REVIEW

Advantages of unilateral percutaneous kyphoplasty for osteoporotic vertebral compression fractures—a systematic review and meta-analysis

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Abstract

Summary Data from English randomized controlled trials comparing unilateral versus bilateral PKP for the treatment of OVCFs were retrieved and analyzed, and the results showed that unilateral PKP is a better choice for the treatment of patients with OVCFs, which will provide a reliable clinical rationale for the treatment of OVCFs.

Purpose To investigate the advantages of unilateral percutaneous kyphoplasty (PKP) for the treatment of osteoporotic vertebral compression fractures(OVCFs).

Methods The systematic evaluation program met all program requirements (CRD 42023422383) by successfully passing the PROSPERO International Prospective Systematic Evaluation Registry. Researchers searched the references of English-language randomized controlled trials comparing unilateral and bilateral PKP for the treatment of osteoporotic vertebral compression fractures published between 2010 and 2023 and manually searched for known primary and review articles. The study statistically analyzed data from all the included literature, which primarily included time to surgery, visual pain score(VAS) and Oswestry disability index(ODI) at postoperative follow-up time points, polymethylmethacrylate (PMMA, bone cement) injection dose, cement leakage, radiation dose, and improvement in kyphotic angle.

Results This meta-analysis searched 416 articles published from 2010 to 2023 based on keywords, and 18 articles were finally included in this study. The results of the forest plot showed that unilateral PKP operative time, amount of bone cement used, and radiation dose to the patient were significantly reduced ($p < 0.01$, $p < 0.01$, and $p < 0.01$, respectively), and unilateral and bilateral PKP had comparable cement leakage ($p = 0.49$, 95% CI $= 0.58$–1.30), and there was no significant difference in the kyphotic angle between unilateral and bilateral PKP ($p = 0.42$, 95% CI $= -2.29$–0.96). During follow-up, there was no significant difference in pain relief between unilateral and bilateral PKP ($p = 0.70$, 95% CI $= -0.09$–0.06), nor was there a significant difference in ODI ($p = 0.27$, 95% CI $= -0.35$–1.24).

Conclusions There is no difference in clinical efficacy between unilateral PKP and bilateral PKP, but unilateral PKP has a shorter operative time, a lower incidence of cement leakage, a lower amount of cement, and a lower radiation dose to the patient and operator. Unilateral PKP is a better option for patients with OVCFs.

Keywords Osteoporosis · Vertebral compression fracture · Lumbar vertebra · Thoracic vertebra · Percutaneous kyphoplasty · Bone cement

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Introduction

Osteoporotic vertebral compression fractures (OVCFs) can be caused by minor injuries or without any significant history of trauma during daily activities. They primarily affect the thoracolumbar spine, resulting in lower back and back pain with or without neurologic symptoms in the lower extremities. In severe cases, bilateral lower extremity paralysis can occur [1]. OVCFs are a grave consequence of osteoporosis [2]. The main cause of this condition is

primary osteoporosis, which results in decreased bone mass, decreased bone strength, and increased spinal fragility. Currently, many risk factors, such as dietary habits, insufficient exercise habits, and hormonal drug abuse, have led to an increase in the prevalence of OVCFs year after year, especially in menopausal women [3]. Accurate estimation of the global prevalence and incidence of OVCFs based on available data becomes challenging due to the insidious course of the disease, low diagnostic rates, lack of awareness among the public and healthcare professionals, and significant variations in epidemiologic data among different countries and ethnic groups. Low cure rates coupled with high rates of underdiagnosis further impede the timely and effective treatment of patients with OVCFs [4].

Minimally invasive percutaneous vertebroplasty (PVP) and PKP are widely used in the treatment of elderly OVCFs [5]. PVP began in the early 1980s. Since PVP cannot restore the normal height of the spine, patients have postoperative pain relief, but the possibility of kyphosis still exists. The leakage rate of PVP bone cement in conventional vertebroplasty can be more than 80% [6]. In the late 1990s, PKP was introduced to inject bone cement into the compressed vertebral body using a balloon expansion molding system based on lessons learned from PVP. PKP not only restores compressed strength and stiffness, but also partially restores the height of the compressed vertebral body, corrects kyphosis, and reduces the pressure on the distended vertebral body, making the cement injections safer and achieving a better therapeutic outcome than PVP. PKP is currently the treatment of choice for OVCFs [7–9].

Currently, the main surgical puncture modalities for PKP in OVCFs are unilateral transpedicular puncture, bilateral transpedicular puncture, and bilateral transverse pedicle puncture [6, 10, 11]. However, there is more disagreement about the clinical efficacy and selection of unilateral and bilateral PKP. This meta-analysis compares the clinical efficacy and surgical risk of unilateral and bilateral PKP for the treatment of OVCFs by comparing the duration of the procedure, the dose of polymethylmethacrylate (PMMA, bone cement) injections, the percentage of cement leakage, the dose of X-ray radiation at preoperative and postoperative follow-up time points, the visual pain score(VAS) and the Oswestry disability index (ODI), and the improvement in the kyphotic angle in the postoperative period.

Methods

Data sources

A meta-analysis and retrospective evaluation of unilateral percutaneous kyphoplasty for osteoporotic vertebral compression fractures was registered according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (PROSPERO: CRD 42023422383). A comprehensive search of the Cochrane Controlled Trials Register, PubMed, MEDLINE, and Web of Science was conducted to manually search the bibliographies of English-language randomized controlled trials comparing unilateral and bilateral PKP for OVCF published between 2010 and 2023. The search included the Current Controlled Trials Register and the Cochrane Database of Controlled Trials. Relevant references were searched for additional citations using the keywords "osteoporosis," "vertebral compression fracture," "lumbar spine," "thoracic spine," "percutaneous kyphoplasty," "unilateral," and "bilateral."
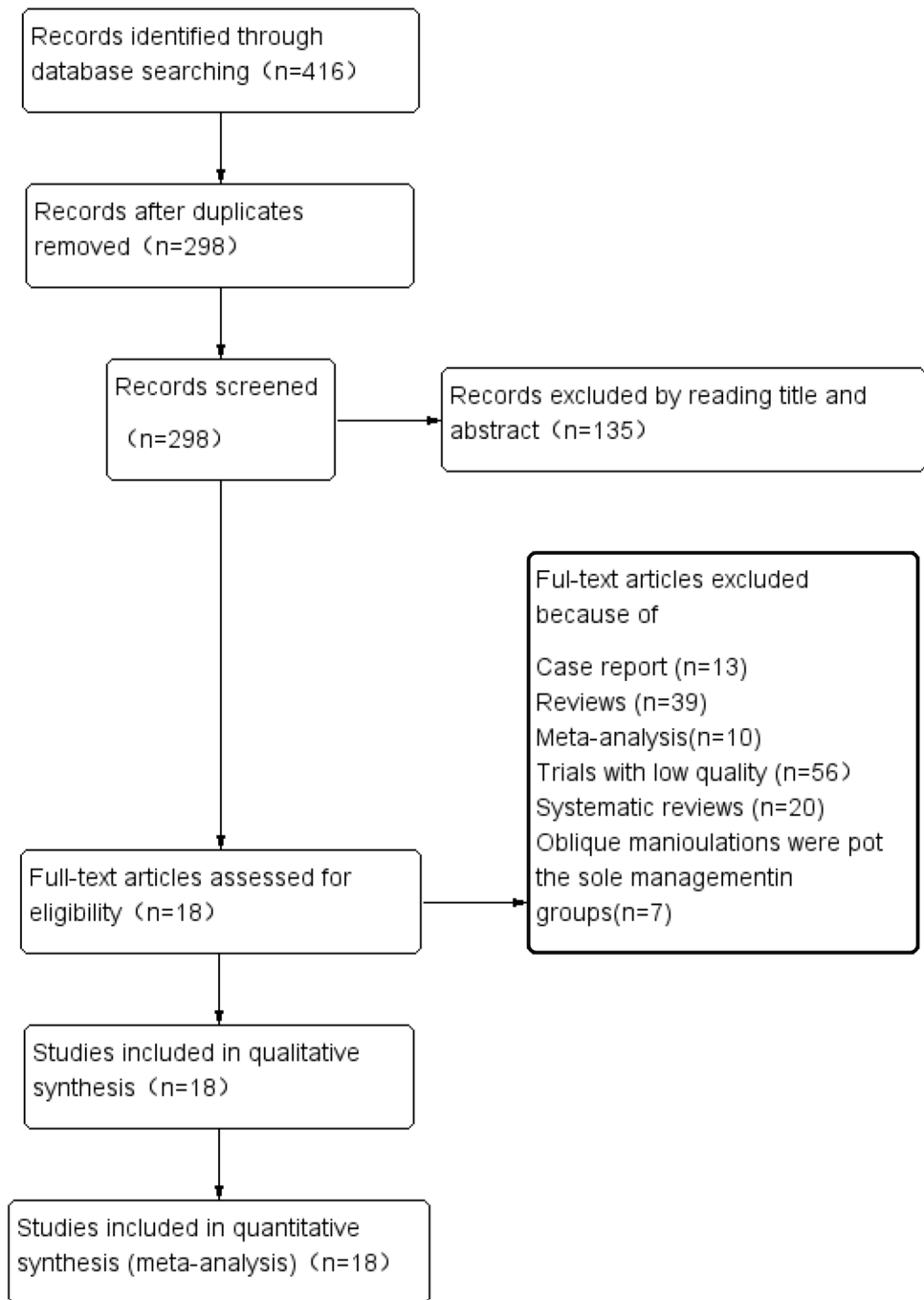
Inclusion criteria

(1) Study design: Prospective or retrospective studies, randomized controlled studies, double-blind or single-blind studies;

(2) Study population: All patients were adults (at least 18 years old) with low back pain caused by OVCFs, and the treatment methods adopted before this study had failed;

(3) Objective: To compare the advantages and disadvantages or clinical outcomes of unilateral and bilateral kyphoplasty;

(4) Outcome measures: The included studies included at least one of the following outcomes: operation time, PMMA injection dose, the proportion of bone cement leakage, operator and patient of radiation dose of X-ray, VAS [12], and ODI [13] at preoperative and postoperative follow-up time points, and kyphotic angle improves condition.

Exclusion criteria

(1) Studies with clinical outcome metrics lacking long-term follow-up results;

(2) Severe degenerative spinal disease, prior vertebral surgery, biomechanical analysis studies, and studies performed in cadavers.

Retrieval strategies

Two authors independently searched for titles, abstracts, and potentially eligible full text of articles based on the search strategy and inclusion criteria and finally summarized all retrieved articles. If the two authors could not reach a consensus on an article, the corresponding author made the final decision on the inclusion of the study (Fig. 1).

Fig. 1 Flow chart of study selection

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┌─────────────────────────┐
│ Records identified through │
│ database searching (n=416) │
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│ Records after duplicates │
│ removed (n=298)          │
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│ Records screened         │ ─────▶ │ Records excluded by reading title │
│ (n=298)                  │        │ and abstract (n=135)          │
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             │                      │ because of                    │
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             │                      │ Case report (n=13)            │
             │                      │ Reviews (n=39)                │
             │                      │ Meta-analysis(n=10)           │
             │                      │ Trials with low quality (n=56)│
             │                      │ Systematic reviews (n=20)     │
             │                      │ Oblique manioulations were pot│
             ▼                      │ the sole managementin         │
┌─────────────────────────┐        │ groups(n=7)                   │
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│ for eligibility (n=18)   │        └──────────────────────────────┘
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│ Studies included in      │
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│ Studies included in      │
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│ (meta-analysis) (n=18)   │
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Data extraction

Data were extracted jointly by two authors and screened and sorted using the Microsoft Word 2021 table tool (Table 1). All literature included in the study was collected based on outcome metrics, including type of study, total number, gender, age, baseline pain intensity (0–10 points), duration of surgery at the follow-up time point, PMMA injection dose, percentage of cement leakage, X-ray radiation dose to the operator and patient, VAS and ODI at the preoperative and postoperative follow-up time points, and vertebral kyphosis angle improvement.

Data analysis

Separate meta-analyses were performed for each outcome using Review Manager software (RevMan version 5.4 Cochrane Collaboration). For the incidence of cement leakage, relative risks (RR) and 95% confidence intervals (95% CI) were calculated using the dichotomous variable method;

Table 1 Characteristics of included studies

Number	Reference	Total no. of subjects (subjects in U/B groups)	Gender (male/female)	Age (years) (mean ± standard deviation)	Follow-up period	Follow-up time point
1	Liang Yan et al.(2014) [46]	309(158/151)	89/220	U: 71.9 ± 4.2 B: 71.1 ± 3.7	From 12 to 28 months, with an average of 16.8 months	1, 3, 6, and 12 months
2	L. Yan et al.(2015) [47]	108 (55/53)	15/39	68.9 ± 4.2	NR	1, 3, 6, 9, and 12 months
3	Jianhua Lu et al.(2023) [48]	79 (37/42)	U: 14/23 B: 13/29	U: 67.4 ± 11.4 B: 70.3 ± 11.9	U: 19.4 ± 8.2 months B: 18.7 ± 8.4 months	3 months, 1 year, and 2 years
4	GOU Yongsheng et al. (2020) [49]	68 (32/36)	U: 10/22 B: 11/25	U: range 60–91 B: range 61–89	10~35 months follow-up time, an average of 18 months	Before operation, at 1 day and 6 months after operation
5	Chung Hun Lee et al. (2020) [50]	96 (28/68)	U: 9/19 B: 14/54	U: 70.5 ± 11.8 B: 74.7 ± 9.2	NR	Before the procedure and 1, 3, 6, and 12 months after the procedure
6	Chunmao Chen et al. (2011) [51]	50 (27/23)	0/50	U: 68.37 ± 7.64 B: 69.43 ± 6.22	NR	2 weeks, 6 months, and 2 years after surgery
7	Dan Pan et al.(2022) [52]	40 (19/21)	U: 7/12 B: 8/13	U: 73.21 ± 7.64 B: 71.62 ± 8.11	U: 27.58 ± 3.69 months B: 28.67 ± 3.61 months	1 day after the operation and the last follow-up
8	Yixuan Tan et al. (2023) [53]	78 (36/42)	U: 10/26 B: 13/29	U: 72.0 ± 7.6 B: 70.1 ± 7.1	U: 35.2 ± 14.0 months B: 34.1 ± 9.0 months	Preoperatively, 24 h, 3 months, and 12 months postoperatively
9	Fei Zhang et al. (2021) [54]	98 (62/36)	U: 20/42 B: 12/24	U: 77.3 ± 8.6 B: 75.6 ± 9.5	NR	Before the procedure and 3 days after the procedure
10	Yuting Zhang et al. (2022) [55]	67 (29/38)	U: 10/19 B: 12/26	U: 73.6 ± 5.7 B: 74.1 ± 4.9	17.1 months	Preoperatively, 6 months postoperatively
11	Zhirong Wang et al. (2011) [56]	62 (31/31)	U: 13/18 B: 17/14	U: 68.3 B: 69.2	U: 16.7 ± 2.5 months B: 15.9 ± 3.2 months	Follow-up time of over 1 year after treatment
12	Liang Zhang et al. (2015) [57]	50(24/26)	U: 8/16 B: 10/16	U: 71.7 ± 7.5 B: 72.1 ± 6.0	NR	Preoperative, 3 days and 2 years postoperatively
13	B. J. Rebolledo et al. (2013) [58]	44(23/21)	U: 4/19 B: 2/19	U: 78.7 ± 7.8 B: 79.3 ± 6.5	NR	Pre-operatively, and at 3 and 12 months post-operatively
14	Jin Tang et al.(2019) [59]	178(83//95)	U: 26/57 B: 32/63	U: 72.3 ± 3.6 B: 73.9 ± 2.8	U: 9.3 ± 1.8 months B: 8.5 ± 1.6 months	Before and 24 h, 3 months, and 6 months after surgery
15	Yunfan Qian et al. (2023) [60]	160(82//78)	U: 9/73 B: 15/63	U: 75.86 ± 7.74 B: 74.23 ± 8.17	NR	Preoperative, postoperative
16	Ming Xing Liu et al. (2018) [61]	85(42/43)	U: 15/27 B: 17/26	U: 67.7 ± 7.4 B: 70.5 ± 12.8	NR	Preoperative, postoperative
17	Atilla Yılmaz et al. (2017) [62]	87(36/51)	28/59	NR	NR	Preoperatively, at post-operative 1 day, and 1 year
18	Yu Qiao et al. (2023) [63]	147(79/68)	U: 18/61 B: 13/55	U: 70.73 ± 6.61 B: 73.27 ± 6.94	6.8 months	1 day, 1 month, and 6 months after surgery

U/B, unilateral/bilateral group; *NR*, not reported

for operative time, VAS and ODI at postoperative follow-up time points, PMMA injection dose, X-ray exposure dose, and improvement in the kyphosis angle, weighted mean difference (WMD) and 95% CI were calculated using the continuous variable method. Inter-study inconsistency was quantified by $I^2 = [(Q - df)/Q] \times 100\%$, where Q is the chi-square statistic and df is its degree of freedom [14–16]. I^2 defines the percentage of variability in the effect estimate that is due to heterogeneity rather than sampling error or chance, with $I^2 > 50\%$ indicating substantial heterogeneity.

$P < 0.05$ was considered statistically significant. I^2 and Q statistics were used to measure the heterogeneity of RCTs. If $I^2 < 50\%$, or $P > 0.1$, a fixed-effect model is used. If the $I^2 \geq 50\%$, or the $P \leq 0.1$, a random effects model is used [17, 18].

Risk of bias assessment

The two authors used the Cochrane Collaboration's bias risk assessment tool for each included study to conduct their independent bias risk assessment. Disagreement is arbitrated by another author. The tool assesses the following aspects of bias: allocation sequence generation, allocation concealment, blinding of researchers and subjects, blinding of outcome evaluators, incomplete outcome data, selective outcome reporting, and any other source of bias. Each item was classified as low risk of bias, fuzzy risk of bias, and high risk of bias. A bias risk assessment was performed on all included studies, and high bias risk, fuzzy bias risk, and low bias risk were listed. RevMan 5.4.1 was used to construct a risk bias map.

Results

Literature search

This study was conducted under the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (crd.york.ac.uk/prospero/display_record. php?RecordID=422383). A total of 416 articles of the relevant type published between 2010 and 2023 were searched. Of those, 118 articles were excluded for duplications, and 135 were excluded by reading the titles and abstracts. The full texts of 186 articles were checked for eligibility, from which 13 were excluded because they were case reports, 39 were excluded for review articles, 10 were excluded for meta-analysis, 56 were excluded for nonrandomized controlled trials,7 were excluded for oblique pulling manipulation not being the sole management in groups, and 20 were excluded for systematic reviews. Finally, 18 trials were included in our analysis. Figure 1 shows the selection process for relevant studies.

Study characteristics

A total of 18 randomized controlled trials were included in this meta-analysis, with a total of 1752 patients with OVCFs, including 494 males and 1258 females. A total of 1806 vertebral bodies diagnosed as OVCF received surgical treatment, of which 883 vertebral bodies received unilateral PKP and 923 patients received bilateral PKP. The shortest follow-up time was 6 months, and the longest

was 2 years (Table 1). Among the 17 studies, the operation time and the amount of bone cement were counted (Table 2). Three studies counted the radiation dose of patients and operators, respectively (Table 3). Thirteen studies compared bone cement leakage after unilateral and bilateral PKP (Table 4). Seven studies compared the kyphosis angle before and after unilateral and bilateral PKP (Table 5).

Meta-analysis results

Seventeen papers reported the operative time for patients, with large heterogeneity across studies ($P < 0.01$, $I^2 = 98\%$), and analysis using a random effects model showed that the operative time for unilateral PKP was significantly shorter than the operative room time for bilateral PKP (MD -16.03; 95% CI (-20.78, -11.27), $P < 0.01$). Three papers reported separately the radiation dose to patients and operators, for which heterogeneity was small for both patients and operators in each study, ($P = 0.87$, $I^2 = 0\%$) and ($P = 0.69$, $I^2 = 0$), respectively, were analyzed using a fixed-effects model, and the results showed that the radiation dose to patients was less for patients with unilateral PKP than for those with bilateral PKP (MD -1.05, 95% CI (-1.20, -0.91), $P < 0.01$), and for operators, there was no significant difference in radiation dose for unilateral PKP compared to bilateral PKP (MD -0.02, 95% CI (-0.04, 0.00), $P = 0.11$). Fifteen papers reported bone cement dosage, with a high degree of heterogeneity between studies ($P < 0.01$, $I^2 = 94\%$), and analyzed using a random effects model. The results showed that bone cement dosage unilateral PKP was less than bilateral PKP (MD -1.8, 95% CI (-2.25, -1.46), $P < 0.01$) (Fig. 2).

Nine papers reported on patients' postoperative VAS scores at 1, 3, 6, and 9 months, with a large heterogeneity among items ($P = 0.004$, $I^2 = 77.3\%$), which were analyzed using a random-effects model, and the results showed that there was no significant difference in postoperative VAS scores between unilateral PKP and bilateral PKP (MD -0.04, 95% CI (-0.17, 0.08)), $P = 0.70$). Three papers reported on patients' postoperative ODI scores, with greater heterogeneity between the items ($P = 0.08$, $I^2 = 61\%$), and the results showed that there was also no significant difference in postoperative ODI scores (MD 0.45, 95% CI (-0.35, 1.24), $P = 0.27$) (Fig. 3).

Three papers reported postoperative cement leakage in patients, with small heterogeneity among the items ($P = 0.03$, $I^2 = 48\%$), and analysis using a random-effects model showed a comparable risk of cement leakage in unilateral and bilateral PKP (MD 0.87, 95% CI (0.58, 1.30), $P = 0.49$). Seven papers reported postoperative improvement in the kyphotic angle; the heterogeneity among them was large ($P < 0.01$, $I^2 = 87\%$), and the results showed no

Table 2 Operation time and cement injection volume

Number	Reference	Operation time (min) (mean ± standard deviation)	The volume of the injected cement (mL) (mean ± standard deviation)
1	Liang Yan et al.(2014)	U: 33.2 ± 5.1 B: 52.5 ± 10.9	U: 3.4 ± 0.8 B: 5.5 ± 0.7
2	L. Yan et al.(2015)	U: 15.6 ± 4.2 B: 38.6 ± 7.9	U: 6.2 ± 0.6 B: 8.5 ± 0.8
3	Jianhua Lu et al.(2023)	U: 49.6 ± 7.4 B: 58.3 ± 9.0	U: 5.0 ± 0.8 B: 6.3 ± 0.7
4	GOU Yongsheng et al.(2020)	U: 38.61 ± 7.68 B: 48.23 ± 9.73	U: 4.79 ± 1.27 B: 5.74 ± 1.38
5	Chung Hun Lee et al.(2020)	U: 36.7 ± 9.7 B: 39.6 ± 12.7	U: 4.4 ± 0.8 B: 5.6 ± 1.0
6	Chunmao Chen et al.(2011)	U: 34.12 ± 6.27 B: 57.33 ± 8.43	U: 4.11 ± 1.25 B: 5.82 ± 1.97
7	Dan Pan et al.(2022)	U: 47.32 ± 7.22 B: 52.52 ± 10.38	U: 3.73 ± 0 .59 B: 5.28 ± 1.17
8	Fei Zhang et al.(2021)	U: 35.7 ± 6.2 B: 53.6 ± 8.7	U: 3.5 ± 0.9 B: 5.6 ± 1.3
9	Yuting Zhang et al.(2022)	U: 34.3 ± 5.7 B: 48.1 ± 6.6	NR
10	Zhirong Wang et al.(2011)	U: 45 ± 16 B: 68 ± 24	U: 3.5 ± 1.2 B: 7.5 ± 2.0
11	Liang Zhang et al.(2015)	U: 41.2 ± 5.2 B: 55.7 ± 7.3	U: 3.1 ± 0.4 B: 5.0 ± 0.5
12	B. J. Rebolledo et al.(2013)	U: 47.6 ± 7.8 B: 71.4 ± 21.5	U: 4.8 ± 1.7 B: 6.3 ± 2.4
13	Jin Tang et al.(2019)	U: 29.8 ± 2.7 B: 31.5 ± 3.9	U: 3.1 ± 0.7 B: 3.5 ± 1.2
14	Yunfan Qian et al.(2023)	U: 32.01 ± 4.48 B: 42.42 ± 6.01	U: 5.46 ± 1.22 B: 8.73 ± 1.20
15	Ming Xing Liu et al.(2018)	U: 25.6 ± 4.2 B: 36.6 ± 8.7	U: 6.2 ± 3.5 B: 8.5 ± 2.2
16	Atilla Yılmaz et al.(2017)	U: 47.5 ± 12.1 B: 91 ± 17.2	U: 4.3 B: 6.7
17	Yu Qiao et al.(2023)	U: 41.60 ± 5.64 B: 66.53 ± 9.40	U: 5.27 ± 0.73 B: 6.87 ± 0.93

Table 3 Radiation dose for patient and operator

Number	Reference	Radiation dose(mSv) (mean ± standard deviation)	
		Patient	Operator
1	Liang Yan et al.(2014)	U: 0.89 ± 0.34 B: 1.98 ± 1.20	U: 0.23 ± 0.12 B: 0.24 ± 0.14
2	L. Yan et al.(2015)	U: 0.88 ± 0.28 B: 1.89 ± 1.05	U: 0.21 ± 0.12 B: 0.24 ± 0.12
3	Ming Xing Liu et al. (2018)	U: 0.88 ± 0.28 B: 1.89 ± 1.05	U: 0.21 ± 0.12 B: 0.24 ± 0.13

significant difference in posterior kyphotic angle between unilateral and bilateral PKP (MD − 0.67, 95% CI (− 2.29, 0.96), $P = 0.42$) (Fig. 4).

Risk of bias

The risk assessment of bias in the included trials based on Cochrane criteria is summarized in Fig. 5. Patients in eighteen trials were randomly assigned to unilateral and bilateral PKP, of which the overall risk of bias was assessed as low for five trials and high for thirteen trials. Trials considered at high risk of bias lacked adequate descriptions of allocation concealment procedures, had incomplete outcome data, and lacked details in one blinding of outcome assessments. There was no difference in the three reviewers' opinions regarding the risk of bias assessment for these trials.

Table 4 Single study of postoperative bone cement leakage

Number	Reference	Unilateral group		Bilateral group	
		Number	Proportion	Number	Proportion
1	Liang Yan et al.(2014)	12	7.6%	22	14.6%
2	L. Yan et al.(2015)	4	7.4%	10	18.5%
3	Jianhua Lu et al.(2023)	1	2.7%	3	7.1%
4	GOU Yongsheng et al.(2020)	9	28.13%	2	5.56%
5	Chung Hun Lee et al.(2020)	4	14.2%	12	17.6%
6	Dan Pan et al.(2022)	4	21.1%	4	19.0%
7	Yixuan Tan et al.(2023)	5	13.9%	7	16.7%
8	Zhirong Wang et al.(2011)	4	12.9%	5	16.1%
9	Liang Zhang et al.(2015)	5	20.8%	9	34.6%
10	B. J. Rebolledo et al.(2013)	2	7%	7	25%
11	Yunfan Qian et al.(2023)	19	23.1%	20	25.6%
12	Atilla Yılmaz et al.(2017)	7	19.4%	4	7.8%
13	Yu Qiao et al.(2023)	7	8.86%	5	7.35%

Table 5 Kyphotic angle before and after treatment with unilateral and bilateral kyphoplasty

Number	Reference	Preoperative (mean ± standard deviation)	Postoperative (mean ± standard deviation)
1	Liang Yan et al.(2014)	U: 18.83 ± 8.22 B: 17.98 ± 7.18	U: 9.25 ± 5.41 B: 12.29 ± 5.36
2	L. Yan et al.(2015)	U: 15.9 ± 6.4 B: 16.2 ± 7.1	U: 9.1 ± 4.7 B: 11.8 ± 3.9
3	Jianhua Lu et al.(2023)	U: 17.22 ± 2.25 B: 16.94 ± 2.95	U: 9.86 ± 2.55 B: 9.45 ± 3.41
4	Chung Hun Lee et al.(2020)	U: 14.2 ± 4.7 B: 13.9 ± 6.5	U: 11.1 ± 2.5 B: 10.6 ± 4.5
5	Dan Pan et al.(2022)	U: 19.95 ± 3.49 B: 19.29 ± 3.45	U: 12.89 ± 2.36 B: 10.71 ± 2.78
6	Ming Xing Liu et al.(2018)	U: 15.9 ± 6.5 B: 16.2 ± 7.1	U: 9.1 ± 4.3 B: 11.8 ± 3.8
7	Atilla Yılmaz et al.(2017)	U: 27.3 ± 6.1 B: 25.2 ± 4.7	U: 21.2 ± 8.2 B: 20.1 ± 3.7

Discussion

According to guidelines from the Bone Health and Osteoporosis Foundation, all patients with a diagnosis of osteoporotic fracture should be tested for bone mineral density (BMD), especially those with fractures associated with low or no trauma, as well as postmenopausal women and older male patients [19], and the European guidelines for the evaluation and treatment of postmenopausal women at risk of fracture due to osteoporosis state that low bone mineral density, as measured by dual-energy X-ray absorptiometry (DXA) testing, is a high-risk factor for the development of compression fractures [20].OVCFs were defined as vertebral compression fractures in the presence of low or no-impact DEXA scans showing t-scores of −2.5 or lower (i.e., BMD 2.5 standard deviations below the mean BMD of 30-year-old women) [21]. As the number of aging people is increasing globally, the incidence of OVCFs is also gradually rising [22]. Considering that barriers to conservative treatment of OVCFs include immobility, loss of bone density and muscle strength, muscle contractures and pressure sores, decreased cardiac function and impaired lung function, deep vein thrombosis, gastrointestinal difficulties, urinary tract, and central nervous system symptoms; therefore, the complications of performing vertebral reinforcement may be fewer than those of not performing surgery [9]. By the Spine Section of the German Society for Orthopaedic and Trauma Surgery in 2018 from the fracture morphology and biomechanical stability, the German Society for Orthopaedics and Trauma Osteoporotic Fracture (DGOU-OF) classification types and Osteoporotic Fracture (OF) scoring system proposed, when the score of OF classification Scoring System Score
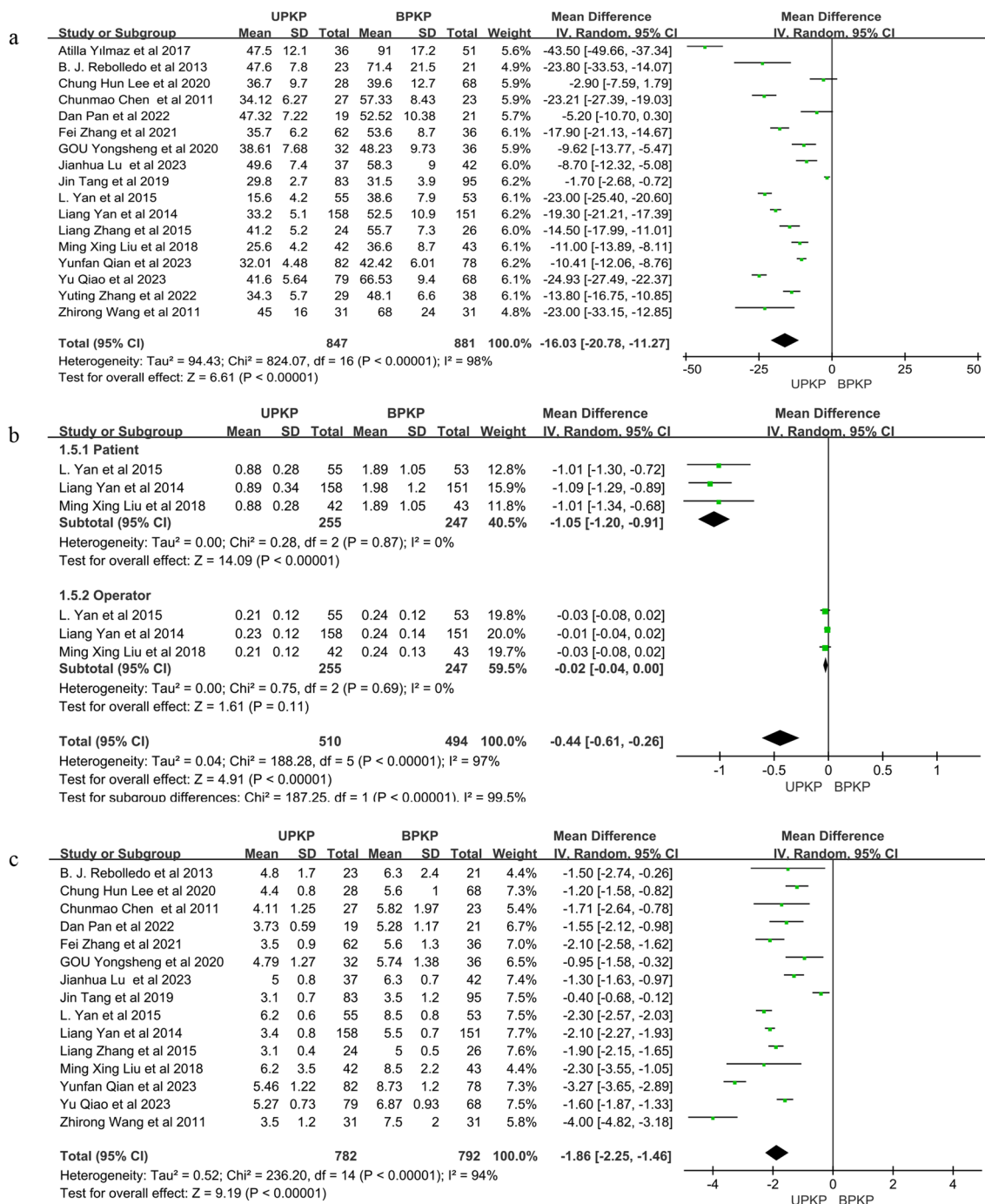
Fig. 2 Forest plot of intraoperative results of unilateral and bilateral PKP. **a** Operative time; **b** patient and operator radiation dose; **c** bone cement volume. CI, confidence interval; UPKP, unilateral PKP; BPKP, bilateral PKP

is ≥ 6 points, the treatment of cement reinforcement of the fractured vertebrae is recommended for patients with OF grading types OF 1 and OF 2, and OF 3 with high mobility and no continuous fracture [23–25]. PKP technology is favored by most clinicians for its advantages of minimally invasive operation, short operation time, low blood loss, fast functional recovery, and quick clinical results [26–30].

In this meta-analysis, there was no significant difference between unilateral PKP and bilateral PKP in terms of VAS score, ODI score, or improvement of kyphotic angle, which suggests that both surgical modalities have comparable clinical efficacy and can effectively treat patients with OVCFs. However, unilateral PKP is a better choice for patients with OVCFs because of the shorter operative
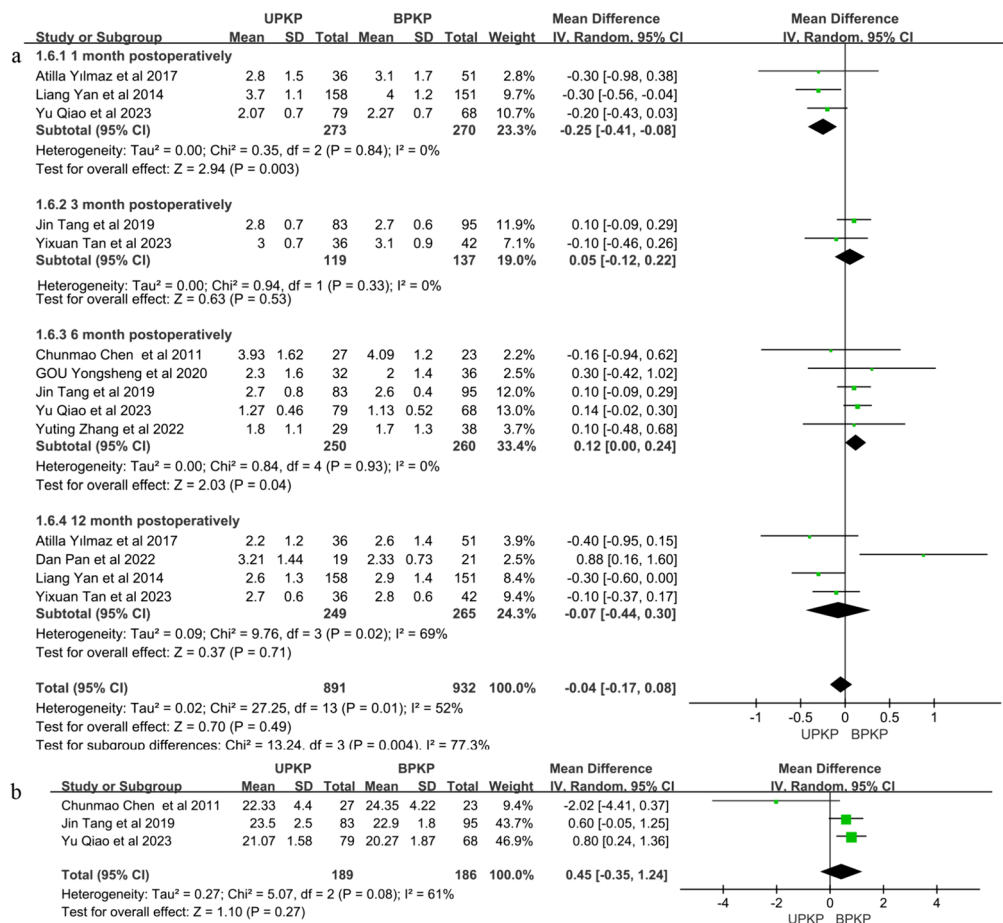
Fig. 3 Forest plot of unilateral PKP and bilateral PKP postoperative follow-up results. **a** VAS scores were followed up 1, 3, 6, and 12 months after surgery; **b** ODI scores were followed up 6 months after surgery. CI, confidence interval; UPKP, unilateral PKP; BPKP, bilateral PKP

time, the lower amount of bone cement, and lower radiation dose to the patient and operator than bilateral PKP.

PKP surgery is performed by injecting bone cement into the vertebral body of a compression fracture to strengthen the vertebral body and restore its height. However, C. Kakazu et al. [31] in a long-term study found that bone cement affects neurological function in humans, including pain, drowsiness, nausea, weakness, fatigue, irritability, dizziness, loss of appetite, and insomnia, and also affects the reproductive function. K-D Kühn et al. [32] concluded that there are several complications with PMMA cement such as surgical embolism, thermal necrosis, toxicity, and allergy. In a study by M H Ereth et al. [33], it was concluded that treatment with bone cement causes embolism, decreased cardiac output, increased pulmonary arterial pressure, and pulmonary vascular resistance, which in turn produces several features of the bone cement implantation syndrome, such as hypotension, hypoxemia, cardiac arrhythmias, cardiac arrest, and other risk factors. The lower amount of bone cement implies a reduction in the side effects of bone cement, and in the postoperative follow-up of this study, there was no

significant difference between unilateral and bilateral PKP in terms of the improvement of patient symptoms and posterior convexity, so it can be concluded that the lower amount of bone cement in unilateral PKP can improve the safety of the operation and reduce the occurrence of intraoperative complications, and unilateral PKP is considered to be selected for the treatment of OVCFs.

A meta-analysis conducted by Li-yu Yang et al. [11] differed from the conclusions of the present study, which concluded that bilateral PKP should be considered as an option for patients with acute pain, severe vertebral height loss, and relatively healthy BMD. The reason for the difference in the conclusions was mainly considered, as in our study, the focus was on patients with osteoporotic lumbar compression fractures, and the majority of the patients were older; BMD was abnormal.

However, in a study by Meng Wang et al. [34], it was shown that a large amount of bone cement may increase the incidence of total vertebral body and neighboring vertebral body fracture in the later stage of the procedure, as well as increase the risk of cemented intervertebral disc leakage
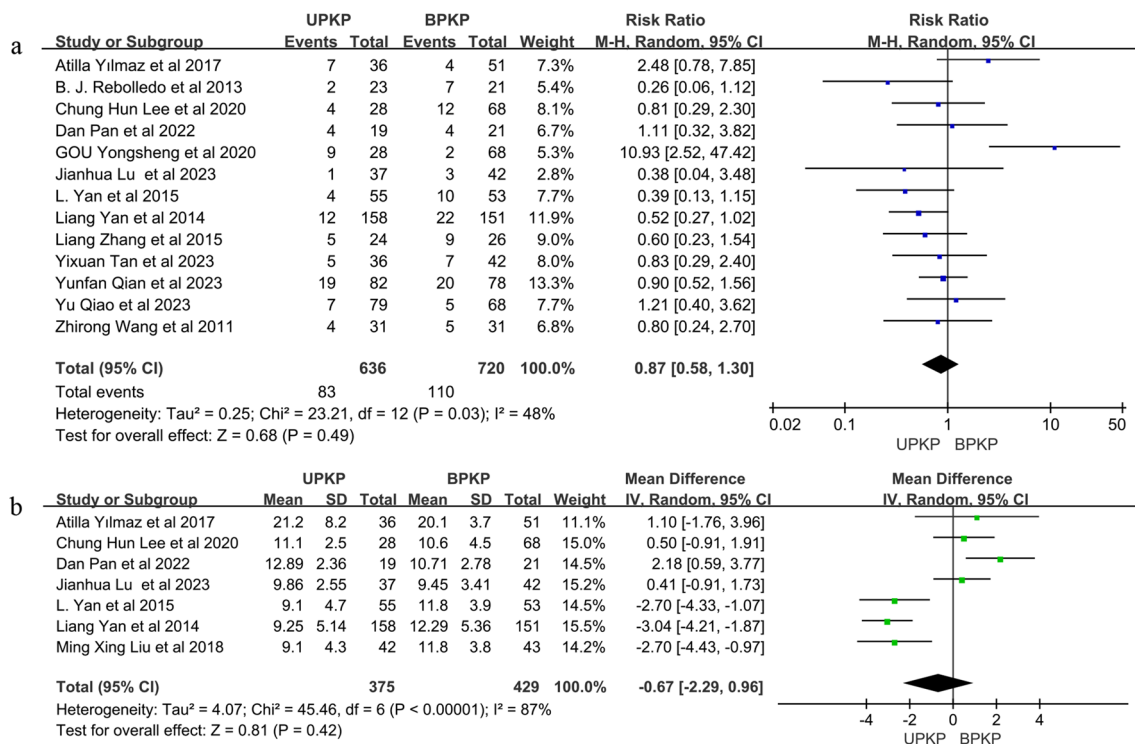
Fig. 4 Forest plot of unilateral and bilateral PKP postoperative results. **a** Proportion of postoperative bone cement leakage; **b** kyphotic angle before and after treatment with unilateral and bilateral kyphoplasty. CI, confidence interval; UPKP, unilateral PKP; BPKP, bilateral PKP

and cement leakage into the posterior spinal canal during surgery. O Lamy et al. [35] showed that the fracture of the neighboring vertebral body had a significant relationship with the amount of bone cement and the mechanical strength of the vertebral body relationship. In our study, the amount of bone cement used in unilateral PKP was less than that in bilateral PKP, and the maintenance of kyphotic angle in unilateral PKP was not significantly different from that in bilateral PKP. Although there was no significant difference in the rate of cement leakage between unilateral and bilateral PKP due to the large sample size of the present study, unilateral PKP has some benefits for patients in terms of the maintenance of clinical outcomes in later stages of the treatment and can reduce the incidence of adjacent vertebral fractures.

X-ray radiation during PKP surgical operations is unavoidable for patients and operators, but the accumulation of X-ray radiation measured over time produces significant hazards for the surgical operator. Dante Luigi Cioffi et al. [36] showed through their study that low-dose exposure to ionizing radiation significantly affects the water of free triiodothyronine, free thyroxine, thyrotropin, and thyroid stimulating hormone. The risk of hypothyroidism in healthcare workers may be increased. Uri P Hadelsberg et al. [37] also concluded that spine surgery is heavily dependent on imaging and radiographic-based equipment is the main imaging modality in the operating room. Increasing awareness of the hazards of radiation exposure and promoting knowledge of ways to reduce exposure to surgeons, nurses, and technicians can reduce radiation exposure. In our study, operative time and X-ray radiation measurements were less for unilateral PKP than for bilateral PKP, and given the health hazards of radiation exposure to patients and surgical operators, the number of puncture fluoroscopies was less for unilateral PKP than for bilateral PKP, and clinicians preferred unilateral PKP.

Xing Cheng et al. [38] conducted a meta-analysis and showed that there were no significant differences in postoperative short-term and long-term VAS, postoperative short-term ODI, and cement leakage and that the mean operative time and cement usage were significantly higher in the unilateral approach than in the bilateral kyphoplasty approach, and the final results of the study did not indicate which surgical procedure would be the best choice for the treatment of OVCFs. Shangzhi Gao et al. [39] questioned the viewpoint of the above study, arguing that the study failed to exclude non-randomized controlled trial studies, the use of erroneous statistical methods, and the absence of racial bias analysis that affected the results of the study. We believe that the disagreement between this meta-analysis and the results of the present study in terms of the duration of surgery and the amount of bone cement used for unilateral PKP may be because fewer
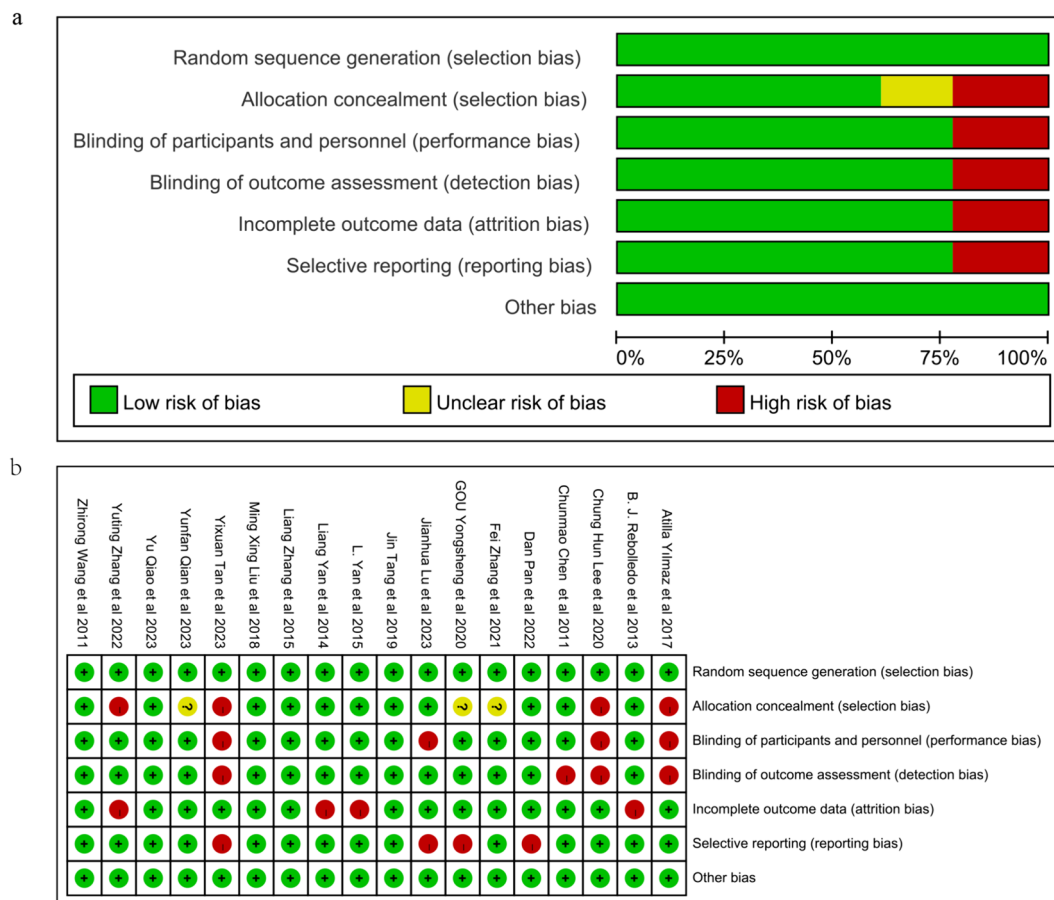
Fig. 5 Summary of risk of bias. **a** Green indicates low risk, red circles indicate high risk, and yellow indicates unclear risk. **b** Green circles with a "+" sign indicate low risk, red circles with a "−" sign indicate high risk, and yellow circles with a "?" sign indicate unclear risk

studies were included in the literature, which created a large bias in the collection of data. Although there is no significant difference in clinical efficacy between unilateral PKP and bilateral PKP, the lower intraoperative risk of unilateral PKP, the lesser harm to the patient and the surgical operator, as well as the evaluation of the various risk factors led us to conclude that unilateral PKP is superior to bilateral PKP. Literature [40–45] reported on the hazards of surgical cement leakage for PKP, and because the unilateral smaller amount of PKP bone cement will reduce the risk of leakage, we also recommend unilateral PKP more for the treatment of OVCFs.

This study also has some limitations; 13 of the 18 papers included in our study were at high risk of bias due to non-disclosure of their randomization technique and treatment group allocation; as none of the studies screened mentioned the severity of the lesion, it can be assumed that these were mixed cases, some optimal and some suboptimal for the chosen intervention. The choice of approach is determined by several factors, and this study focuses on whether to choose unilateral or bilateral PKP for the treatment of OVCFs. The indications for surgery for OVCFs are particularly important

to know. Currently, the DGOU-OF classification types recognized by most scholars recommend the treatment of cement reinforcement of the fractured vertebrae when the osteoporotic fracture (OF) classification Scoring System Score is ≥ 6 points for patients with OF classification types OF 1 and OF 2, and OF 3 with high mobility and no continuity fracture [46–48].

In a word, our meta-analysis confirmed that the clinical outcome of unilateral PKP for the treatment of OVCFs was not worse than that of bilateral PKP. There were no significant differences in the improvement of postoperative VAS, postoperative ODI, cement leakage, and postoperative kyphotic angle. The mean operative time, cement dosage, and frequency of X-ray exposure were significantly higher in bilateral than in unilateral PKP.

Conclusion

The postoperative clinical outcomes and imaging findings in patients with OVCF were similar in both unilateral and bilateral PKP. However, the operative time, the amount

of cement used, and the radiation dose to the patient and operator were lower with unilateral PKP, and considering the serious consequences of cement toxicity and the occurrence of adjacent vertebral fractures, we can conclude that unilateral PKP is superior to bilateral PKP in the treatment of patients with OVCFs.

Declarations

Ethics approval Not applicable.

Consent to participate All patients included in the study signed informed consent for the conduct of the study.

Conflicts of interest None.

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