoperative AVH (23.1 ± 2.2 mm *vs*. 20.4 ± 2.6 mm, $p < 0.05$), kyphotic Cobb angle (8.5 ± 1.9° *vs*. 10.6 ± 1.9°, $p < 0.05$), and ODI scores (19.0 [18.0, 21.0] *vs*. 21.0 [19.0, 23.0], $p = 0.001$) compared to Group 2. Postoperative VAS scores showed no significant difference between the groups (2.0 [2.0, 3.0] *vs*. 2.0 [2.0, 3.0], $p = 0.354$). Both groups exhibited significant postoperative improvements in all clinical outcomes ($p < 0.05$).

Conclusion: Although both techniques effectively relieve pain and correct deformity, manual reduction combined with PVP offers more favorable radiographic restoration, improved functional outcomes, shorter operation time, and less radiation exposure compared to PKP.

Keywords: Kyphoplasty, manual reduction, osteoporotic vertebral compression fractures, percutaneous vertebroplasty.

effective intervention which provides rapid pain relief and markedly improves quality of life and survival rates.[4] This procedure involves the injection of specialized bone cement, typically polymethylmethacrylate (PMMA), into the fractured vertebra through a small skin incision.[5] The cement fills the intravertebral space, enhancing stability and mechanical strength, thereby alleviating pain and partially restoring vertebral height.[6] However, compared to percutaneous kyphoplasty (PKP), standard PVP is less effective in restoring vertebral body height and correcting kyphotic deformity.[7] Although PKP offers more favorable fracture reduction and height restoration, it often results in a clumped distribution of bone cement within the vertebral body, rather than a diffuse interdigitation throughout the trabecular bone. This localized cement pattern may compromise the durability of pain relief and elevate the risk of subsequent fractures in adjacent vertebrae.[8,9] Although bilateral PKP results in more favorable bone cement distribution and superior long-term outcomes,[10] it entails a longer operative duration, increased radiation exposure, as well as higher risks of bone cement introduction and leakage compared to the unilateral approach.[11]

Manual reduction, a technique with established roots in traditional fracture management, employs controlled external forces to restore anatomical alignment. Its principle involves reversing the traumatic mechanism. In the context of OVCFs, this technique aims to passively stretch the relaxed anterior longitudinal ligament by applying sustained ventral pressure, thereby facilitating vertebral height restoration and kyphosis correction. The historical application of closed reduction techniques for spinal fractures provides a foundational rationale for its use.[12] Recent clinical studies have investigated its combination with vertebral augmentation, reporting promising outcomes in terms of height restoration and sagittal alignment correction.[13]

Based on the above considerations and the emerging supportive evidence, we postulate that combining PVP with manual reduction may offer rapid pain alleviation for OVCF patients, effectively restore vertebral height, and present a relatively favorable cost-effectiveness profile. Moreover, robust comparative studies specifically evaluating manual reduction combined with PVP versus PKP alone in the treatment of OVCFs remain scarce. In the present study, we, therefore, aimed to evaluate the efficacy of manual reduction combined with PVP versus PKP alone for OVCFs and to provide a basis for clinical decision-making in this patient population.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Sichuan University Affiliated Chengdu Second People's Hospital, Department of Orthopedics Surgery between January 2021 and January 2024. A total of 191 patients with thoracolumbar OVCFs who underwent vertebral augmentation were initially assessed for eligibility. Inclusion criteria were as follows: (1) acute single-segment thoracolumbar OVCFs; (2) vertebral body compression degree < 50%; (3) bone mineral density (BMD) T-score < –2.5; (4) preoperative imaging confirming integrity of the posterior vertebral wall and pedicles; and (5) unilateral surgical approach. Exclusion criteria were as follows: (1) severe underlying medical conditions rendering patients unfit for surgery, such as significant cardiac, pulmonary, hepatic, or renal dysfunction; (2) severe systemic infectious disease or local infection at the surgical site; (3) coagulation abnormalities or severe bleeding tendency; (4) presence of nerve root or spinal cord compression symptoms requiring open decompression surgery; (5) fractures due to old injuries, tuberculosis, or tumors; and (6) concomitant fractures in other locations. After screening, 136 eligible patients (46 males, 90 females; mean age: 76.8 ± 8.4 years; range, 60 to 94 years) were enrolled. Study flowchart is shown in Figure 1. A written informed consent was obtained from each patient. The study protocol was approved by the Chengdu Second People's Hospital Institutional Review Board (Date: 13.08.2020, No: AF-SOP-18-01/02.0). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Surgical process

All procedures were performed under local anesthesia by two experienced surgeons from the same team. The patients were assigned to either Group 1 (manual reduction + PVP, n = 60) or Group 2 (PKP alone, n = 76). In Group 1, patients were positioned prone. Under fluoroscopy, manual reduction was performed: one assistant provided axillary counter-traction while another applied ankle traction for 4 min. The surgeon applied slow, controlled, and sustained ventral pressure over the fractured vertebra's spinous process to restore height and correct kyphosis. This maneuver emphasized a gradual axial force to avoid high-velocity or impulsive thrusts, considering the osteoporotic bone quality. Reduction adequacy

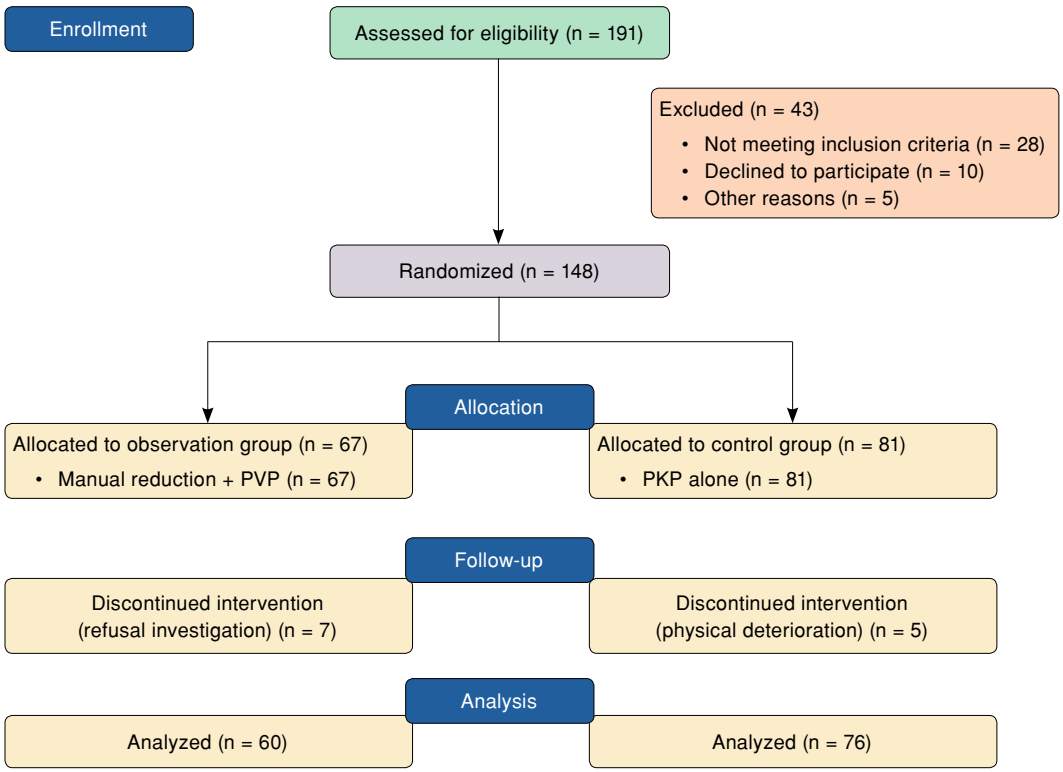


FIGURE 1. Study flowchart.
PVP, percutaneous vertebroplasty; PKP, percutaneous kyphoplasty.

was confirmed fluoroscopically. Subsequently, standard unilateral PVP was performed via a transpedicular approach. Bone cement was injected under fluoroscopy, until it approached within ~5 mm of the posterior wall (Figure 2). To ensure consistency and reproducibility of the manual reduction technique across all patients in Group 1, a standardized protocol was rigorously followed. The procedure was performed with the patient in a consistent prone position. The roles of the two assistants (providing counter-traction at the axillae and ankles) and the surgeon (applying ventral pressure) were fixed. The application of sustained ventral pressure was specifically centered on the spinous process of the fractured vertebra under fluoroscopic guidance. The duration of the initial traction and reduction phase was maintained for approximately four minutes for all cases. The conscious state of patients under local anesthesia served as an additional safety check, enabling immediate reporting of any discomfort, which did not occur. The endpoint of the reduction was objectively defined as the fluoroscopic confirmation of satisfactory restoration of vertebral height and reduction of the kyphotic angle. While the magnitude of the applied force was adjusted qualitatively by the surgeon based on patient-specific factors such as body habitus and anticipated bone quality, the fundamental steps of the maneuver were uniformly applied.

In Group 2, patient positioning and approach were identical. After cannula placement, a balloon tamp was inserted, inflated under fluoroscopy to reduce the fracture, then removed. High-viscosity bone cement was injected into the created cavity.

Postoperatively, all patients were closely monitored for vital signs within 24 h. Ambulation under brace protection was initiated after 24 h to avoid excessive spinal motion. Conventional anti-osteoporosis medication was administered to all patients.

Outcome measures

Recorded parameters were as follows: operative time, fluoroscopy frequency, cement volume, cement leakage, cement distribution, anterior vertebral height (AVH), kyphotic Cobb angle, and Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) scores.

Radiographic assessments

The AVH and kyphotic Cobb angle were measured on standardized standing lateral radiographs by two

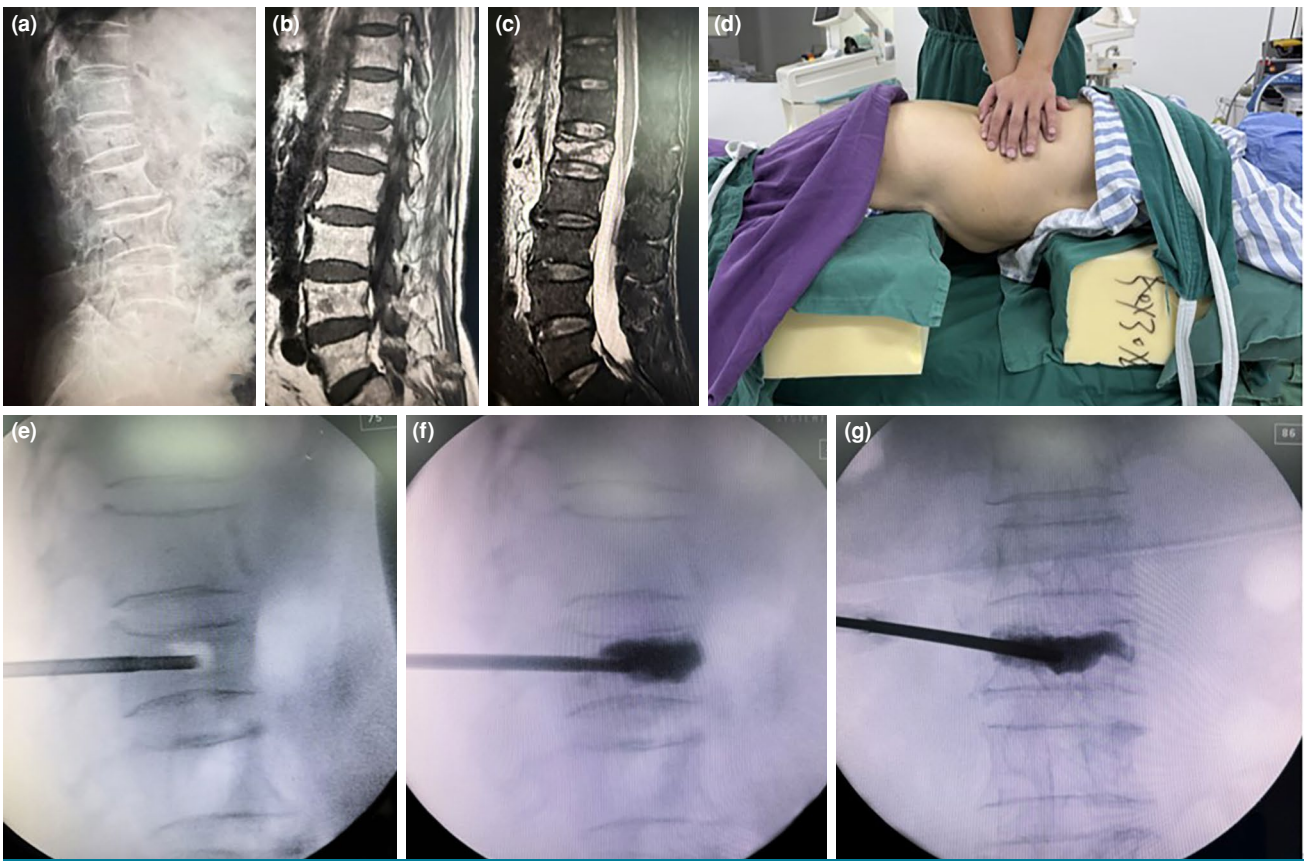


FIGURE 2. Illustrative case of an L1 OVCF treated with manual reduction combined with PVP. **(a)** Preoperative lateral radiograph showing an L1 vertebral compression fracture with mild local kyphotic deformity; **(b, c)** Preoperative MRI in sagittal view demonstrates a high-intensity edema signal within the L1 vertebral body on T2-weighted and STIR sequences, confirming an acute fracture; The supine position unloads the spine, often leading to a partial spontaneous restoration of vertebral height compared to the standing radiograph in **(a)**; **(d)** Intraoperative photograph depicting the manual reduction technique; **(e)** Intraoperative lateral C-arm fluoroscopic image obtained after application of the manual reduction maneuver with the patient in the prone position. The vertebral height restoration shown here represents the combined effect of postural correction (from standing to prone) and the subsequent active manual reduction; **(f, g)** Postoperative anteroposterior and **(f)** lateral **(g)** radiographs showing the final result. The bone cement exhibits optimal filling of the vertebral body without evidence of leakage. Notably, the cement demonstrates a bilateral and symmetrical distribution pattern within the vertebra on the AP view, corresponding to a favorable distribution grade.

OVCF, osteoporotic vertebral compression fractures; PVP, percutaneous vertebroplasty; MRI, magnetic resonance imaging; STIR, Short Tau Inversion Recovery.

blinded spinal surgeons. The AVH restoration ratio was calculated as (postoperative AVH/estimated normal AVH) × 100%. The kyphotic Cobb angle was measured between the endplates of the vertebrae adjacent to the fracture.

Functional assessments

The VAS (0-10) and the Chinese version of ODI were assessed preoperatively and at follow-ups by staff not involved in surgery. The ODI score, one of the gold-standard tools for evaluating spinal treatment outcomes, exhibits an inverse relationship with functional disability levels.[14]

Reliability assessment

To ensure measurement consistency and minimize observer bias, inter-observer reliability was assessed for all radiographic measurements. The two independent evaluators repeated all measurements after a two-week interval. The intraclass correlation coefficient (ICC) was calculated for both intra-observer and inter-observer reliability. The ICC values for all radiographic measurements exceeded 0.85, indicating excellent reliability. Any discrepancies greater than 5% in AVH measurements or 3° in Cobb angle measurements were re-evaluated jointly to reach a consensus.

Cement distribution assessment

Cement distribution on postoperative AP radiographs was graded using a validated four-point scale (Grades 1/4).[15] Grades 1/2 were considered "favorable," Grades 3/4 "unfavorable." Cement leakage was detected intraoperatively and on postoperative radiographs, categorized by location.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 26.0 software (IBM Corp., Armonk, NY, USA). Continuous data were presented in mean ± standard deviation (SD) or median (min-max), while categorical data were presented in number and frequency. Intergroup comparisons were conducted using independent samples t-tests, while intragroup comparisons utilized paired samples t-tests. Categorical data were compared using the chi-square tests or Fisher exact probability test as appropriate. Ordinal data were analyzed using non-parametric rank-sum tests. A two-tailed p value of <0.05 was considered statistically significant.

RESULTS

In the whole cohort, the most common comorbidity was diabetes mellitus. The mean time from injury to surgery was 3.8 ± 1.6 days. The majority of fractures (69/136) were located in the thoracic spine. The most frequent mechanism of injury was ground-level falls. No significant differences were observed in the baseline characteristics between the two groups (Table I).

The mean follow-up was 17.2 ± 3.7 (range, 12 to 24) months. Group 1 demonstrated a significantly shorter operative time (29.2 ± 5.1 min *vs.* 32.4 ± 8.2 min, $p < 0.05$) and required fewer intraoperative fluoroscopy scans (18.9 ± 1.7 *vs.* 21.9 ± 3.0, $p < 0.05$), compared to Group 2. The volume of bone cement used was greater in Group 2 (4.9 ± 0.8 mL *vs.* 4.0 ± 0.7 mL, $p < 0.05$). Furthermore, the quality of cement distribution within the vertebral body was greater in Group 1 (e.g., Grade 1/2: 80.0% *vs.* 56.6%, $p < 0.05$). However, the rate of cement leakage was comparable between the two groups (Group 1: 21.7% *vs.* Group 2: 18.4%, $p > 0.05$). The mean follow-up was comparable between Group 1

TABLE I
Baseline demographic and clinical characteristics of Group 1 and Group 2

	Group 1		Group 2			
Variable	n	Mean ± SD	n	Mean ± SD	χ^2/t	p
Age (years)		75.8 ± 8.1		77.6 ± 8.7	–1.237	0.218
Sex					2.951	0.086
Male	25		21			
Female	35		55			
BMI (kg/m^2)		21.3 ± 1.7		21.7 ± 2.2	–1.059	0.291
Comorbidity					0.032	0.858
Hypertension	8		5			
Diabetes mellitus	19		22			
CHD	6		5			
Fracture segment					0.037	0.847
Thoracic vertebrae (T9/10/11/12)	31 (3/8/10/10)		38 (5/10/12/11)			
Lumbar vertebra (L1/2/3/4/5)	29 (15/8/4/1/1)		38 (18/12/5/2/1)			
Time from injury to surgery (days)		3.80 ± 1.59		3.78 ± 1.6	0.087	0.931
Cause of the injury					0.526	0.769
Falling on level ground	30		39			
Lifting heavy objects	18		19			
Others	12		18			
Total	60		76			

SD, standard deviation; BMI, body mass index; CHD, coronary heart disease. Between-group comparisons were performed using independent samples t-tests for continuous variables and chi-square tests for categorical variables. No statistically significant differences were observed in any baseline characteristic, indicating that the groups were well-matched for comparison (all $p > 0.05$).

TABLE II
Comparison of perioperative outcomes between Group 1 and Group 2

	Group 1		Group 2			
Variables	n	Mean ± SD	n	Mean ± SD	χ^2/t	*p*
Surgical time (min)		29.2 ± 5.1		32.4 ± 8.2	–2.624	0.010
Number of intraoperative fluoroscopy		18.9 ± 1.7		21.9 ± 3.0	–6.861	< 0.001
Amount of cement injected (mL)		4.9 ± 0.8		4.0 ± 0.7	6.774	< 0.001
Cement leakage						
Yes	13		14			
No	47		62			
Cement distribution pattern						
I	25		25			
II	23		18			
III	10		22			
IV	2		11			
Adjacent-level fracture	10		17		0.685	0.408
Length of stay (days)		5.5 ± 1.6		5.6 ± 1.6	–0.444	0.658
Follow-up time (months)		17.3 ± 3.5		17.1 ± 3.9	0.238	0.812
Total	60		76			

SD, standard deviation. Data were presented as mean ± standard deviation or number of patients (n). *P*-values were derived from independent samples t-tests for continuous variables and chi-square tests (or Fisher's exact test) for categorical variables. Statistically significant between-group differences ($p < 0.05$) were highlighted in bold. The cement distribution pattern was graded on a four-point scale (1-4), where Grades 1 and 2 represent favorable distribution. The incidence of adjacent-level fractures was assessed during a mean follow-up of 17.2 months. Among the new adjacent-level fractures, the majority in both groups occurred at vertebrae contiguous to the treated level (Group 1: 8/10, 80.0%; Group 2: 14/17, 82.4%). The remainder were non-contiguous fractures. The distribution pattern (contiguous vs. non-contiguous) did not differ significantly between the groups ($p > 0.05$).

(17.3 ± 3.5 months) and Group 2 (17.1 ± 3.9 months) ($p = 0.812$) (Table II).

During the follow-up period, the incidence of new adjacent-level vertebral compression fractures was assessed via radiographic evaluation. A total of 27 new adjacent-level fractures were identified. The incidence was 16.7% (10/60) in Group 1 and 22.4% (17/76) in Group 2, indicating no statistically significant difference between the two groups ($p > 0.05$) (Table II). Furthermore, serial radiographic measurements performed at the final follow-up visit demonstrated no significant loss of the initially achieved vertebral height correction (as measured by AVH) or recurrence of kyphotic deformity (as measured by Cobb angle) in either group compared to the immediate postoperative values. Critically, no complications directly attributable to the manual reduction maneuver, such as iatrogenic fractures or neurological damage, were

TABLE III
Radiographic outcomes: Comparison of AVH and kyphotic Cobb angle before and after surgery

		AVH (mm)				Kyphotic Cobb angle			
	Cases	Preoperative	Postoperative			Preoperative	Postoperative		
	n	Mean ± SD	Mean ± SD	t	*p*	Mean ± SD	Mean ± SD	t	*p*
Group 1	60	17.0 ± 2.4	23.1 ± 2.2	–85.345	< 0.001	16.5 ± 2.1	8.5 ± 1.9	20.731	< 0.001
Group 2	76	17.1 ± 2.5	20.4 ± 2.6	–34.015	< 0.001	16.6 ± 2.1	10.6 ± 1.9	24.823	< 0.001
t		–0.381	6.485			–0.447	–6.498		
p		0.704	< 0.001			0.655	< 0.001		

AVH, anterior vertebral height; SD, standard deviation; Intragroup comparisons (preoperative *vs.* postoperative) were performed using paired samples t-tests, with all changes being statistically significant ($p < 0.001$). Intergroup comparisons at each time point were performed using independent samples t-tests.

observed intraoperatively or during the immediate postoperative period in Group 1. Furthermore, no other major complications, such as symptomatic cement embolism or new neurological deficits, were recorded in either group throughout the study.

Compared to preoperative values, both groups showed significant improvements in postoperative AVH and kyphotic Cobb angle ($p < 0.05$ for all). Preoperatively, there were no significant differences in AVH or Cobb angle between the two groups ($p > 0.05$ for all). However, at the postoperative assessment, Group 1 exhibited significantly better outcomes in both AVH (restored to 23.1 ± 2.2 mm *vs.* 20.4 ± 2.6 mm in Group 2, $p < 0.05$) and Cobb angle (corrected to [8.5 ± 1.9°] *vs.* [10.6 ± 1.9°], $p < 0.05$) compared to Group 2 (Table III).

Significant improvements in VAS and ODI scores were observed postoperatively within each group compared to their respective preoperative scores ($p < 0.001$ for all). No significant intergroup differences were found in the preoperative VAS and ODI scores ($p > 0.05$ for all). At the final follow-up, the difference in postoperative VAS scores between the groups was not statistically significant (Group 1: 2.0 [2.0, 3.0] *vs.* Group 2: 2.0 [2.0, 3.0], $p = 0.354$). In contrast, Group 1 achieved significantly lower postoperative ODI scores than Group 2 (Group 1: 19.0 [18.0, 21.0] *vs.* Group 2: 21.0 [19.0, 23.0], $p = 0.001$) (Table IV).

DISCUSSION

In the present study, we evaluated the efficacy of manual reduction combined with PVP versus PKP alone for OVCFs. Our study results demonstrated that the operative time and the number of intraoperative fluoroscopies in Group 1 were significantly lower than those in Group 2. This finding aligns with the inherent procedural simplicity of PVP compared to PKP, as PKP involves additional steps such as balloon insertion, inflation, and deflation. Our results are consistent with previous studies reporting longer operative times and higher radiation exposure for PKP.[11] This efficiency in the combined technique is attributed to omitting these cumbersome steps associated with balloon application, substantially saving procedural time, and avoiding additional iatrogenic radiation exposure to the patient from excessive fluoroscopy.

Previous studies and meta-analyses have indicated that standard PVP carries a higher risk of bone cement leakage compared to PKP.[7,16] However,

TABLE IV
Clinical outcomes: Comparison of VAS pain scores and ODI scores before and after surgery

	Cases	VAS scores					ODI scores				
		Preoperative		Postoperative			Preoperative		Postoperative		
	n	Median	IQR	Median	IQR	*p*	Median	IQR	Median	IQR	*p*
Group 1	60	7.0	6.0-8.0	2.0	2.0-3.0	< 0.001	40.0	39.0-42.0	19.0	18.0-21.0	< 0.001
Group 2	76	7.0	6.0-8.0	2.0	2.0-3.0	< 0.001	40.0	38.0-41.0	21.0	19.0-23.0	< 0.001
Between-group p-value (Mann-Whitney U)		0.451		0.354 (U = 2165.0)			0.380		0.001 (U = 1554.5)		

VAS, Visual Analog Scale; ODI, Oswestry Disability Index. IQR, interquartile range. VAS scores range from 0 (no pain) to 10 (worst imaginable pain). ODI scores are expressed as a percentage (0% to 100%), with higher scores indicating greater disability. Within-group comparisons were performed using Wilcoxon signed-rank test. Between-group comparisons were performed using Mann-Whitney U test.

our findings showed no significant difference in the incidence of cement leakage between the two groups. This can be explained by two factors: firstly, the void created anteriorly in the vertebral body after manipulative reduction may reduce resistance during cement injection, potentially lowering the risk of leakage; secondly, the use of high-viscosity, paste-like bone cement, as employed in our study, is characterized by its high cohesion and inherently lower leakage rate.[17] This suggests that, with proper technique and cement selection, the risk of leakage associated with PVP can be reduced to levels comparable to those observed with PKP.

Furthermore, the volume of bone cement used in Group 1 was significantly higher, and its distribution within the vertebra was significantly greater to that in Group 2, without a statistically significant increase in leakage rates ($p > 0.05$). This indicates that manipulative reduction combined with PVP is not only safe and feasible but also allows for increased cement volume and improved bilateral cement distribution without significantly elevating the risk of leakage. The more diffuse, interdigitating cement distribution observed in our study, similar to the favorable patterns (Grades 1/2) defined by Chu et al.,[15] is crucial. This pattern may create a more gradual transition in stiffness between the treated and adjacent vertebrae, potentially mitigating stress concentration at the endplates; i.e., a hypothesized mechanism for adjacent segment fractures.[8] This is supported by our follow-up data, which showed a comparable incidence of new adjacent-level fractures between the two groups, despite the larger cement volume and better distribution in Group 1. This finding is clinically significant, as the risk of subsequent adjacent fractures is a major concern following vertebral augmentation. Our results contrast with some concerns that better filling might increase adjacent fracture risk, suggesting that the pattern of distribution (diffuse *vs.* clumped) might be more critical than the volume alone.[9]

The manual reduction maneuver was found to be safe in our cohort, with no instances of iatrogenic fracture or neurological compromise. We believe that this safety is attributable to the technique's principle of applying a controlled, sustained, and axial force to reverse the flexion-compression mechanism of the injury, rather than utilizing high-velocity or impulsive thrusts. The procedure was performed under fluoroscopic guidance, allowing for real-time monitoring of spinal alignment during reduction. Furthermore, the conscious state of patients under local anesthesia provided an additional safety check, as they could immediately report any onset of radicular pain or neurological symptoms, which did not occur in any case.

Regarding radiographic and functional outcomes, both groups showed significant postoperative improvements, confirming the established efficacy of vertebral augmentation.[5,7] More intriguingly, Group 1 achieved more favorable restoration of AVH and correction of the kyphotic Cobb angle compared to Group 2. This indicates that the combined approach effectively addresses the limitation of PVP alone in restoring vertebral height and sagittal alignment, achieving corrective effects comparable to or exceeding those typically associated with PKP.[7] The enhanced radiographic correction likely contributed to the significantly better postoperative ODI score in Group 1, underscoring that functional improvement extends beyond pain relief (which was equivalent between the groups). These findings are consistent with a recent systematic review[13] reporting comparable or superior radiographic outcomes for PVP combined with postural reduction versus PKP.

Nonetheless, this study has several limitations that should be acknowledged. First, as a single-center, retrospective study, the relatively small sample size may have affected statistical power and generalizability of the results. Second, the non-randomized assignment of patients to groups may have introduced selection bias, although baseline characteristics were comparable. Third, the manual reduction technique, although performed according to a standardized protocol, inherently involves a qualitative component. The magnitude of the applied force was adjusted based on the surgeon's experience and perception of patient factors such as body habitus and bone quality, rather than being quantitatively measured against parameters such as weight, height, or age. The lack of objective, quantitative metrics for force application is a limitation, and future studies employing force sensors or other measurement devices could further standardize and optimize this technique. Further multi-center, large-scale prospective, randomized-controlled studies are warranted to confirm our findings and establish standardized protocols for manual reduction techniques.

In conclusion, both manipulative reduction combined with PVP and PKP alone are effective in alleviating pain, reducing the fractured vertebra, and correcting kyphotic deformity in patients with OVCFs. However, the integration of manipulative

reduction with PVP enhances these benefits, leading to more significant improvements in vertebral height restoration, kyphosis correction, and functional outcome. Additionally, the combined approach is associated with a shorter operative time, reduced reliance on intraoperative C-arm fluoroscopy, and achieves more favorable cement distribution without increasing the risk of cement leakage or adjacent segment fractures compared to PKP. Further studies are needed to validate these findings and refine patient selection and procedural strategies.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: D.Z.L., Z.K.Y., T.P.W.: Conception and design; D.Z.L., Y.H.: Collection and assembly of data; D.Z.L.: Analysis and interpretation of the data, drafting of the article; Y.H.: Statistical expertise; Y.Z.: Critical revision of the article for important intellectual content. All authors read and approved the final manuscript.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding: The authors received no financial support for the research and/or authorship of this article.

AI Disclosure: The authors declare that artificial intelligence (AI) tools were not used, or were used solely for language editing, and had no role in data analysis, interpretation, or the formulation of conclusions. All scientific content, data interpretation, and conclusions are the sole responsibility of the authors. The authors further confirm that AI tools were not used to generate, fabricate, or 'hallucinate' references, and that all references have been carefully verified for accuracy.

REFERENCES

1. Zhang T, Peng Y, Li J. Comparison of clinical and radiological outcomes of vertebral body stenting versus percutaneous kyphoplasty for the treatment of osteoporotic vertebral compression fracture: A systematic review and meta-analysis. Jt Dis Relat Surg 2024;35:218-30. doi: 10.52312/jdrs.2023.1356.
2. Dai C, Liang G, Zhang Y, Dong Y, Zhou X. Risk factors of vertebral re-fracture after PVP or PKP for osteoporotic vertebral compression fractures, especially in Eastern Asia: A systematic review and meta-analysis. J Orthop Surg Res 2022;17:161. doi: 10.1186/s13018-022-03038-z.
3. Al Taha K, Lauper N, Bauer DE, Tsoupras A, Tessitore E, Biver E, et al. Multidisciplinary and coordinated management of osteoporotic vertebral compression fractures: Current state of the art. J Clin Med 2024;13:930. doi: 10.3390/jcm13040930.
4. Beall DP, Phillips TR. Vertebral augmentation: An overview. Skeletal Radiol 2023;52:1911-20. doi: 10.1007/s00256-022-04092-8.
5. Buchbinder R, Johnston RV, Rischin KJ, Homik J, Jones CA, Golmohammadi K, et al. Percutaneous vertebroplasty for osteoporotic vertebral compression fracture. Cochrane Database Syst Rev 2018;4:CD006349. doi: 10.1002/14651858.CD006349.pub3.
6. Yang H, Liu H, Wang S, Wu K, Meng B, Liu T. Review of percutaneous kyphoplasty in China. Spine (Phila Pa 1976) 2016;41:B52-8. doi: 10.1097/BRS.0000000000001804.
7. Cai D, Zhang B, Li J, Wang P, Tao X. Clinical effect of percutaneous kyphoplasty and percutaneous vertebroplasty in managing osteoporotic vertebral compression fractures: A single-center propensity score-matched study. Ann Ital Chir 2024;95:848-58. doi: 10.62713/aic.3634.
8. Lv B, Ji P, Fan X, Yuan J, Xu T, Yao X, et al. Clinical efficacy of different bone cement distribution patterns in percutaneous kyphoplasty: A retrospective study. Pain Physician 2020;23:E409-16.
9. Yang K, Zhu X, Sun X, Shi H, Sun L, Ding H. Bone cement distribution patterns in vertebral augmentation for osteoporotic vertebral compression fractures: A systematic review. J Orthop Surg Res 2025;20:568. doi: 10.1186/s13018-025-05868-z.
10. Yang R, Huang Z, Shao S, Liu J, Xia S, Li W, et al. Comparison of unilateral and bilateral robot-assisted percutaneous kyphoplasty in treating osteoporotic vertebral compression fracture. World Neurosurg 2025;197:123911. doi: 10.1016/j.wneu.2025.123911.
11. Sun H, Li C. Comparison of unilateral and bilateral percutaneous vertebroplasty for osteoporotic vertebral compression fractures: A systematic review and meta-analysis. J Orthop Surg Res 2016;11:156. doi: 10.1186/s13018-016-0479-6.
12. Bakhsheshian J, Dahdaleh NS, Fakurnejad S, Scheer JK, Smith ZA. Evidence-based management of traumatic thoracolumbar burst fractures: A systematic review of nonoperative management. Neurosurg Focus 2014;37:E1. doi: 10.3171/2014.4.FOCUS14159.
13. Zhao H, Ren K, Dong X, Liao B. The clinical efficacy of percutaneous vertebroplasty combined with postural reduction versus kyphoplasty: A systematic review and meta-analysis. J Back Musculoskelet Rehabil 2025;38:655-61. doi: 10.1177/10538127241296690.
14. Hambrecht J, Köhli P, Duculan R, Chiapparelli E, Lan R, Guven AE, et al. The disaggregated oswestry disability index: What is the most predictive subsection for patient satisfaction after lumbar surgery? Spine (Phila Pa 1976) 2025;50:E308-13. doi: 10.1097/BRS.0000000000005154.
15. Chu W, Tsuei YC, Liao PH, Lin JH, Chou WH, Chu WC, et al. Decompressed percutaneous vertebroplasty: A secured bone cement delivery procedure for vertebral augmentation in osteoporotic compression fractures. Injury 2013;44:813-8. doi: 10.1016/j.injury.2012.10.017.
16. Chang X, Lv YF, Chen B, Li HY, Han XB, Yang K, et al. Vertebroplasty versus kyphoplasty in osteoporotic vertebral compression fracture: A meta-analysis of prospective comparative studies. Int Orthop 2015;39:491-500. doi: 10.1007/s00264-014-2525-5.
17. Wang Q, Sun C, Zhang L, Wang L, Ji Q, Min N, et al. High- versus low-viscosity cement vertebroplasty and kyphoplasty for osteoporotic vertebral compression fracture: A meta-analysis. Eur Spine J 2022;31:1122-30. doi: 10.1007/s00586-022-07150-w.