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REVIEW **Open Access**

Effect of vertebral kyphoplasty versus vertebroplasty on pain and indicators of imaging parameters of the injured vertebrae in patients with osteoporotic vertebral compression fractures: a meta-analysis

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Abstract

Objective To systematically evaluate the effects of vertebroplasty (VP) and kyphoplasty (KP) on pain and spinal imaging parameters in patients with osteoporotic vertebral compression fractures (OVCF).

Methods A comprehensive search of eight databases was conducted from inception to November 2024 to identify randomised controlled trials (RCTs) published in Chinese and English. Eligible studies included clinical RCTs comparing KP and VP in patients with OVCF, assessing vertebral pain and imaging parameters. Risk of bias and methodological quality were assessed using the Cochrane Appraisal Tool. Combined effects were calculated using a random effects model. Heterogeneity was assessed using the I^2 test.

Results A total of 16 randomised controlled trials involving 1738 patients were included. The analysis revealed no statistically significant difference between KP and VP in pain reduction ($SMD=0.08$, $95\%\ CI=$ -0.04 to 0.20, $P=0.19$) or spinal function ($SMD=0.04$, $95\%\ CI=$ -0.11 to -0.19, $P=0.62$). However, KP demonstrated significantly better outcomes than VP in vertebral compression rate ($SMD=1.39$, $95\%\ CI=0.81$ to 1.96, $P<0.00001$), Cobb angle ($SMD=1.83$, $95\%\ CI=0.99$ to 2.68, $P<0.0001$) and the incidence of cement leakage ($OR=1.92$, $95\%\ CI=1.41$ to 2.62, $P<0.0001$).

Conclusion Our results suggest that KP is more effective than VP in improving postoperative vertebral compression rate and Cobb angle, and reducing the incidence of cement leakage.

Keywords Kyphoplasty, Vertebroplasty, Osteoporosis, Spinal fractures, Meta-analysis

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Introduction

Osteoporosis is a systemic bone disease characterized by bone loss and degeneration of the skeletal microarchitecture, with vertebral fractures being the most common complication [1]. Osteoporotic vertebral compression fractures (OVCF) often result in acute and chronic back pain, spinal deformity, functional impairment, and a significant reduction in quality of life [2]. If left untreated, OVCF can impose a substantial burden on both patients and healthcare systems.

Effective management of OVCF focuses on alleviating pain and stabilizing the fractures. In recent years, minimally invasive procedures, including vertebroplasty (VP) and kyphoplasty (KP), have emerged as promising treatment options. These procedures aim to stabilise vertebral fractures, reduce pain, and improve quality of life, offering an alternative to conservative management [3–5].

While both VP and KP have shown efficacy in improving clinical outcomes, the question of which procedure offers superior outcomes remains unresolved. This debate arises due to differences in procedural techniques, clinical outcomes, and potential complications. VP involves direct injection of bone cement into the vertebral body to stabilize the fracture, whereas KP uses a balloon to restore vertebral height before cement injection, which may offer an advantage in reducing the risk of cement leakage and improving vertebral alignment. However, KP is technically more complex than VP, requiring more precise balloon placement and more advanced equipment [6–8].

Previous systematic reviews and meta-analyses have often included studies with small sample sizes or non-randomized controlled trials, which may limit the reliability of the results [9–10]. Given these limitations, this study aims to conduct a meta-analysis comparing VP and KP in terms of pain reduction, fracture stability, and complication rates, incorporating a larger and more recent cohort of randomised controlled trials (RCTs). This analysis seeks to provide robust, evidence-based recommendations for the treatment of OVCF, considering the technical aspects and clinical outcomes of both procedures.

Methods

Inclusion and exclusion criteria

Inclusion criteria: (1) Type of study: randomized controlled trial (RCT), no restriction on blind implementation, text limited to Chinese and English; (2) Study population: patients with a definite diagnosis of osteoporosis by bone densitometry and vertebral compression fracture by magnetic resonance scanning of the spine; (3) Intervention: KP and VP were given to patients in the two groups, respectively; KP included balloon kyphoplasty (BKP) and percutaneous kyphoplasty (PKP), and VP included percutaneous vertebroplasty (PVP) and high-viscosity cement vertebroplasty (HVCV); (4) Outcome indicators: ①Pain: obtained by visual analogue scale (VAS) score; ②Injured spine imaging parameter index (vertebral compression ratio, Cobb angle). ③Spinal cord function: obtained from the Spinal Disability Index (ODI) score; ④ Incidence of cement leakage. Included studies should contain at least one of the above outcome indicators. Exclusion criteria: (1) studies with insufficient data, duplicate publications, or inaccessible full text.

Search strategy

CNKI, Wanfang, Vip, Chinese Biomedical Literature Database, PubMed, Cochrane Library, Embase, and Web of science databases were searched. The searches were all conducted from inception to November 2024. The search terms are "Fractures, Compression" OR "Osteoporotic vertebral compression fractures", "Vertebroplasty", "Kyphoplasty" OR "Balloon Vertebroplasty". A combination of subject terms and free words was used to simultaneously search for references incorporated into the literature. The English search strategy is exemplified by pubmed: (((((Fractures, Compression [MeSH Terms])) OR (Osteoporotic vertebral compression fractures [Title/Abstract])) AND (vertebroplasty [MeSH Terms])) AND ((Kyphoplasty [MeSH Terms]) OR (Balloon Vertebroplasty [Title/Abstract]))) AND (randomized controlled trial [Publication Type]).

Literature screening and data extraction

Literature screening was initially conducted using the NoteExpress reference management system to automatically filter relevant studies. The preliminary selection was based on the title and abstract, followed by full-text screening to exclude studies that did not meet the inclusion criteria. Data extraction was conducted independently by two researchers, following the NERC criteria. In cases of disagreement, a third researcher was consulted for resolution. The extracted data included: title, author, year of publication, age, sample size, intervention, drug dose, treatment period, and outcome indicators.

Quality evaluation of literature

The methodological quality of included studies was assessed by two independent researchers using the Cochrane Handbook for Systematic Reviews of Interventions (Version 5.1.0) [11]. The following criteria were evaluated: whether the study described the specific method and process of randomized sequence generation; whether the study described the method of hiding the allocation sequence; whether the study avoided all study subjects' and interviewees' access to information about the intervention; whether the study provided evaluators with valid information about the intervention; whether data for each of the study's endpoints were reported in full, and whether missing data were reported; whether the study whether valid or invalid outcomes were selectively reported; other biases. Grade A if the above criteria were fully met; grade B if partially met; grade C if not met at all (Grade A: high quality, Grade B: moderate quality, Grade C: low quality). In case of disagreement between the evaluations of 2 researchers, a third researcher was consulted to make a determination. In order to assess the inter-rater agreement between evaluators, Cohen's kappa statistic was calculated. This statistical test is commonly used to measure the agreement between two raters when classifying data into categories. Kappa values were interpreted as follows: values less than 0.2 indicate poor agreement, values between 0.21 and 0.40 indicate fair agreement, values between 0.41 and 0.60 indicate moderate agreement, values between 0.61 and 0.80 indicate substantial agreement, and values above 0.80 indicate almost perfect agreement.

Statistical analysis

RevMan5.2 statistical software was used to analyze the clinical heterogeneity by adopting I^2 test. When $P \geq 0.05$ and $I^2 < 50\%$, it indicated that there was no statistical heterogeneity among the studies, and the fixed-effect model was used for Meta-analysis; conversely, it indicated that there was statistical heterogeneity among the studies, and the source of difference was first analyzed, and if there was no obvious clinical difference and no definite source of statistical difference could be found, the random-effect model was used for Meta-analysis. The VAS score, vertebral compression rate, Cobb angle and ODI score indexes were continuous variables, so the standardized mean difference (SMD) and its 95% confidence interval (CI) were used as the effect sizes; the odds ratio (OR) and its 95% CI were used as the effect sizes for the counting parameter of the incidence of cement leakage. $P < 0.05$ was considered as the statistical significance of the difference.

Results

The database search yielded a total of 6,591 documents, and the literature screening process is shown in Fig. 1.

Basic characteristics of the included literature and the results of methodological quality evaluation.

A total of 16 studies [12–27] were included, comprising five in English and eleven in Chinese. These studies involved 1,738 patients with OVCF, with 868 patients in the VP group and 870 in the KP group. The basic study characteristics are summarised in Table 1. The methodological quality assessment classified four studies as Grade A (high quality) and twelve studies as Grade B (moderate quality). The risk of bias assessment diagram is presented in Fig. 2.

Meta-analysis results

13 studies [13, 14, 15, 16, 18, 19, 20, 21, 22, 23, 24, 26–27] reported pain on VAS scores, with large heterogeneity among studies ($P < 0.\ 00001$, $I^2 = 71\%$), and less heterogeneity among studies after sensitivity analysis excluding the study by Ganqing Li et al. [21] ($P = 0.\ 09$, $I^2 = 38\%$), solidified with a fixed-effects model. The results suggested that the difference in VAS scores between the two groups was not statistically significant (SMD = 0.08, 95% CI = -0.04 to 0.20, $P = 0.\ 19$), as shown in Fig. 3.

Parametric indicators of imaging of the injured vertebrae

Six studies [12–13, 17–18, 20–21] reported vertebral compression rate, with large heterogeneity among studies ($P < 0.\ 00001$, $I^2 = 88\%$), and a random-effects model was used after sensitivity analysis. The results showed that patients in the KP group had a significantly lower vertebral compression rate compared to the VP group (SMD = 1.39, 95% CI = 0.81 to 1.96, $P < 0.\ 00001$), as shown in Fig. 4.

Eight studies [12–13, 15, 17–18, 20, 21, 22] reported Cobb angle with large heterogeneity among studies ($P < 0.\ 00001$, $I^2 = 96\%$), and a random-effects model was used after sensitivity analysis. The results indicated that patients in the KP group had significantly lower Cobb angle values than those in the VP group (SMD = 1.83, 95% CI = 0.99 to 2.68, $P < 0.\ 0001$), as shown in Fig. 5.

Five studies [14, 19, 23–25] reported ODI scores, and the heterogeneity among studies was small ($P = 0.\ 34$, $I^2 = 12\%$), so a fixed-effects model was used. The analysis showed no statistically significant difference in ODI scores between the two groups (SMD = 0.04, 95% CI = -0.11 to -0.19, $P = 0.\ 62$), as shown in Fig. 6.

10 studies [14–20, 23–25] reported the incidence of cement leakage, with large heterogeneity among studies ($P = 0.\ 0004$, $I^2 = 70\%$). After conducting sensitivity analysis and excluding the study by Wang et al. [24], heterogeneity decreased ($P = 0.\ 04$, $I^2 = 50\%$), allowing for the use of a fixed-effects model. The results indicated that KP was associated with a significantly lower incidence of cement leakage compared to VP (OR = 1.92, 95% CI = 1.41 to 2.62, $P < 0.\ 0001$), as shown in Fig. 7.

Discussion

The results of this study showed that patients with KP were better than patients with VP in terms of vertebral compression rate, Cobb angle, and the incidence of cement leakage ($P < 0.05$); however, the differences between the two groups in terms of pain and ODI scores were not statistically significant ($P > 0.05$).

Of note, the findings of this study do not yet al. low for the conclusion that KP is superior to VP in reducing postoperative pain, which is inconsistent with the results of several studies [28–29]. Previous systematic evaluations

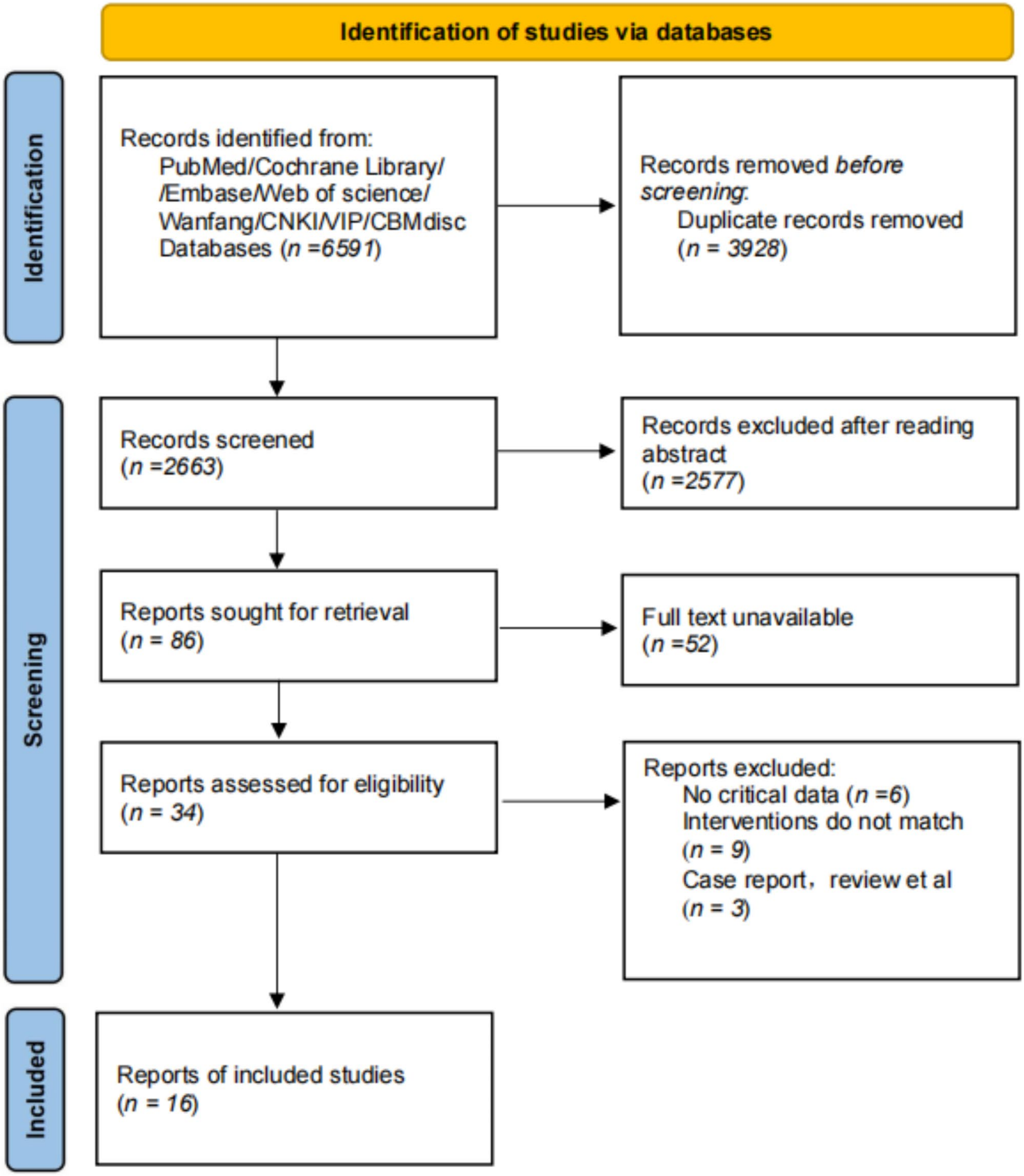

Fig. 1 Flowchart of the literature screening process

have concluded [9–10, 30] that patients in the KP group had significantly less pain compared to patients in the VP group. However, these systematic evaluations combined randomized and nonrandomized controlled studies or included a limited number of trials, and the reliability of the results may have been compromised. Although KP is more effective in correcting kyphosis deformity, this does not directly translate to better pain relief. The effectiveness of both VP and KP in pain management depends on individual factors such as the severity of the fracture,

Table 1 Basic characteristics of the included literature

Author and Year	Country	Surgical		Sample size		Age		Gender		Follow-up time	Measurement tool
		VP	KP	VP	KP	VP	KP	VP	KP		
Li 2009 [11]	China	PVP	PKP	15	15	65.00 ± 10.45	67.50 ± 12.70	M: 5 F: 10	M: 7 F: 8	2 months	②③
Wang 2011 [12]	China	PVP	PKP	32	32	64.80 ± 9.50	65.50 ± 10.70	M: 12 F: 20	M: 14 F: 18	1 year	①②③
Ji 2013 [13]	China	PVP	PKP	24	24	74.83 ± 4.91	76.33 ± 4.10	M: 6 F: 18	M: 4 F: 20	6 months	①④⑤
He 2015 [14]	China	PVP	PKP	75	75	67.00 ± 5.00	68.00 ± 5.00	M: 28 F: 47	M: 29 F: 46	1 year	①③⑤
Xu 2016 [15]	China	PVP	PKP	40	40	67.50 ± 4.30	67.50 ± 4.30	-	-	1 year	①⑤
Huang 2016 [16]	China	PVP	PKP	61	61	69.10 ± 5.30	68.40 ± 4.90	M: 38 F: 23	M: 39 F: 22	-	②③⑤
Shao 2016 [17]	China	PVP	PKP	50	50	63.20 ± 3.50	64.10 ± 3.20	M: 17 F: 33	M: 19 F: 31	1 year	①②③⑤
Huang 2018 [18]	China	PVP	PKP	25	25	76.67 ± 9.52	73.23 ± 8.43	M: 11 F: 14	M: 10 F: 15	3~12 months	①④⑤
Chi 2019 [19]	China	PVP	PKP	68	69	75.00 ± 6.00	76.00 ± 6.00	M: 13 F: 55	M: 12 F: 57	3 months	①②③⑤
Li 2020 [20]	China	PVP	PKP	43	43	68.94 ± 3.97	69.11 ± 4.05	M: 24 F: 19	M: 23 F: 20	7 days	①②③
Ma 2021 [21]	China	PVP	PKP	37	37	70.35 ± 7.21	69.58 ± 6.37	M: 16 F: 21	M: 18 F: 19	1 year	①③
Zhou 2024 [22]	China	PVP	PKP	47	47	73.27 ± 3.49	71.86 ± 3.77	M: 9 F: 38	M: 8 F: 39	1 year	①④⑤
Wang 2015 [23]	China	HVCV	BKP	54	53	69.43 ± 8.94	68.63 ± 8.39	M: 14 F: 40	M: 12 F: 41	1 year	①④⑤
Dohm 2014 [24]	USA	PVP	BKP	191	190	-	-	-	-	24 months	④⑤
Liu 2010 [25]	Taiwanese	PVP	BKP	50	50	74.30 ± 6.40	72.30 ± 7.60	M: 12 F: 38	M: 11 F: 39	6 months	①
Evans 2016 [26]	USA	VP	KP	56	59	75.10 ± 10.10	76.10 ± 10.00	M: 12 F: 44	M: 20 F: 39	1 year	①

Note: VP: vertebroplasty, KP: kyphoplasty; HVCV: High-viscosity cement vertebroplasty; BKP: Balloon kyphoplasty; PVP: Percutaneous vertebroplasty; PKP: percutaneous kyphoplasty; M: Male; F: Female; ① VAS score, ② vertebral compression rate, ③ Cobb angle, ④ ODI score, ⑤ incidence of cement leakage

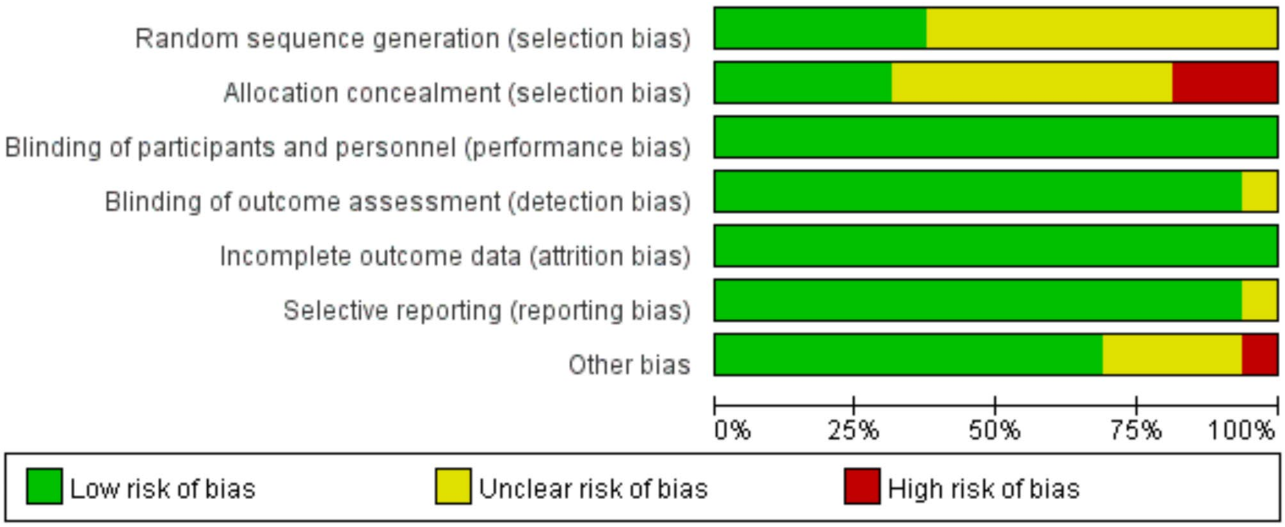

Fig. 2 Graph of risk of bias assessment of the included literature

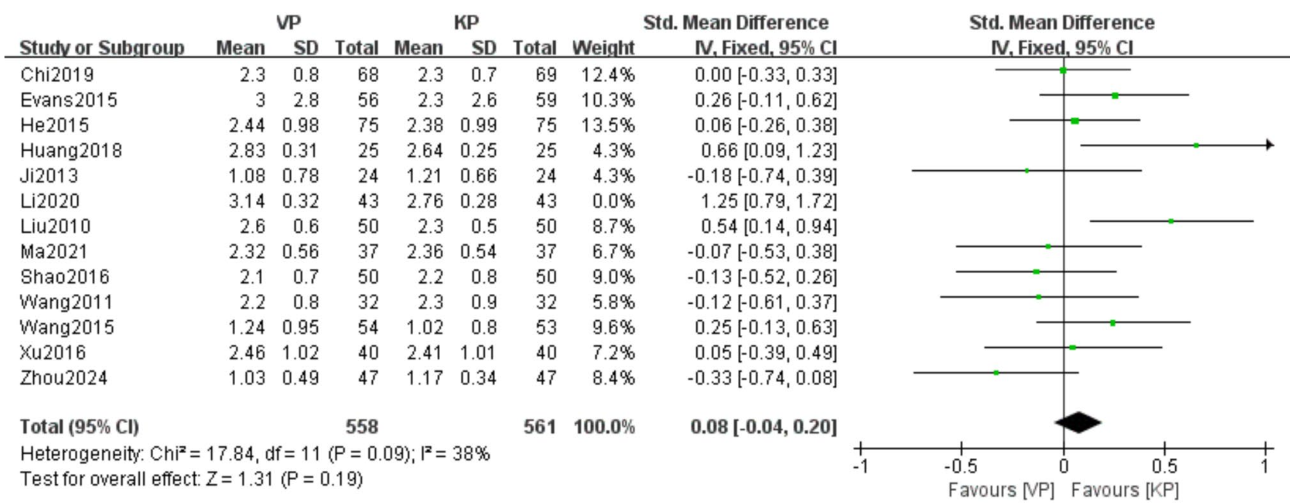

Fig. 3 Forest plot of Meta-analysis of VAS scores

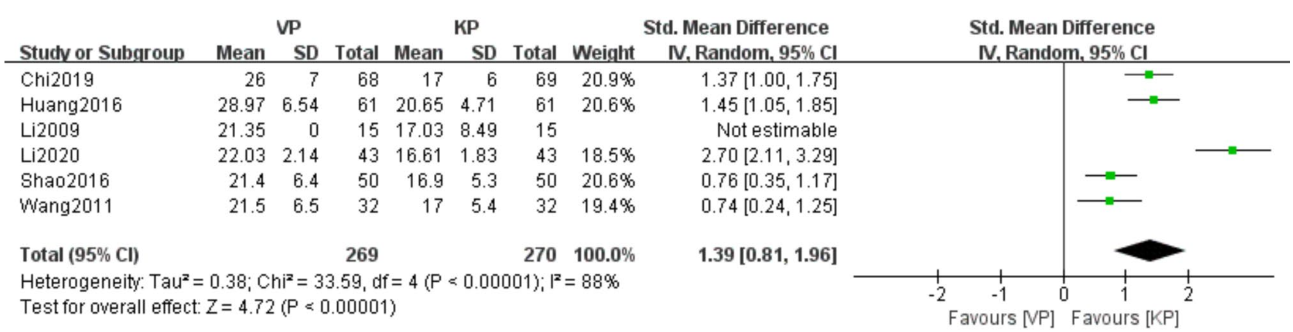

Fig. 4 Meta-analyzed forest plot of vertebral compression ratio

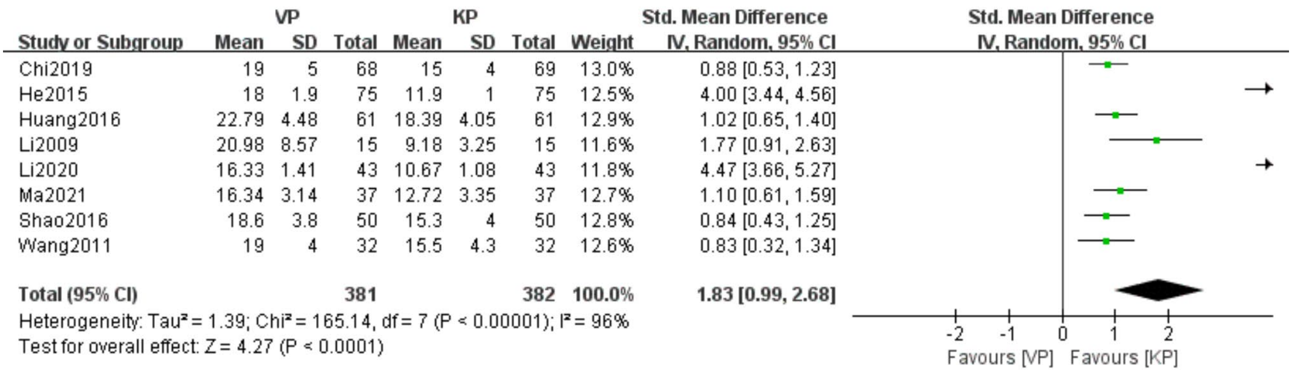

Fig. 5 Meta-analyzed forest plot of Cobb's Corner

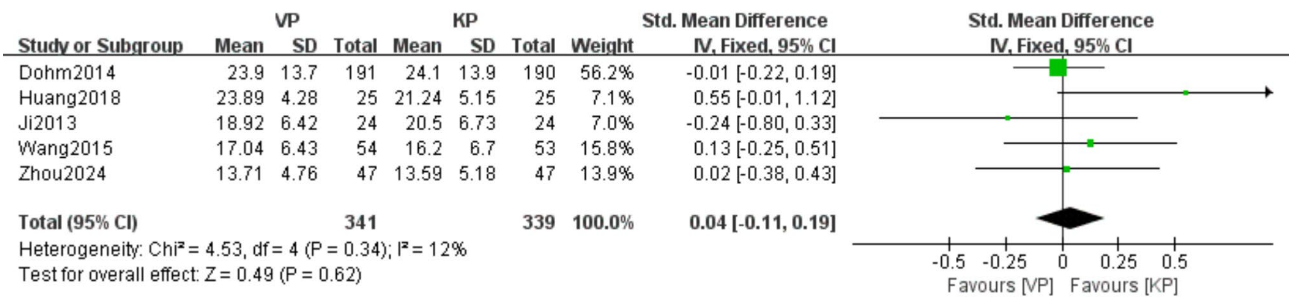

Fig. 6 Forest plot for Meta-analysis of ODI scores

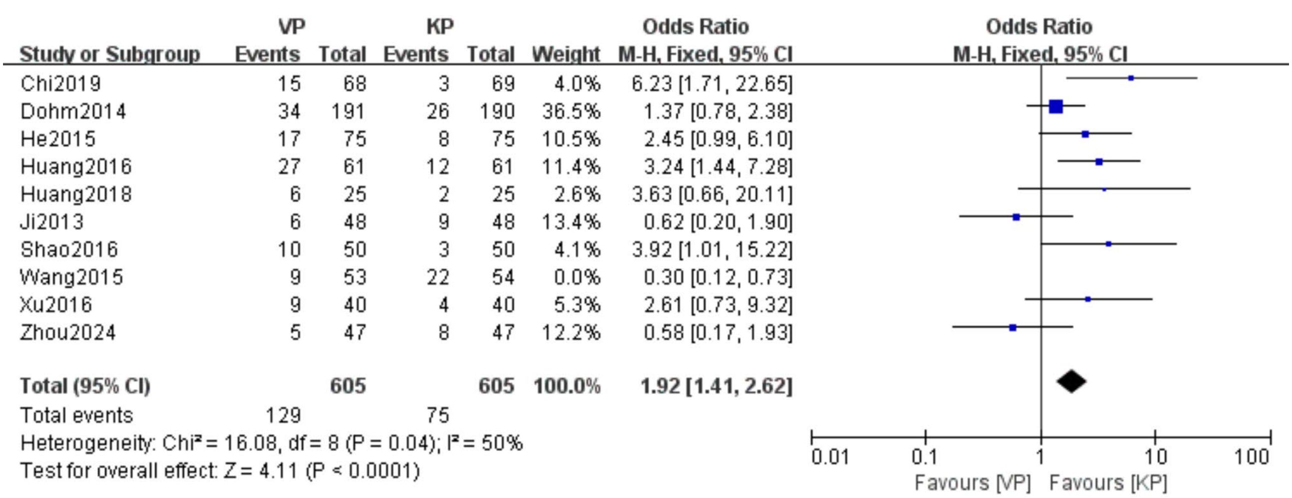

Fig. 7 Meta-analyzed forest plots for the incidence of cement leakage

comorbidities, and patient-specific characteristics. Our study found no significant difference in spinal function between the two groups, which contradicts the findings of Lin Yunzhong et al. [29]. This discrepancy may be due to the small number of studies assessing spinal function (only five), highlighting the need for more large-scale, long-term studies to definitively compare the effects of VP and KP on spinal function in patients with OVCF.

This study showed that KP patients had better outcomes than VP patients in terms of vertebral compression rate, Cobb angle, and incidence of cement leakage. These results align with those of Zhu et al. [10]. The superior outcomes in KP may be due to the balloon expansion that creates a cavity within the vertebral body, restoring its height and improving both the compression rate and Cobb angle, while VP directly injects cement into the vertebra without this height restoration [29]. Both VP and KP stabilize the fracture, restore vertebral strength, and relieve pain, allowing patients to return to normal activities more quickly. However, KP uses higher viscosity bone cement under lower pressure, which reduces cement leakage and complications [31]. Therefore, KP is likely the optimal treatment for improving imaging parameters and minimizing complications.

In addition to the traditional surgical treatments of VP and KP, recent advancements in non-invasive pain management techniques have shown promise in improving pain relief for patients with OVCF. One such approach is neuromodulation, which includes techniques like transcranial magnetic stimulation (TMS), which has been shown to significantly reduce pain perception in patients with OVCF [32–37]. Non-invasive methods such as transcutaneous electrical nerve stimulation (TENS), medication delivery through intradiscal injection, and physical therapy interventions are increasingly being explored as adjunctive treatments that help manage pain and improve function, particularly in cases where surgery may not be indicated or where the patient may prefer non-invasive options. These approaches provide a complementary option alongside traditional surgical methods, potentially improving long-term pain management while reducing the need for invasive procedures.

Although non-invasive methods like TMS and TENS have been shown to be effective in reducing pain, they should not be viewed as replacements for VP and KP, but rather as adjuncts to these traditional treatments. The combination of surgical and non-invasive interventions may provide a more comprehensive approach to managing pain and improving quality of life in OVCF patients, particularly those with chronic or severe pain. The incorporation of non-invasive pain management options presents a promising future direction for improving the outcomes of OVCF treatment.

One notable aspect of this meta-analysis is that almost all the included studies were conducted in China. The large number of OVCF patients in China due to the high prevalence of osteoporosis, especially among the elderly population, contributes to the substantial body of research in this area. China has one of the largest aging populations in the world, and osteoporosis is increasingly recognized as a major public health concern, leading to a higher incidence of fractures and a greater demand for effective treatment options such as VP and KP.

However, this meta-analysis has several limitations. One of the key limitations is the high heterogeneity observed across studies. The presence of both mild and severe fractures across studies introduces additional complexity in ensuring full comparability of the patient populations. Although the included studies were RCTs, the small sample sizes and some did not specify whether blinding was used or if allocation concealment was implemented, which introduces the potential for bias. Additionally, the follow-up time varied across studies, which could introduce further inconsistency in evaluating long-term outcomes. It is important to note that the predominance of studies from a single country may limit the generalizability of the findings to other populations. While the results of this meta-analysis provide valuable insights, further studies from diverse geographical regions and healthcare systems would help to confirm the applicability of these findings globally.

In summary, KP was superior to VP in terms of vertebral compression rate, Cobb angle, and complications, but it is not yet possible to conclude that KP or VP is more advantageous in relieving postoperative pain and improving spinal function. Due to the limitation of the quality of the included trials, the results of this study need to be further validated by a large-scale RCT.

Abbreviations

KP	Kyphoplasty
VP	Vertebroplasty (VP)
OVCF	Osteoporotic vertebral compression fractures
RCTs	Randomized controlled trials
BKP	Balloon kyphoplasty
PKP	Percutaneous kyphoplasty
PVP	Percutaneous vertebroplasty
HVCV	High-viscosity cement vertebroplasty
TMS	Transcranial magnetic stimulation
TENS	Transcutaneous electrical nerve stimulation

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Not applicable.

Author contributions
Conception and design: ZJYAdministrative support: KQWProvision of study materials or patients: YJCollection and assembly of data: All authors. Data analysis and interpretation: JCManuscript writing: All authors. Final approval of manuscript: All authors.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). As this study involves the summary and analysis of other studies, it does not involve medical ethics approval or patient-informed consent.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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