

High-Viscosity versus Low-Viscosity Bone Cement in the Management of Osteoporotic Vertebral Compression Fractures: A Systematic Review and Meta-Analysis

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Abstract

Background: Clinical uncertainty persists regarding the optimal cement viscosity for vertebral augmentation in osteoporotic vertebral compression fractures (OVCFs). **Objective:** To compare the efficacy and safety of high-viscosity (HVC) versus low-viscosity (LVC) bone cement in percutaneous vertebroplasty for OVCFs. **Methods:** PubMed, Embase, Cochrane Library, Web of Science, and China National Knowledge Infrastructure (CNKI) were searched from inception to April 15, 2026, without language restriction; however, only English and Chinese language publications were eligible. The primary outcome was cement leakage rate; secondary outcomes included pain (visual analog scale, VAS), functional disability (Oswestry Disability Index, ODI), vertebral height restoration, and complications. Random-effects meta-analysis was performed, with effect sizes expressed as odds ratios (ORs) or mean differences (MDs), along with 95% confidence intervals (CIs). **Results:** Four studies (1 RCT, 3 retrospective cohorts) comprising 218 patients (110 HVC, 108 LVC) with 235 treated vertebrae were included. In separate meta-analyses by unit of analysis, limited evidence suggested lower cement leakage with HVC: per-patient OR 0.19 (95% CI 0.09 - 0.40) and per-vertebra OR 0.22 (95% CI 0.08 - 0.63). No significant differences were observed between groups for final follow-up VAS scores (MD -0.06, 95% CI -0.19 to 0.07, $p = 0.35$; $I^2 = 0\%$) or ODI scores (MD -0.28, 95% CI -2.94 to 2.38, $p = 0.84$; $I^2 = 31\%$). Vertebral height restoration and complication rates were similar between groups, but these findings were based on sparse narrative data. **Conclusion:** Low-certainty evidence suggests that high-viscosity cement may reduce radiographic

cement leakage compared with low-viscosity cement in PVP, but available data do not show superior pain relief or functional recovery. Because the evidence base is small and includes mixed study designs, conclusions should be interpreted cautiously. Large, adequately powered randomized controlled trials are needed.

Keywords

Osteoporotic Vertebral Compression Fracture, Bone Cement Viscosity, Vertebroplasty, Cement Leakage, Meta-Analysis

1. Introduction

Osteoporotic vertebral compression fractures (OVCFs) represent a devastating consequence of osteoporosis, affecting approximately 700,000 individuals annually in the United States alone [1]. Global prevalence data indicate that osteoporosis affects 19.7% of the adult population, with an additional 40.4% exhibiting osteopenia, fundamentally altering the biomechanical integrity of vertebral bodies [2]. The clinical significance of OVCFs extends far beyond acute pain; these fractures are associated with a 5-fold increased risk of subsequent vertebral fractures and a 2-fold elevation in hip and other fracture risk [1]. Alarming, only one-third of vertebral fractures receive a clinical diagnosis, with global multicenter studies reporting missed diagnosis rates as high as 34% in postmenopausal women aged 65 - 80 years [3]. This under recognition, combined with substantial morbidity including progressive kyphosis, restrictive lung disease, early satiety, and heightened mortality, mandates effective therapeutic interventions.

Percutaneous vertebral augmentation (PVA), encompassing vertebroplasty (PVP) and kyphoplasty (PKP), has emerged as the minimally invasive standard of care for the management of OVCF. Polymethylmethacrylate (PMMA) bone cement remains the predominant filling material, offering rapid polymerization, excellent biomechanical strength, and predictable handling characteristics [4]. However, PMMA is biologically inert, generates exothermic polymerization heat, and carries inherent risks including cement leakage (reported in 5 - 40% of cases) and pulmonary cement embolism [5]. Cement viscosity has been identified as a critical yet incompletely characterized variable governing procedural safety and efficacy.

The mechanistic relationship between cement viscosity and clinical outcomes involves complex flow dynamics within osteoporotic cancellous bone. Low-viscosity cement demonstrates superior trabecular penetration and interdigitation, potentially achieving more favorable distribution patterns. Diffuse spongy morphology has been associated with superior pain relief (VAS scores 1.81 ± 0.67 vs. block patterns) and lower adjacent fracture rates (8.1% vs. higher rates with solid patterns) [6]. Conversely, low viscosity significantly increases leakage risk, with studies demonstrating that leakage escalates markedly when injection volumes exceed 6 mL for low-viscosity preparations [7]. High-viscosity cement offers theo-

retical advantages of reduced leakage and more controlled deployment; comparative data show that high-viscosity cement injected at 6 - 8 mL achieves comparable efficacy with less extravasation [7]. However, high viscosity may compromise trabecular penetration, potentially limiting biomechanical restoration and long-term outcomes.

Current evidence presents substantive contradictions that preclude consensus guidelines. The 2018 Cochrane review found no demonstrable clinically important benefits for vertebroplasty compared with sham procedures, regardless of pain duration [8]. The 2019 ASBMR task force concluded no significant benefit for vertebroplasty versus placebo and recommended against routine balloon kyphoplasty [9]. Nevertheless, observational studies consistently demonstrate superior pain relief and functional recovery with PVA, with cement distribution pattern emerging as a more significant predictor of outcomes than volume alone [10]. Meta-analyses show that percutaneous curved kyphoplasty reduces operative time and cement leakage [11]. Only one randomized trial has directly compared cement viscosities; the limited evidence base includes that RCT and retrospective studies, leaving uncertainty in optimal selection, fill volume, and long-term structural and clinical outcomes.

This study aims to conduct a direct comparative meta-analysis evaluating clinical outcomes of low- versus high-viscosity PMMA cement in PVP for OVCF. We hypothesized that high-viscosity cement may be associated with a lower risk of radiographic cement leakage than low-viscosity cement, while pain relief, functional outcomes, vertebral height restoration, and adjacent vertebral fracture rates may not differ materially between groups. Because the available evidence base is small and includes mixed study designs, the findings are intended to inform evidence gaps and future trial design rather than establish definitive practice recommendations.

2. Materials and Methods

2.1. Study Design and Registration

This systematic review and meta-analysis were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement [12].

2.2. Eligibility Criteria

Studies were included if they met the following criteria: (1) population: adult patients (aged ≥ 50 years) with radiologically confirmed osteoporotic vertebral compression fractures (OVCFs); (2) intervention: percutaneous vertebroplasty (PVP) using high-viscosity cement (HVC); (3) comparator: PVP using low-viscosity cement (LVC); (4) outcomes: at least one of the following visual analog scale (VAS) for pain, Oswestry Disability Index (ODI), cement leakage rate (overall and by location), vertebral height restoration, complication rates, or adjacent vertebral fracture; (5) study design: randomized controlled trials (RCTs) or prospective/ret-

rospective comparative cohort studies; (6) extractable numeric data available.

Exclusion criteria were: (1) mixed pathological fractures (e.g., malignant or traumatic non-osteoporotic); (2) studies comparing HVC PVP versus LVC kyphoplasty (PKP) as the primary comparison; (3) case series without a comparator; (4) review articles, editorials, or conference abstracts without full-text data; (5) duplicate publications; (6) non-English or non-Chinese language publications without available translation.

2.3. Search Strategy

A comprehensive literature search was performed across PubMed, Embase, Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, and China National Knowledge Infrastructure (CNKI) from inception to April 15, 2026. The search strategy combined Medical Subject Headings (MeSH) and free-text terms: (“vertebroplasty” OR “PVP” OR “vertebral augmentation”) AND (“high viscosity” OR “low viscosity” OR “cement viscosity”) AND (“osteoporotic vertebral compression fracture” OR “OVCF” OR “vertebral fracture”) AND (“randomized” OR “cohort” OR “comparative” OR “controlled”). Reference lists of included studies and relevant meta-analyses were manually screened for additional eligible studies. The search strategy was developed following the Cochrane Handbook guidelines [13]. No language restriction was applied at the search stage; however, only publications in English or Chinese with available translation were ultimately included.

2.4. Study Selection and Data Extraction

Two independent reviewers screened titles, abstracts, and full texts against eligibility criteria. Disagreements were resolved by consensus or consultation with a third reviewer. A standardized data extraction form, based on the Cochrane Data Collection Form for intervention reviews [14], was used to collect: (1) study characteristics (first author, year, country, design, sample size, follow-up duration); (2) patient demographics (age, sex, fracture level distribution); (3) intervention details (cement type, viscosity specifications, injected volume); (4) outcome data (means, standard deviations, event counts, and total denominators for each time point); (5) methodological information for bias assessment.

For studies reporting outcomes at multiple time points, the longest available follow-up was used for the primary analysis, with intermediate time points included in sensitivity analyses when applicable. Where data were presented only graphically, numerical extraction was performed using WebPlotDigitizer version 4.6 (Automeris, LLC) by two independent extractors, with discrepancies resolved through re-extraction and consensus.

2.5. Outcomes Definition

The primary outcome was cement leakage rate, defined as the proportion of vertebrae (or patients, as reported) with extravertebral cement extravasation detected on postoperative radiography or computed tomography. Secondary outcomes included: (1) pain relief measured by VAS (0 - 10 scale); (2) functional improvement

measured by ODI (0 - 100 scale); (3) vertebral height restoration (percentage of anterior vertebral body height relative to adjacent normal vertebra); (4) procedure-related complications (pulmonary cement embolism, neural compression, infection); (5) adjacent vertebral fracture rate; (6) operative time (minutes); (7) injected cement volume (milliliters).

2.6. Risk of Bias Assessment

Two reviewers independently assessed methodological quality. For RCTs, the Cochrane Risk of Bias 2.0 tool was used to evaluate five domains: randomization process, deviations from the intended intervention, missing outcome data, measurement of outcomes, and selection of reported results. For cohort studies, the Newcastle-Ottawa Scale (NOS) was used to assess selection (4 items), comparability (2 items), and outcome (3 items), with scores ≥ 7 considered low risk of bias, 5 - 6 moderate risk, and ≤ 4 high risk. The detailed risk of bias judgments for each included study are presented in **Table 1** (RCTs) and **Table 2** (cohort studies).

The certainty of evidence for key outcomes was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework. Certainty was considered in relation to risk of bias, inconsistency, indirectness, imprecision, and publication bias. Because the included evidence consisted of one RCT and three retrospective comparative cohorts with small sample sizes, conclusions were interpreted conservatively.

Table 1. Risk of bias assessment for randomized controlled trials (Cochrane RoB 2).

Study	Randomization process	Deviations from intended interventions	Missing outcome data	Measurement of outcome	Selection of reported results	Overall judgment
Zhang <i>et al.</i> 2015 [15]	Some concerns	High risk	Low risk	Low risk	Some concerns	Some concerns

Table 2. Risk of bias assessment for cohort studies (Newcastle-Ottawa Scale).

Study	Selection (0 - 4)	Comparability (0 - 2)	Outcome (0 - 3)	Total (0 - 9)	Overall risk
Li <i>et al.</i> 2020 [16]	2	1	3	6	Moderate
Zhang <i>et al.</i> 2017 [17]	1	1	3	5	Moderate-High
Zeng <i>et al.</i> 2015 [18]	1	0	3	4	High

2.7. Statistical Analysis

Meta-analyses were performed using Review Manager version 5.4 (The Cochrane Collaboration, Oxford, UK) and Stata/SE version 17.0 (StataCorp LLC, College Station, TX, USA). Effect measures were calculated as odds ratios (ORs) with 95% confidence intervals (CIs) for dichotomous outcomes (cement leakage, complications, adjacent fractures) and mean differences (MDs) with 95% CIs for continuous outcomes (VAS, ODI, vertebral height, operative time, cement volume). Given anticipated clinical and methodological heterogeneity across studies, the

random-effects model (DerSimonian-Laird method) was applied for all pooled analyses. Statistical significance was set at $p < 0.05$.

Heterogeneity was quantified using the I^2 statistic, with the following interpretation: 0 - 40% might not be important, 30 - 60% moderate heterogeneity, 50 - 90% substantial heterogeneity, and 75 - 100% considerable heterogeneity. When I^2 exceeded 50%, sources of heterogeneity were explored through sensitivity analyses.

Owing to the limited number of studies, prespecified subgroup analyses by study design, follow-up duration, and leakage detection method could not be performed. Sensitivity analyses were conducted by excluding studies at high risk of bias ($NOS \leq 4$) and by considering only RCT data where applicable.

Publication bias was not formally assessed for the primary outcome because fewer than 10 studies were available.

3. Results

3.1. Study Selection and Characteristics

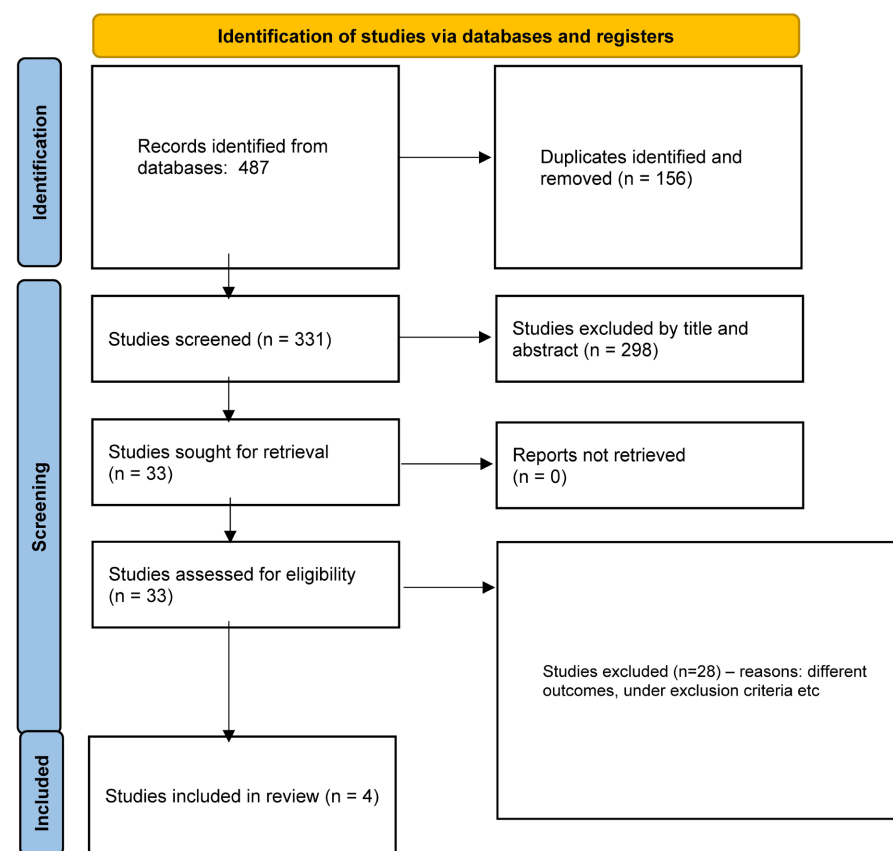


Figure 1. Prisma 2020 flow diagram. Records were identified, deduplicated, screened, assessed for eligibility, and narrowed to four studies included in the quantitative synthesis.

From the systematic literature search, 487 records were identified. After duplicate removal ($n = 156$), title and abstract screening ($n = 331$) excluded 298 records.

Full-text assessment of 33 articles resulted in inclusion of 4 studies [15]-[18] meeting all eligibility criteria for the primary viscosity-only PVP comparison. One study that was initially considered (Wang *et al.*, 2022 [19]) was identified as a meta-analysis rather than a primary comparative study and was therefore excluded from the quantitative synthesis. The PRISMA flow diagram is presented in **Figure 1**.

Table 3 summarizes the characteristics of the 4 included studies. A total of 218 patients (110 HVC, 108 LVC) with 235 treated vertebrae were analyzed across studies. Sample sizes ranged from 32 to 80 patients per study. Follow-up duration varied from 12 months to 5 years. All studies originated from China. One study was an RCT [15], and three were retrospective comparative cohorts [16]-[18].

Table 3. Characteristics of included studies.

Study	Country	Design	HVC (n)	LVC (n)	Vertebrae (HVC/LVC)	Follow-up	Cement type HVC	Cement type LVC
Li <i>et al.</i> 2020 [16]	China	Retrospective cohort	40	40	40/40	1 year	Confidence (DePuy)	Not specified
Zhang <i>et al.</i> 2017 [17]	China	Retrospective cohort	36	30	36/30	1 year	Not specified	Not specified
Zhang <i>et al.</i> 2015 [15]	China	RCT	14	18	17/22	24.5 months	Not specified	Not specified
Zeng <i>et al.</i> 2015 [18]	China	Retrospective cohort	20	20	26/24	2 - 5 years	Not specified	Not specified

3.2. Cement Leakage Outcomes

Because pooling per-patient and per-vertebra data can distort effect estimates, two separate meta-analyses were performed according to unit of analysis.

Per-patient analysis (2 studies, 146 patients): Li *et al.* 2020 [16] and Zhang *et al.* 2017 [17] reported leakage at the patient level. The pooled OR for HVC versus LVC was 0.19 (95% CI 0.09 - 0.40, $p < 0.0001$) with low heterogeneity ($I^2 = 0\%$) (**Figure 2(A)**).

Per-vertebra analysis (2 studies, 89 vertebrae): Zhang *et al.* 2015 [15] and Zeng *et al.* 2015 [18] reported leakage per vertebra. The pooled OR was 0.22 (95% CI 0.08 - 0.63, $p = 0.005$) with low heterogeneity ($I^2 = 0\%$) (**Figure 2(B)**).

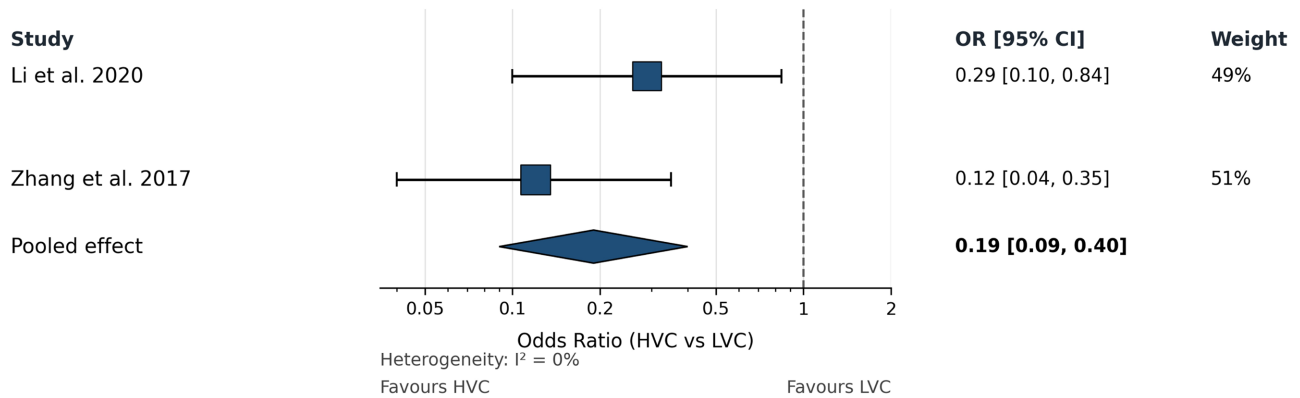
In both analyses, the direction and magnitude of effect consistently favored HVC.

Detailed study-level data are presented below:

- Li *et al.* 2020 [16] reported leakage in 6/40 (15.0%) HVC patients versus 15/40 (37.5%) LVC patients (OR 0.29, 95% CI 0.10 - 0.84).
- Zhang *et al.* 2017 [17] reported overall leakage of 30.55% (11/36) in HVC versus 77.77% (23/30) in LVC (OR 0.12, 95% CI 0.04 - 0.35).
- Zhang *et al.* 2015 [15] reported CT-detected leakage per vertebra: 5/17 (29.4%) in HVC versus 15/22 (68.2%) in LVC (OR 0.20, 95% CI 0.05 - 0.79).

- Zeng *et al.* 2015 [18] reported leakage per vertebra: 2/26 (7.7%) in HVC versus 6/24 (25.0%) in LVC (OR 0.25, 95% CI 0.05 - 1.25).

(A)

Per-patient cement leakage

(B)

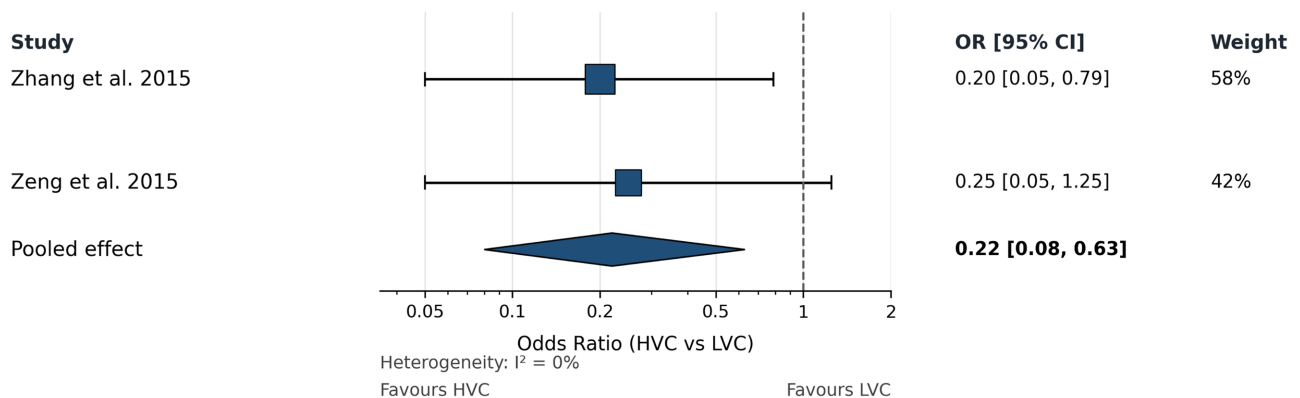
Per-vertebra cement leakage

Figure 2. (A) Forest plot: cement leakage (Per-patient analysis). Both included studies favored HVC, with a pooled odds ratio of 0.19 and no observed heterogeneity. (B) Forest plot: cement leakage (Per-vertebra analysis). The per-vertebra analysis favored HVC, with a pooled odds ratio of 0.22 and no observed heterogeneity.

3.3. Pain Relief (Visual Analog Scale)

Three studies reported VAS scores at baseline and follow-up with extractable data [15]-[17]. At baseline, there was no significant difference between groups (MD -0.11, 95% CI -0.48 to 0.26, $p = 0.56$, $I^2 = 0\%$). At final follow-up (range 12 - 24.5 months), both groups showed substantial improvement from baseline, but between-group differences were not statistically significant (MD -0.06, 95% CI -0.19 to 0.07, $p = 0.35$, $I^2 = 0\%$) (Figure 3). For Zhang *et al.* 2017 [17], numerical VAS data were not directly reported in the text; the mean difference and confidence interval were extracted from the published figure using WebPlotDigitizer version 4.6, yielding a final follow-up MD of 0.00 (95% CI -0.45 to 0.45). The other studies provided numeric values as described.

VAS at final follow-up

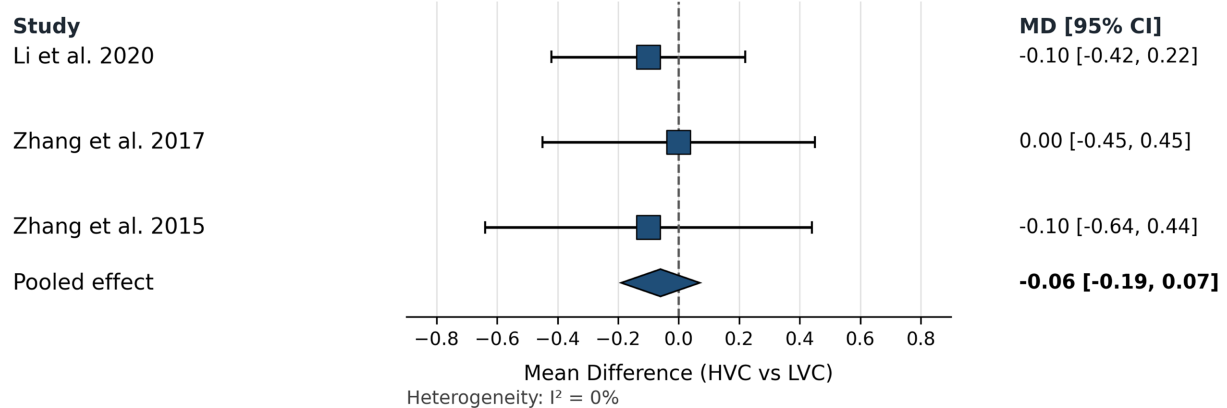


Figure 3. Forest plot: VAS at final follow-up. Pain outcomes at final follow-up were similar between groups, with a pooled mean difference of -0.06 .

ODI at final follow-up

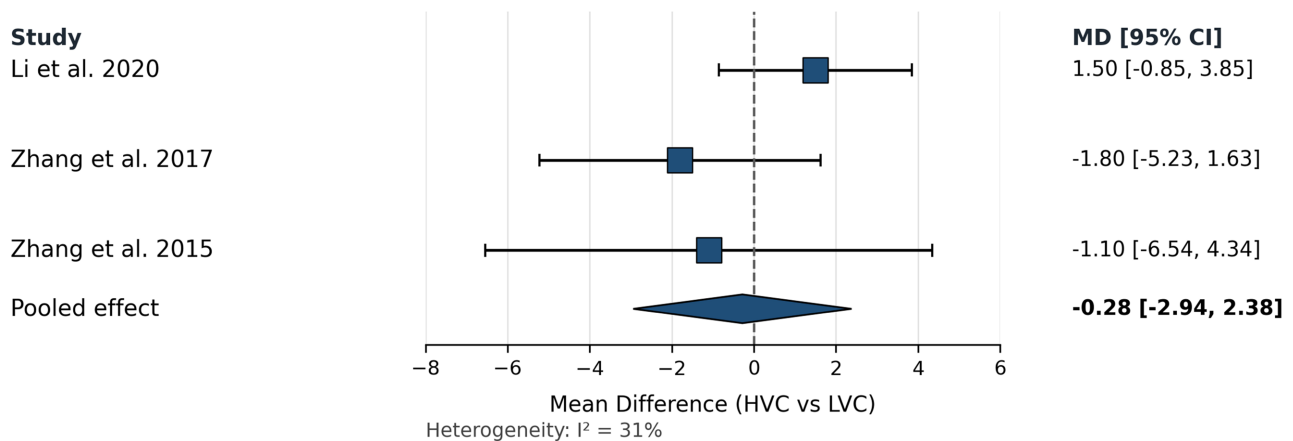


Figure 4. Forest plot: ODI at final follow-up. Functional outcomes at final follow-up showed no clear difference between groups, with moderate-low heterogeneity.

3.4. Functional Outcome (Oswestry Disability Index)

Three studies reported ODI scores with extractable data [15]–[17]. Baseline ODI showed no significant difference (MD 0.86, 95% CI -2.13 to 3.85 , $p = 0.57$, $I^2 = 0\%$). At final follow-up, the pooled analysis showed no significant difference between HVC and LVC (MD = -0.28 , 95% CI -2.94 to 2.38 , $p = 0.84$, $I^2 = 31\%$) (Figure 4).

For Zhang *et al.* 2017 [17], ODI values were also extracted from the figure, giving an MD of -1.80 (95% CI -5.23 to 1.63). We found final follow-up ODI scores, HVC vs. LVC. Li 2020 (MD 1.50 , 95% CI -0.85 to 3.85), Zhang 2017 (MD -1.80 ,

95% CI -5.23 to 1.63), Zhang 2015 (MD -1.10, 95% CI -6.54 to 4.34). Pooled MD -0.28, 95% CI -2.94 to 2.38; $I^2 = 31\%$. See **Figure 4**. Li *et al.* 2020 [16] reported ODI: preop HVC 77.2 ± 7.5 vs. LVC 75.7 ± 8.1 ($p = 0.39$); at 2 days: 29.5 ± 7.1 vs. 28.2 ± 6.5 ($p = 0.39$); at 6 months: 27.3 ± 6.0 vs. 25.6 ± 5.7 ($p = 0.20$); at 1 year: 26.8 ± 5.5 vs. 25.3 ± 5.3 ($p = 0.21$). The trend favored LVC at later time points, but differences were not statistically significant. Zhang *et al.* 2017 [17] reported no significant between-group difference in ODI at final follow-up ($p > 0.05$). Specific numerical values were not extractable. Zhang *et al.* 2015 [15] reported ODI improved from 71.6 ± 7.5 to 24.7 ± 6.9 in HVC and from 73.1 ± 6.8 to 25.8 ± 6.4 in LVC, with no significant difference between groups ($p = 0.62$).

3.5. Vertebral Height Restoration

Two studies reported vertebral height data with sufficient detail [15] [16]. Neither study demonstrated significant between-group differences in the restoration of anterior vertebral height. Li *et al.* 2020 [16] reported anterior vertebral height percentage: preop HVC $42.5 \pm 11.1\%$ vs. LVC $41.4 \pm 12.6\%$ ($p = 0.68$); at 2 days postop: $45.2 \pm 11.8\%$ vs. $44.2 \pm 13.7\%$ ($p = 0.73$); at 1 year: $41.6 \pm 10.2\%$ vs. $40.3 \pm 10.7\%$ ($p = 0.58$). The small initial height gain was not maintained at 1 year, with no viscosity-related difference. Zhang *et al.* (2015) [15] reported that both groups showed significant restoration of vertebral height postoperatively, with no between-group difference ($p > 0.05$). Specific percentages were not extractable from the published data.

3.6. Operative Time and Cement Volume

Two studies reported operative time and cement volume [15] [16]. Operative time showed no significant difference between HVC and LVC (Li *et al.* 2020 [15]: 31.2 ± 7.5 vs. 33.3 ± 8.0 min, $p = 0.23$; Zhang *et al.* 2015 [15]: $p = 0.46$). Cement volume was significantly lower in the HVC group in Li *et al.* (2020) [16] (3.2 ± 0.6 vs. 4.1 ± 0.8 mL, $p < 0.001$) but showed no significant difference in Zhang *et al.* (2015) [15] ($p = 0.67$). Pooled analysis was not performed due to inconsistent reporting and potential clinical heterogeneity.

3.7. Complications and Adjacent Fractures

All available complication data were narrative. Li *et al.* (2020) [16] reported two non-adjacent fractures in the HVC group and one in the LVC group within 6 months ($p > 0.05$). No postoperative refracture of cemented vertebrae occurred in either group. Zeng *et al.* (2015) [18] reported no postoperative refracture in either group during follow-up. No pulmonary cement embolism events were reported in any included study. Neural compression secondary to cement leakage was not reported in any included study.

3.8. Subgroup and Sensitivity Analyses

Sensitivity analyses were limited to the primary leakage outcome. Exclusion of the

high-risk-of-bias study (Zeng *et al.* 2015 [18], NOS = 4) from the per-vertebra analysis yielded a single-study OR of 0.20 (95% CI 0.05 - 0.79), consistent with the main findings. When restricting to the single RCT (Zhang *et al.* 2015 [15]), the per-vertebra OR was identical. The per-patient pooled estimate remained stable after removing Zhang *et al.* 2017 (OR 0.29, 95% CI 0.10 - 0.84). Overall, results were robust to the exclusion of individual studies.

3.9. Publication Bias

Funnel plot assessment for the primary outcome (cement leakage) was not performed due to the small number of included studies ($k = 4$). Egger's test has low power for $k < 10$, and formal assessment would be misleading.

Table 4. Summary of pooled effect estimates.

Outcome	No. of studies	HVC (n)	LVC (n)	Effect estimate (95% CI)	p-value	I ²
Cement leakage (per-patient, OR)	2	76	70	0.19 (0.09 - 0.40)	<0.0001	0%
Cement leakage (per-vertebra, OR)	2	43	46	0.22 (0.08 - 0.63)	0.005	0%
VAS at final follow-up (MD)	3	90	88	-0.06 (-0.19 to 0.07)	0.35	0%
ODI at final follow-up (MD)	3	90	88	-0.28 (-2.94 to 2.38)	0.84	31%

Table 5. Cement leakage by study, detailed extractable data.

Study	HVC leakage (n/N)	HVC rate (%)	LVC leakage (n/N)	LVC rate (%)	OR (95% CI)	Leakage assessment method
Li <i>et al.</i> 2020 [16]	6/40	15.0	15/40	37.5	0.29 (0.10 - 0.84)	Radiography
Zhang <i>et al.</i> 2017 [17]	11/36	30.6	23/30	76.7	0.12 (0.04 - 0.35)	Radiography
Zhang <i>et al.</i> 2015 [15]	5/17*	29.4	15/22*	68.2	0.20 (0.05 - 0.79)	CT
Zeng <i>et al.</i> 2015 [18]	2/26*	7.7	6/24*	25.0	0.25 (0.05 - 1.25)	Radiography

3.10. Certainty of Evidence (GRADE)

Using the GRADE framework, the certainty of evidence for cement leakage was rated low because the pooled estimate was based on a small evidence base with one RCT and three retrospective studies, with methodological limitations and imprecision. The certainty of evidence for VAS and ODI was rated low to very low because only three studies contributed data and confidence intervals were compatible with little or no difference. Vertebral height restoration, complications, and adjacent fractures were rated very low because they were narratively synthesized from sparse data. Accordingly, all conclusions were revised to use cautious language such as “limited evidence suggests” and “low-certainty evidence indicates,” and the need for large-scale randomized controlled trials was emphasized.

4. Discussion

This meta-analysis synthesized data from 4 comparative studies comprising 218

patients. Limited, low-certainty evidence suggests that high-viscosity cement (HVC) may reduce radiographic cement leakage compared with low-viscosity cement (LVC) when both are used in percutaneous vertebroplasty (PVP) for osteoporotic vertebral compression fractures. The pooled estimates favored HVC in both per-patient (OR 0.19, 95% CI 0.09 - 0.40) and per-vertebra (OR 0.22, 95% CI 0.08 - 0.63) analyses. However, this radiographic finding did not translate into demonstrably better patient-reported outcomes: final follow-up VAS and ODI scores were similar between groups, and vertebral height restoration and complications were only narratively assessed from limited data. Therefore, the findings should be interpreted as hypothesis-generating rather than definitive.

Biomechanical Interpretation

Within PVP, the observed difference in leakage is biologically plausible because cement viscosity affects flow through cancellous bone, cortical defects, and venous channels. High-viscosity cement is more cohesive and less prone to uncontrolled spread, which may reduce extravertebral migration during injection. Low-viscosity cement may penetrate trabecular spaces more easily, but this same property can increase the chance of leakage if cortical integrity is compromised or if injection continues after early extravasation is observed. These mechanisms relate specifically to PVP and should not be extrapolated to balloon kyphoplasty, where balloon cavity creation changes injection pressure, cement distribution, and leakage pathways.

Clinical Implications

Patient selection may help guide viscosity choice in PVP, although the current evidence is limited. High-viscosity cement may be considered when preoperative imaging shows features associated with leakage risk, such as cortical disruption, intravertebral clefts, severe collapse, or suspected venous communication. Low-viscosity cement may remain reasonable in selected mild-to-moderate fractures without cortical breach, provided injection is performed slowly under continuous fluoroscopic monitoring. These statements should be interpreted as cautious clinical considerations rather than firm recommendations because only one RCT and three retrospective cohorts were available. Large, multicenter RCTs with standardized injection protocols are required before definitive viscosity-selection algorithms can be proposed [20].

Comparison with Previous Literature

Previous reviews sometimes combined PVP and PKP studies or compared HVC-PVP with LVC-PKP, which creates indirect comparisons involving different procedures and leakage mechanisms. In contrast, the present review restricted eligibility to direct HVC-PVP versus LVC-PVP comparisons and excluded studies in which kyphoplasty was the primary comparator. Therefore, earlier PKP-related findings are not used here to explain the pooled PVP-only effect. The revised interpretation focuses strictly on cement viscosity within PVP and recognizes that the small number of eligible studies limits the strength of any comparison with prior literature [19] [21].

Strengths

The systematic literature search was comprehensive, covering five databases with a consistent date and language specification. Inclusion of both an RCT and observational comparative studies enhances generalizability, while the separate per-patient and per-vertebra leakage analyses avoid unit-of-analysis error. Sensitivity analyses confirmed stability.

Limitations

Several limitations warrant caution. First, predominantly observational data (3 of 4 studies were retrospective cohorts) introduce selection bias; higher-risk fractures may have been preferentially treated with HVC, potentially attenuating or exaggerating observed differences. Second, cement formulations were not consistently specified, and most studies did not provide quantitative viscosity measurements, limiting comparability across products. Third, follow-up durations varied from 12 months to 5 years, limiting assessment of long-term outcomes such as adjacent-level fracture, cement fatigue, or vertebral recollapse. Fourth, publication bias remains possible, but formal funnel-plot assessment was precluded by the small number of included studies ($k = 4$). Fifth, major adverse events such as pulmonary cement embolism or neural compromise were not observed in the included studies; however, the total sample size of 218 patients is insufficient to detect rare complications reliably.

Future Directions

Future research should prioritize large, adequately powered randomized controlled trials that directly compare HVC-PVP and LVC-PVP using standardized eligibility criteria, cement preparation protocols, injection volumes, imaging follow-up, and outcome definitions. Quantitative viscosity reporting (for example, dynamic viscosity and working time at standardized temperatures) would improve reproducibility and allow more meaningful pooling across studies. Future trials should also assess rare complications, vertebral recollapse, adjacent-level fracture, quality of life, and cost-effectiveness over longer follow-up periods.

5. Conclusion

Low-certainty evidence suggests that high-viscosity cement may reduce radiographic cement leakage compared with low-viscosity cement in percutaneous vertebroplasty, based on separate per-patient and per-vertebra analyses. Available data do not demonstrate superior pain relief or functional recovery with either viscosity formulation, and vertebral height restoration and complications were supported only by sparse narrative evidence. Because the evidence base is small and includes mixed study designs, these conclusions should be interpreted cautiously. Cement selection should be individualized according to fracture morphology, cortical integrity, leakage risk, and surgeon experience. Large, well-designed randomized controlled trials with standardized viscosity reporting are needed to confirm these findings.

Plain Language Summary

Osteoporosis weakens bones, making spinal vertebrae prone to compression fractures that cause severe back pain and disability. To treat these fractures, doctors may inject bone cement into the collapsed vertebra, a procedure called vertebroplasty. The cement comes in two consistencies: “thick” (high-viscosity) and “runny” (low-viscosity). This study analyzed four previous studies involving 218 patients. Limited evidence suggests that thick cement may be less likely to leak outside the vertebra than runny cement. However, both types of cement showed similar pain relief and functional outcomes in the available studies. Because only one randomized trial and three retrospective studies were available, the findings should be interpreted cautiously, and larger randomized trials are needed before firm conclusions can be made.

Data Availability

All extracted data are presented in the tables and figures. The full data extraction sheet is available from the corresponding author upon reasonable request.

Acknowledgments

None.

Conflicts of Interest

The authors declare no competing interests.

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Abbreviations

Abbreviation	Full form
<i>OVCF</i>	Osteoporotic vertebral compression fracture
<i>VAS</i>	Visual analog scale
<i>ODI</i>	Oswestry Disability Index
<i>PMMA</i>	Polymethylmethacrylate
<i>RCT</i>	Randomized controlled trial
<i>HVC</i>	High-viscosity cement
<i>LVC</i>	Low-viscosity cement
<i>PVP</i>	Percutaneous vertebroplasty
<i>PKP</i>	Percutaneous kyphoplasty
<i>CI</i>	Confidence interval
<i>OR</i>	Odds ratio
<i>MD</i>	Mean difference