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ORIGINAL ARTICLE

Unilateral extrapedicular versus unilateral and bilateral transpedicular approaches in percutaneous vertebral augmentation for osteoporotic vertebral compression fractures: A meta-analysis

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ABSTRACT

Objectives: The present meta-analysis aims to perform a comprehensive, evidence-based comparison of the effectiveness and safety of the unilateral extrapedicular approach (UEA) percutaneous vertebral augmentation and transpedicular approach percutaneous vertebral augmentation for osteoporotic vertebral compression fractures (OVCFs).

Materials and methods: Publications indexed up to May 2025 were interrogated across Cochrane Library, Web of Science, PubMed, Embase, and SpringerLink using the combined keywords "unilateral extrapedicular approach", "transpedicular approach", "percutaneous vertebral augmentation", "percutaneous vertebroplasty", "percutaneous kyphoplasty", and "osteoporotic vertebral compression fractures". Mean difference (MD) and risk difference (RD) served as summary metrics, each expressed with 95% confidence intervals (CIs).

Results: Eight clinical trials involving 830 patients were included. The UEA significantly shortened operative time (MD=–4.26; 95% CI:–6.15 ~ –2.37; p<0.00001), compared to unilateral transpedicular approach (UTA), while no statistically significant differences were observed in cement leakage (RD:–0.01; 95% CI:–0.09 ~ 0.07; p=0.88), cement injection volume (MD=0.20; 95% CI:–0.02 ~ 0.41; p=0.07), or intraoperative fluoroscopy times (MD=–1.15; 95% CI:–3.62 ~ 1.32; p=0.36). Notably, UEA demonstrated significant advantages over bilateral transpedicular approach (BPA) in reducing cement leakage rate (RD:–0.08; 95% CI:–0.14 ~ –0.02; p=0.01), decreasing cement injection volume (MD=–1.51; 95% CI:–2.98 ~ –0.04; p=0.04), shortening operative time (MD=–9.64; 95% CI:–13.25 ~ –6.04; p<0.00001), and minimizing intraoperative fluoroscopy times (MD=–8.12; 95% CI:–12.36 ~ –3.88; p=0.0002). However, no significant intergroup differences were found between UEA and BPA in postoperative Visual Analog Scale (VAS) (MD=–0.04; 95% CI:–0.24 ~ 0.17; p=0.73), postoperative Cobb angle (MD=–0.37; 95% CI:–0.54 ~ 1.28; p=0.42) or Oswestry Disability Index (ODI) (MD=–0.54; 95% CI:–2.81 ~ 1.72; p=0.64).

Conclusion: In the management of OVCFs, UEA offers shorter operative time compared with UTA. Additionally, UEA shows remarkable superiority over BPA in cement injection volume, cement leakage rate, intraoperative fluoroscopy frequency and operative time.

Keywords: Meta-analysis, osteoporotic vertebral compression fractures, percutaneous vertebral augmentation, transpedicular approach, unilateral extrapedicular approach.

Among all fragility fractures, osteoporotic vertebral compression fractures (OVCFs) are the most frequent fractures in routine practice. Lifetime probability of any osteoporotic fracture approximates 50% in women and 20% in men, with OVCFs accounting for the largest proportion and typically precipitated by trivial trauma. Beyond altering spinal alignment and precipitating kyphosis, OVCFs substantially compromise quality of life through combined detriment to physical performance and psychological well-being.[1,2]

The treatment of OVCFs is primarily categorized into conservative and surgical therapies. Patients with mild pain symptoms may be managed with conservative approaches such

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as bed rest, brace application, and symptomatic analgesia. However, surgical intervention is often indicated for patients with unrelieved pain after conservative treatment or those who are unsuitable for prolonged bed rest. Contemporary management of OVCFs centers on percutaneous vertebral augmentation (PVA), a category which includes both percutaneous kyphoplasty (PKP) and percutaneous vertebroplasty (PVP).[3] Conventionally, PVA procedures are performed via the bilateral pedicular approach (BPA), which offers the advantage of achieving more symmetrical cement filling, whereas many surgeons prefer the unilateral transpedicular approach (UTA) for its benefits of reduced radiation exposure, shorter operation time, and lower cement leakage rate.[4,5] Nevertheless, to achieve contralateral pedicle cement filling with UTA, surgeons need to increase the inward angle of the puncture needle, which significantly elevates the probability of needle penetration through the pedicle and invasion of the spinal canal, nerve roots and dura mater.[6] Therefore, an alternative safer and more effective puncture technique may be warranted. Unilateral extrapedicular approach (UEA), a surgical technique which the puncture needle and working channel bypass the pedicle, was initially used for treating thoracic compression fractures and has since been gradually extended to lumbar lesions.[7,8] The core advantage of this approach lies in the ability of the puncture needle to reach the vertebral midline with ease, which not only facilitates uniform diffusion of bone cement in the central vertebral region, but also significantly reduces the risk of complications associated with traditional pedicular puncture.[9]

In recent years, several studies have reported the unique advantages of UEA in the treatment of OVCFs.[10,11] A previous meta-analysis[12] showed that the modified unilateral approach, encompassing both extra- and transpedicular trajectories, conferred significantly shorter operative time, lower radiation dose, reduced cement volume, and decreased leakage rates compared to conventional BPA, without compromising Visual Analog Scale (VAS), Oswestry Disability Index (ODI), Cobb angle, or vertebral height recovery. However, that study did not separately contrast UEA with UTA or BPA, leaving their relative efficacy undetermined. Moreover, there remains controversy regarding whether UEA can successfully integrate the unilateral operational advantages of UTA while overcoming its anatomical limitations, further reducing the number of fluoroscopic procedures, effectively avoiding the bilateral trauma caused by BPA, and significantly shortening the operation duration. In this review, we, therefore, aimed to compare the clinical efficacy of UEA versus UTA or BPA in PVA for OVCFs, providing evidence-based and practical recommendations for clinicians.

MATERIALS AND METHODS

Search strategy

This meta-analysis adhered to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was registered at PROSPERO:CRD420251136873. A comprehensive search strategy was performed by combining the following Medical Subject Headings: "unilateral extrapedicular approach", "transpedicular approach", "percutaneous vertebral augmentation", "percutaneous vertebroplasty", "percutaneous kyphoplasty", and "osteoporotic vertebral compression fractures". These queries were applied to the title, abstract, or keyword fields within Web of Science, the Cochrane Library, Embase, PubMed and Springer databases. The search was conducted without limitations on publication date or study design, and the final update was completed in May 2025. After automated deduplication, two independent reviewers screened the titles and abstracts for relevance. Subsequently, the full texts of potentially eligible articles were assessed against predefined inclusion criteria. Finally, the reference lists of all retained studies were manually inspected to capture any additional pertinent publications. Ethical approval was unnecessary for this meta-analysis, as all data were sourced from pre-existing published studies. The study adhered to the ethical principles outlined in the Declaration of Helsinki.

Inclusion criteria

Further data extraction and quality assessment were conducted on the selected studies based on the following inclusion criteria: *(i)* the study population comprised individuals with OVCFs who received PVA; *(ii)* the investigation provided a direct comparison between the UEA and either the UTA or BPA; and iii) the reported endpoints encompassed cement leakage incidence, operative duration, injected cement volume (mL), fluoroscopy counts, ODI values, sagittal Cobb angle measurements and VAS. Two reviewers independently assessed conformity with these criteria; whenever consensus was lacking, identifiers were concealed and a third senior investigator rendered the final decision.

Exclusion criteria

We excluded articles that were: *(i)* redundancy-identical datasets already captured or publication type classified as narrative review, single-patient report, congress abstract, pooled synthesis, or bench study; *(i)* therapeutic regimens deviating from the predefined protocol or absence of a comparator arm; *(iii)* numerical data either erroneous, fragmentary, or presented in a format preventing reliable extraction; and *(iv)* endpoints bearing no relevance to the prespecified analytic variables.

Data extraction

Two independent researchers extracted data from the included articles. The extracted information and data included: publication year, study type, first author's name, sample size and intervention measures. Outcome indicators included: bone cement leakage, operation time, number of fluoroscopy times, bone cement injection volume (mL), VAS, ODI, and Cobb angle.

Quality assessment

The evidence quality of the included studies was evaluated by two independent researchers. For randomized-controlled trials (RCT), quality appraisal was performed following the Cochrane Handbook for Systematic Reviews of Interventions.[13] Regarding non-randomized controlled trials (non-RCT), the Methodological Index for Non-Randomized Studies (MINORS) was applied for quality assessment.[14]

Statistical analysis

Statistical analysis was performed using the RevMan version 5.4 software (The Cochrane Collaboration, London, UK). Continuous endpoints were summarized via mean difference (MD), whereas risk difference (RD) was adopted for binary outcomes; both metrics were accompanied by 95% confidence intervals (95% CIs). Between-study inconsistency was appraised with the I^2 statistic and the p value. If I^2 remained below 50% and p value exceeded 0.10, homogeneity was assumed and a fixed-effect model was employed; otherwise, heterogeneity was judged substantial and a random-effects model was implemented.

RESULTS

Search results

A total of 836 potentially relevant studies were initially retrieved, with no additional studies

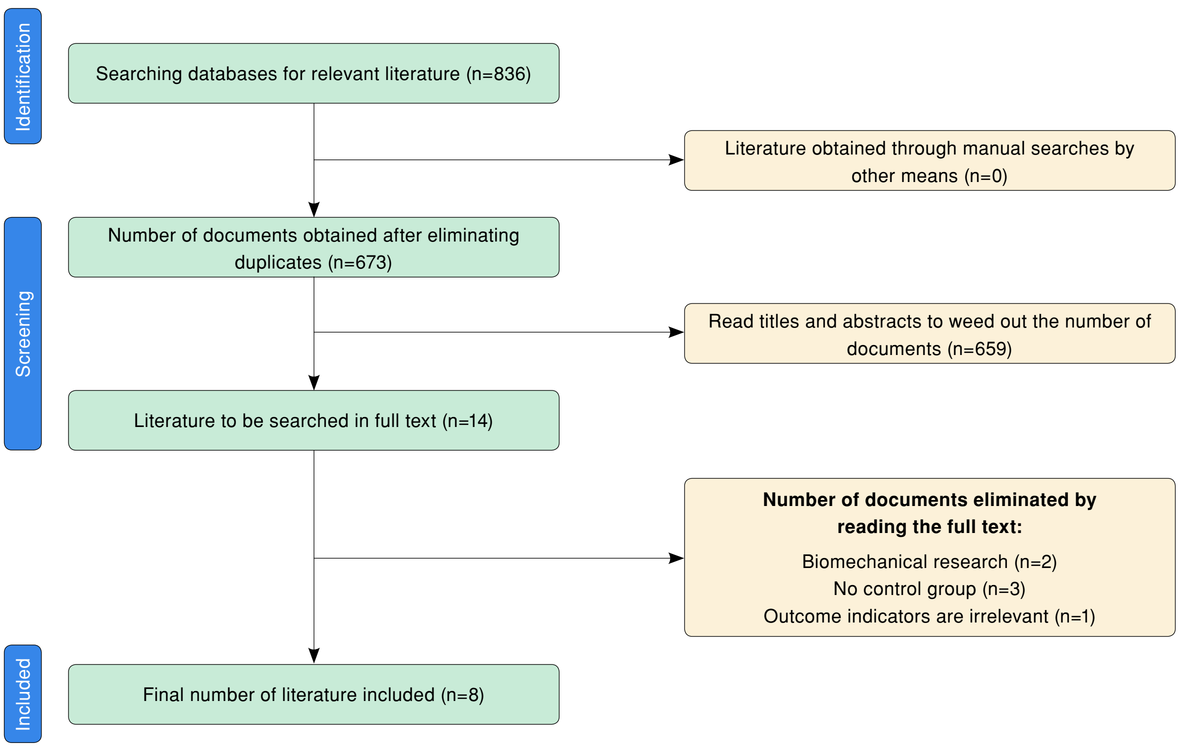

FIGURE 1. Flowchart of the study selection process.

TABLE I
Quality assessment for non-randomized trials

Quality assessment for non-randomized trials	Tang et al.[15] 2025	Zheng et al.[16] 2025	He et al.[17] 2022	Wang et al.[18] 2012	Xu et al.[19] 2024	Zhao et al.[20] 2025	Zhu et al.[21] 2022
A clearly stated aim	2	2	2	2	2	2	2
Inclusion of consecutive patients	2	2	2	2	2	2	2
Prospective data collection	0	0	0	0	0	0	0
Endpoints appropriate to the aim of the study	2	2	2	2	2	2	2
Unbiased assessment of the study endpoint	2	2	2	2	2	2	2
A follow-up period appropriate to the aims of study	2	2	2	2	2	2	2
Less than 5% loss to follow-up	1	2	1	1	2	1	2
Prospective calculation of the sample size	0	1	0	0	0	0	0
An adequate control group	2	2	2	2	2	2	2
Contemporary groups	2	2	2	2	2	2	1
Baseline equivalence of groups	2	2	2	2	2	2	2
Adequate statistical analyses	2	2	2	1	2	1	2
Total score	19	21	19	18	20	18	19

identified from other sources. Endnote software successfully identified and excluded 163 duplicate studies. Titles and abstracts were then comprehensively screened, leading to the exclusion of 659 studies. Finally, eight articles were included after full-text review.[15-22] The retrieval process is illustrated in Figure 1.

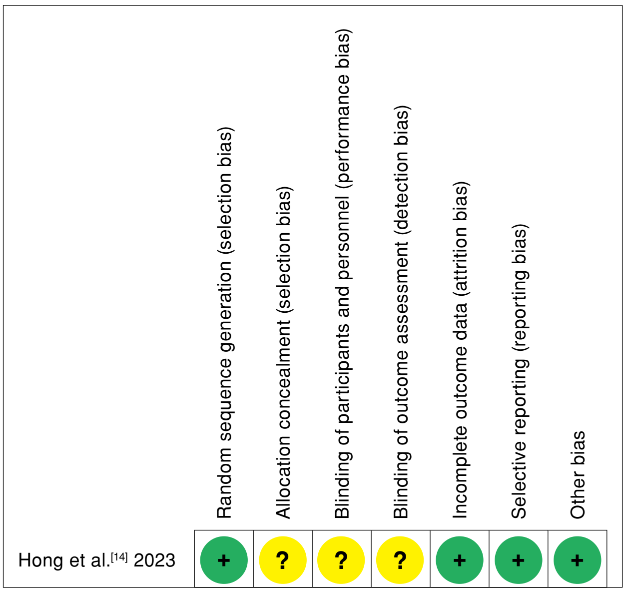

FIGURE 2. The summary of bias risk of randomized controlled trials.

Risk of bias assessment

Methodological quality assessments of the RCTs are presented in Figure 2, while those for non-RCTs are detailed in Table I. The MINORS scores ranged from 18 to 21.

Characteristics of the included studies

Table II summarizes the baseline demographics and other pertinent data extracted from the eligible studies.

Outcomes of the meta-analysis

Cement leakage

Eight studies[15-22] reported postoperative cement leakage without detectable inter-study heterogeneity (p=0.54, I^2=0%). Consequently, a fixed-effect model was adopted. Aggregate results demonstrated that leakage incidence in the UEA cohort was markedly reduced relative to the BPA cohort (RD:–0.08; 95% CI:–0.14 ~ –0.02; p=0.01),

TABLE II Characteristics of included studies								
Study	Date	Design	Group	Cases	Age year	Procedure	Female	Follow-up (mo)
Hong et al.[14]	2023	RCT	UEA	40	73.64±7.15	PKP	37	12
			UTA	40	72.84±6.94	PKP	34	12
Tang et al.[15]	2025	RCS	UEA	74	76.7±9.7	PVP	48	15.8±2.8
			UTA	62	76.1±9.3	PVP	39	15.3±2.3
Zheng et al.[16]	2025	RCS	UEA	42	73.55 ± 8.76	PVP	27	12
			UTA	48	75.33 ± 9.15	PVP	32	12
He et al.[17]	2022	RCS	UEA	47	NR	PKP	NR	12
			BPA	42	NR	PKP	NR	12
Wang et al.[18]	2012	RCS	UEA	28	65.5±9.6	PVP	16	NR
			BPA	26	69.3±8.7	PVP	14	NR
Xu et al.[19]	2024	RCS	UEA	62	69.4±5.2	PKP	37	12
			BPA	74	68.8±7.8	PKP	42	12
Zhao et al.[20]	2025	RCS	UEA	76	70.33±6.84	PVP	66	58.83±7.01
			BPA	93	71.67±6.77	PVP	77	60.25±6.60
Zhu et al.[21]	2022	RCS	UEA	34	70.1±6.8	PKP	29	12
			BPA	42	71.4±8.7	PKP	34	12

RCT: Randomized controlled trial; PKP: Percutaneous kyphoplasty; RCS: Retrospective controlled study; PVP: Percutaneous vertebroplasty; UEA: Unilateral extrapedicular approach; UTA: Unilateral transpedicular approach; BPA: Bilateral pedicle approach; NR: No report.

whereas the contrast with the UTA cohort failed to reach significance (RD:–0.01; 95% CI:–0.09 ~ 0.07; p=0.88) (Figure 3, Table III).

Cement volume (mL)

Seven studies[16-22] provided data on injected cement volume, yet displayed pronounced heterogeneity (p<0.00001, I^2=100%), prompting the use of a random-effects model. The synthesis revealed that the UEA arm received significantly less cement than the BPA arm (MD=–1.51; 95% CI:–2.98 ~ –0.04; p=0.04). Conversely, the difference relative to the UTA arm was not significant (MD=0.20; 95% CI:–0.02 ~ 0.41; p=0.07) (Figure 4, Table III).

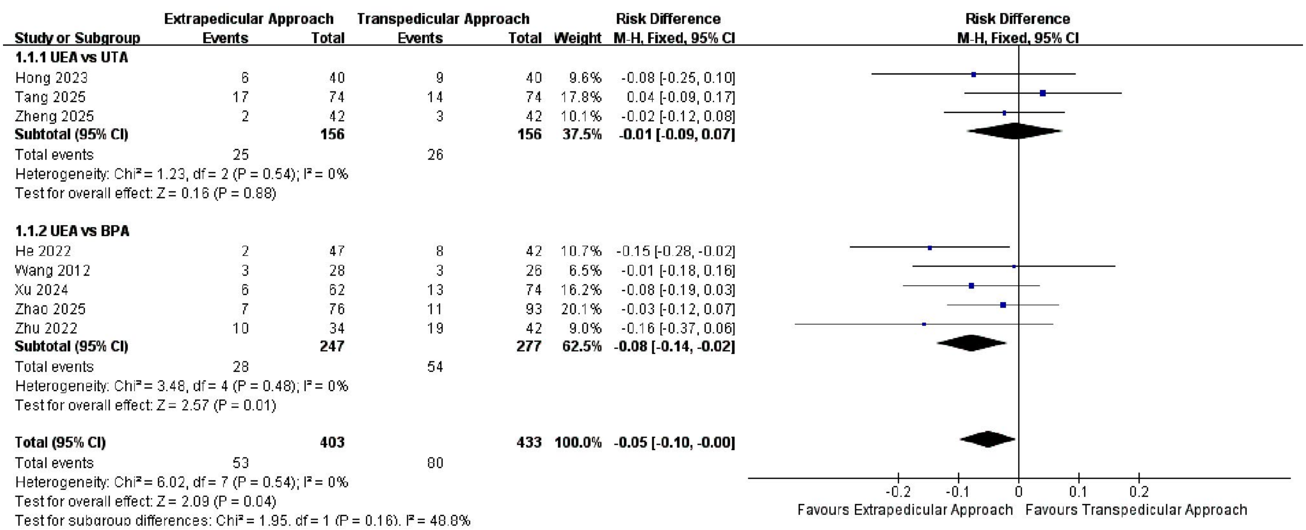

FIGURE 3. Forest plot showing the incidence of cement leakage.

CI: Confidence interval; UEA: Unilateral extrapedicular approach; UTA: Unilateral transpedicular approach; BPA: Bilateral pedicle approach.

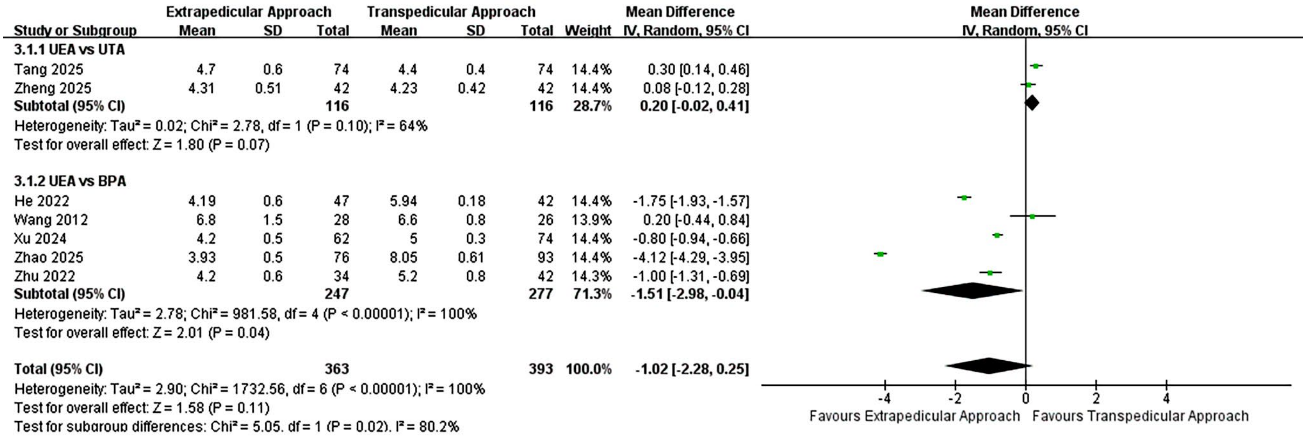

FIGURE 4. Forest plot showing cement volume.

SD: Standard deviation; CI: Confidence interval; UEA: Unilateral extrapedicular approach; UTA: Unilateral transpedicular approach; BPA: Bilateral pedicle approach.

TABLE III

Meta-analysis results

				Overall effect		Heterogeneity	
Outcome	Studies	Groups	Effect estimate	95% CI	*p*	I^2 (%)	*p*
Cement leakage	3	UEA *vs.* UTA	–0.01	–0.09 to 0.07	0.88	0	0.54
	5	UEA *vs.* BPA	–0.08	–0.14 to –0.02	0.01	0	0.48
Cement volume (mL)	2	UEA *vs.* UTA	0.20	–0.02 to 0.41	0.07	64	0.10
	5	UEA *vs.* BPA	–1.51	–2.98 to –0.04	0.04	100	<0.00001
Operation time	2	UEA *vs.* UTA	–4.26	–6.15 to –2.37	<0.00001	28	0.24
	5	UEA *vs.* BPA	–9.64	–13.25 to –6.04	<0.00001	93	<0.00001
Fluoroscopy frequency	2	UEA *vs.* UTA	–1.15	–3.62 to 1.32	0.36	98	<0.00001
	5	UEA *vs.* BPA	–8.12	–12.36 to –3.88	0.0002	99	<0.00001
Oswestry disability index	4	UEA vs BPA	–0.54	–2.81 to 1.72	0.64	88	<0.0001
Visual Analog Scale	5	UEA *vs.* BPA	–0.04	–0.24 to 0.17	0.73	67	0.02
Cobb angle°	3	UEA *vs.* BPA	0.37	–0.54 to 1.28	0.42	56	0.10

CI: Confidence interval; UEA: Unilateral extrapedicular approach; UTA: Unilateral transpedicular approach; BPA: Bilateral pedicle approach.

Operation time

Seven studies[16-22] documented operative duration, yet demonstrated substantial heterogeneity (p<0.00001, I^2=95%); therefore, a random-effects model was applied. Aggregated estimates indicated that UEA required significantly less time than both UTA (MD=–4.26; 95% CI:–6.15 ~ –2.37; p<0.00001) and BPA (MD=–9.64; 95% CI:–13.25 ~ –6.04; p<0.00001) (Figure 5, Table III).

Fluoroscopy frequency

Seven studies[16-22] reported intraoperative fluoroscopy counts; marked heterogeneity was evident (p<0.00001, I^2=100%), warranting a random-effects model. Aggregated results revealed that UEA required substantially fewer images than BPA (MD=–8.12; 95% CI:–12.36 ~ –3.88; p=0.0002), whereas no difference emerged relative to UTA (MD=–1.15; 95% CI:–3.62 ~ 1.32; p=0.36) (Figure 6, Table III).

Oswestry Disability Index

Four studies[18,20-22] documented ODI scores; marked heterogeneity was detected (p<0.0001, I^2=88%), necessitating a random-effects model. The pooled estimate revealed no clinically or statistically meaningful disparity between the UEA and BPA cohorts (MD=–0.54; 95% CI:–2.81 ~ 1.72; p=0.64) (Figure 7, Table III).

Visual Analog Scale

Five studies[18-22] supplied postoperative VAS data; moderate heterogeneity was evident (p=0.02, I^2=67%), warranting a random-effects model. The pooled result indicated no discernible inter-group difference (MD=–0.04; 95% CI:–0.24 ~ 0.17; p=0.73) (Figure 8, Table III).

Cobb angle

Three studies[18,19,21] reported the postoperative Cobb angle, a random-effects model was applied for statistical heterogeneity observed among them (p=0.10, I^2=56%). Pooled analysis showed no significant statistical difference in the postoperative Cobb angle between the UEA and BPA groups (MD=0.37; 95% CI:–0.54 ~ 1.28; p=0.42) (Figure 9, Table III).

Sensitivity and heterogeneity analysis

Given the substantial heterogeneity (I^2>90%) observed in cement volume, operative time and fluoroscopy frequency, we conducted systematic sensitivity analyses and heterogeneity diagnostics. By sequentially excluding each individual study and re-estimating the pooled effect, we evaluated whether the observed heterogeneity was driven by any single trial.

After the sequential exclusion of relevant studies, the heterogeneity in bone cement injection

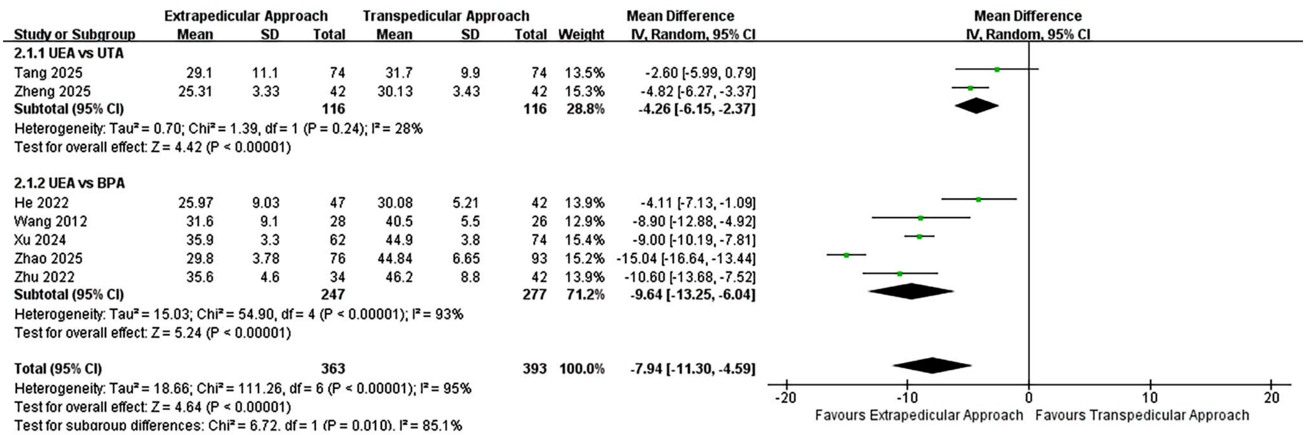

FIGURE 5. Forest plot showing operation time.

SD: Standard deviation; CI: Confidence interval; UEA: Unilateral extrapedicular approach; UTA: Unilateral transpedicular approach; BPA: Bilateral pedicle approach.

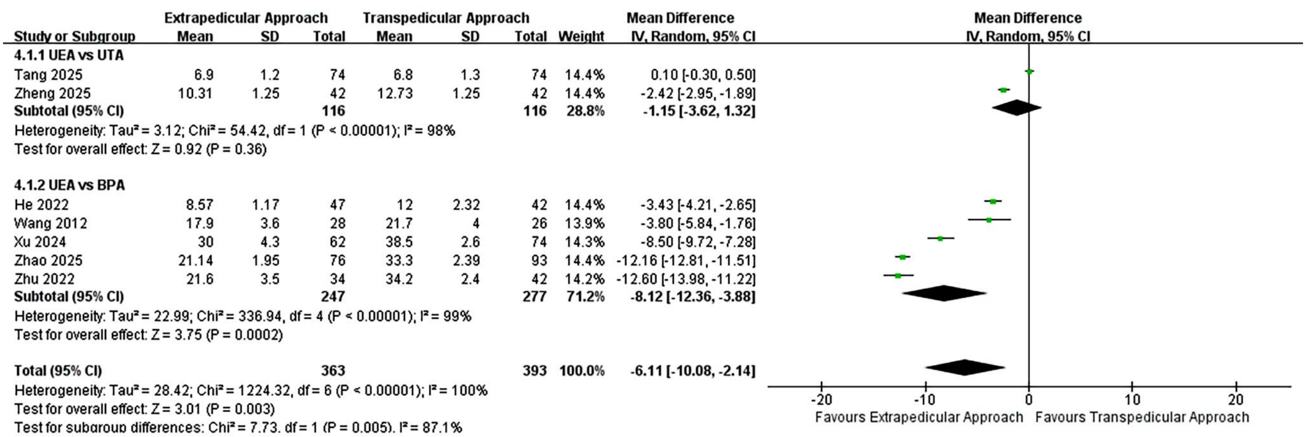

FIGURE 6. Forest plot showing fluoroscopy frequency.

SD: Standard deviation; CI: Confidence interval; UEA: Unilateral extrapedicular approach; UTA: Unilateral transpedicular approach; BPA: Bilateral pedicle approach.

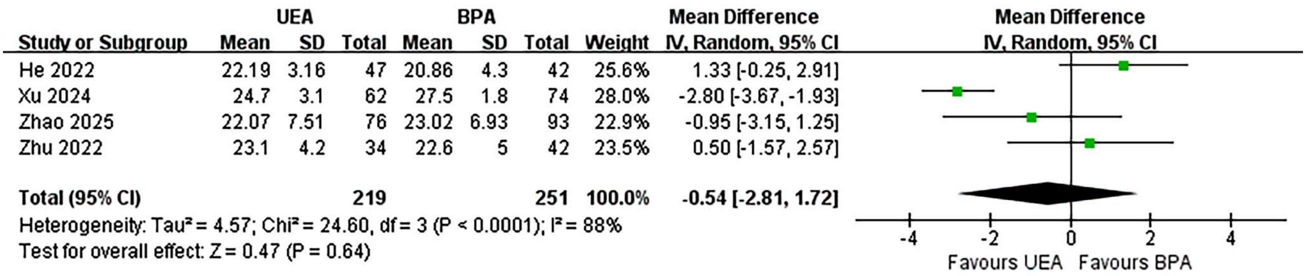

FIGURE 7. Forest plot showing Oswestry Disability Index.
UEA: Unilateral extrapedicular approach; BPA: Bilateral pedicle approach; SD: Standard deviation; CI: Confidence interval.

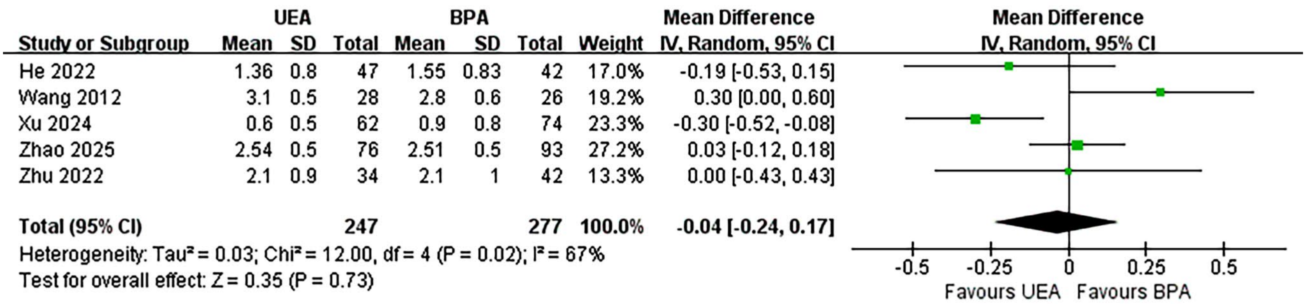

FIGURE 8. Forest plot showing Visual Analog Scale.
UEA: Unilateral extrapedicular approach; BPA: Bilateral pedicle approach; SD: Standard deviation; CI: Confidence interval.

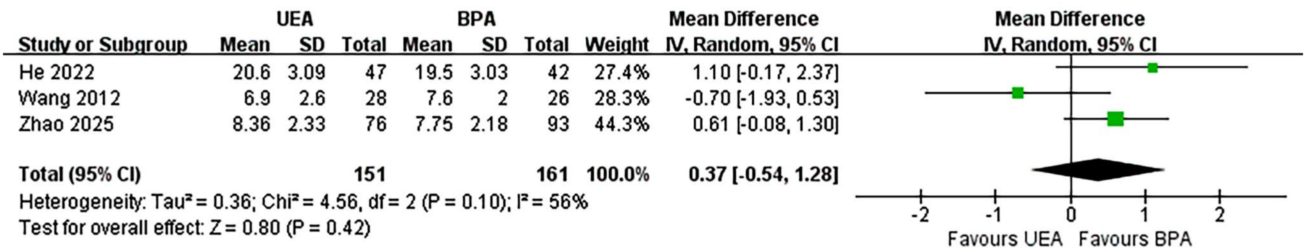

FIGURE 9. Forest plot showing Cobb angle.
UEA: Unilateral extrapedicular approach; BPA: Bilateral pedicle approach; SD: Standard deviation; CI: Confidence interval.

volume and fluoroscopy frequency did not decrease significantly. Notably, when the study by Zhao et al.[21] was excluded, the heterogeneity of the operation time indicator decreased significantly (I^2=72%). We further inferred the potential sources of heterogeneity by re-reading the full texts of the included studies. First, differences were observed in surgical procedures. Although Zhao et al.[21] adopted the UEA, this study integrated preoperative computed tomography (CT)-guided puncture path planning, which might have led to variations in operation time, fluoroscopy frequency, and bone cement distribution outcomes compared to other studies which used the UEA without such preoperative planning. Second, there were potential discrepancies in baseline characteristics of patients. All studies enrolled patients with single-segment thoracolumbar OVCFs; however, the follow-up duration in Zhao et al.[21] (49 to 70 months) was considerably longer than that in other studies (12 to 26 months). Additionally, subtle differences existed in the inclusion criteria regarding the severity of osteoporosis (e.g., stratification by T-score) and the degree of vertebral compression (e.g., the proportion of vertebral height loss) across studies. These variations might have affected the assessment of long-term efficacy and complications. Third, disparities were noted in study design and quality. All included studies had a retrospective design; Xu et al.[20] and Zhu et al.[22] mentioned controlling bias through strict inclusion and exclusion criteria, whereas Wang et al.[19] did not elaborate on the measures taken to ensure intergroup balance. Furthermore, the sample size varied substantially across studies (ranging from 49 to 193 cases), which might have resulted in differences in statistical power and subsequently impacted the stability of the pooled effect size results.

DISCUSSION

As global demographic ageing accelerates, osteoporosis has become the dominant skeletal metabolic disorder among older adults, with thoracolumbar OVCFs representing one of its most frequent sequelae.[23] In this context, PVA has gained primacy for managing thoracolumbar OVCFs, attributable to its capacity to restore partial vertebral height while delivering rapid analgesia; equally important, the minimally invasive nature of the procedure markedly reduces morbidity linked to prolonged recumbency.[24,25] However, outcomes differ substantially according to the chosen trajectory. The earliest technique involved bilateral transpedicular injection, yet concerns over bilateral pedicle compromise and cumulative radiation exposure prompted a shift toward unilateral transpedicular access. This modification, however, poses a risk to asymmetric cement dispersion and, when extreme angulation is required, inadvertent breach of the spinal canal.[26,27] Whether the UEA can reconcile the merits of both UTA and BPA transpedicular routes, therefore, still remains controversial.

This meta-analysis, comprising eight studies, aims to compare the clinical efficacy of UEA versus UTA or BPA in performing PVA for treating OVCFs, providing evidence-based and practical reference suggestions for clinicians. The pooled results demonstrated that UEA had a significantly shorter operation time compared to UTA. Meanwhile, compared to BPA, UEA exhibited remarkable advantages in terms of bone cement leakage rate, bone cement injection volume, operation time, and the number of intraoperative fluoroscopic sessions.

The results of our meta-analysis indicate that UEA significantly shortens operative duration relative to both the UTA and BPA techniques. Concomitantly, UEA requires fewer intraoperative fluoroscopic images than BPA. Accumulating evidence indicates that prolonged surgery is linearly linked to a higher incidence of surgical site infections (SSIs): every additional 15, 30, or 60 min raises SSI risk by 13%, 17%, and 37%, respectively.[28] Extended operating intervals also heighten patient distress and hinder postoperative recovery-manifested as delayed gastrointestinal motility and protracted pain perception. Moreover, Tang et al.[16] demonstrated that lengthier procedures were accompanied by greater occult hemorrhage, an event that might be particularly deleterious in individuals with pre-existing comorbidities. Likewise, increased fluoroscopy translates into higher radiation exposure, prolonging both dosage and contact time and amplifying attendant hazards.[29] Collectively, these data underscore the imperative to refine operative protocols and curtail surgical time in order to mitigate postoperative morbidity and enhance overall patient prognosis.

Between UEA and UTA, we observed comparable cement volumes and leakage incidences. Relative to BPA, however, UEA exhibited marked reductions in both metrics. The intravertebral cement dose is a dominant determinant of extravasation risk, with larger quantities proportionally elevating the likelihood of breach.[30] Overfilling not only augments leakage probability but may also impair neural or reproductive physiology, precipitating bone-cement implantation syndrome. Additional leakage predictors encompass cortical discontinuities, intraosseous vacuum clefts, and prominent basivertebral venous channels.[31] Once injected in its fluid phase, bone cement follows paths offering minimal resistance within the vertebral trabecular network. During ensuing polymerization, exothermic energy and cytotoxic monomers are released prior to final hardening into an inert mass. Should this migration stray beyond the target zone, neighboring tissues may sustain substantial thermal or chemical injury, precipitating a cascade of adverse events. Published reports have catalogued grave sequelae ranging from radicular compression and myelopathy to pulmonary and even cardiac embolism.[32-34]

Once bone cement is injected into the injured spine, the heat generated by the polymerization reaction immediately disrupts the sinus vertebral nerve attached to the spine, abruptly relieving the patient's pain and improving mobility.[35] In our study, no significant differences were observed in postoperative VAS, ODI scores, or Cobb angles among UEA, UTA, and BPA groups. Zhu et al.[22] indicated that, when bone cement reached an appropriate volume with proper distribution, regardless of the puncture technique used, it could effectively alleviate pain and improve the patient's functional status. Additionally, uniformly filled bone cement could correct local vertebral body anterior height loss and kyphotic angle caused by vertebral height reduction, demonstrating the ability to restore vertebral height and improve alignment. This finding implies that resumption of routine ambulation after surgery is feasible without notable functional compromise, likely mitigating the hazards of extended recumbency including venous thromboembolism of the lower limbs, hypostatic pneumonia, and catheter-associated urinary infection.[36]

Nonetheless, this meta-analysis has several limitations. First, the review included only 1 RCT and 7 non-RCTs, while non-RCTs can lower the evidence quality of a meta-analysis. Second, some studies did not clearly state patient age and sex ratios. Third, the current evidence mainly comes from the Chinese population, which limits the extrapolation of the conclusion. In the future, more multi-center RCTs are needed for verification. Fourth, follow-up periods differed across studies, which might have introduced result bias. Fifth, In the study, the efficacy of UEA was compared to that of UTA or BPA, but no direct or indirect comparison was made between UTA and BPA, which may lead to interpretation bias. Finally, the absence of the postoperative indicator vertebral body height restoration may also have an impact on the evaluation of postoperative efficacy.

In conclusion, UEA appears to be significantly superior to the BPA in terms of cement dosage, leakage rate, intraoperative fluoroscopy times, and operative time, suggesting that UEA is a safer and more efficient alternative, when BPA is the reference. Compared to the UTA, the only demonstrable advantage of UEA is a modest reduction in operative time. Therefore, the benefits of UEA seem to be most pronounced in settings where BPA is the standard practice. Further multi-center, large-scale RCTs are still warranted to confirm these findings and to clarify the relative merits of UEA versus UTA.

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

Author Contributions: Contributed to conception and design of this study, study selection and data extraction of the finally included studies were done independently assessed the methodological quality of each included stud, contributed to preparation of the manuscript: J.F.D., W.D.C., L.L. The final version of the article was approved by all the authors.

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