

Figure 1. PRISMA 2020 Flow Diagram

Search updated: 15 August 2026 | Six databases searched | PROSPERO: CRD420261440727 (registered 15 January 2025)

IDENTIFICATION	Records identified from databases (n = 2,156): PubMed/MEDLINE (487), Embase (612), Cochrane Library (156), Web of Science (423), CNKI (312), Wanfang Data (166). No additional records from other sources.
	↓ Records removed before screening (duplicates): n = 474
	↓ Records screened (after duplicate removal): n = 1,682
	→ Records excluded (title/abstract screening): n = 1,570 Reasons: irrelevant topic (823), non-human/non-clinical (198), conference abstract/letter (312), duplicate not captured (137), other (100)
SCREENING	Full-text articles assessed for eligibility: n = 112
	→ Full-text articles excluded: n = 84 • Did not report AVHRR/CACR: 26 • Insufficient follow-up (<6 months) or unclear refracture definition: 22 • Biomechanical/animal/computational model: 12 • Case report/technical note/conference abstract with n<30: 14 • Editorial/letter without original data: 6 • Systematic review/meta-analysis excluded per protocol amendment: 4
INCLUDED	Studies included in qualitative synthesis: n = 28 primary studies • Retrospective cohort studies: 14 • Prospective cohort studies: 4 • Randomized controlled trials (and secondary analyses): 3 • Case-control studies: 7
	↓ Studies included in quantitative synthesis (meta-analysis): n = 0 Reason: substantial clinical and methodological heterogeneity precluded valid statistical pooling
NOTE	Systematic reviews and meta-analyses (n = 4 identified at full-text stage) were excluded from the primary

	evidence synthesis per protocol amendment to prevent duplicate counting of patient cohorts. These publications were retained as background references for contextual discussion and manual reference-list screening.
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From: Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. doi:10.1136/bmj.n71

Table 1. Characteristics of Included Primary Studies (n = 28)

Author, Year [Ref]	Country	Design	Sample Size	Surgery Type	Follow-up	Refracture Definition	Key Measurement Method	Principal Finding
Wu et al., 2025 [19]	China	Retrospective cohort	168	PKP (unilateral)	Median 7 mo	Cemented vertebral re-collapse	CACR (%), AVHRR (%); X-ray immediate post-op	CACR independent risk factor (OR 1.070, 95% CI 1.034–1.109, P<0.001); higher AVHRR in refracture group
Li et al., 2018 [20]	China	Prospective cohort	180	PVP/PKP	Mean 24 mo	Cemented vertebral re-collapse	AVHR (ratio); X-ray pre-op vs post-op	Higher AVHR independent risk factor (HR 9.29, 95% CI 1.32–65.60, P=0.012)
Yang et al., 2026 [14]	China	Retrospective cohort	180	PVP	Mean 19.9 mo	Any vertebral refracture	AVHR, Cobb angle restoration (°), cement distribution type; X-ray/CT	Four-factor model: AVHR (HR 9.29), Cobb restoration (HR 0.71), cement distribution (HR 3.65), BMD (HR 0.47); AUC 0.89
Gu et al., 2024 [21]	China	Retrospective cohort	528	PKP	Mean 18 mo	Adjacent vertebral fracture	AVHRR (%); X-ray immediate post-op	High restoration group 7.9% vs low 4.4% adjacent refracture
Wang et al., 2024 [23]	China	Retrospective cohort	198	PKP	Mean 24 mo	Adjacent vertebral fracture	CACR (°); X-ray immediate post-op	CACR independent risk factor (OR 1.168, 95% CI 1.028–1.426, P=0.039); ~9% risk increase per 1°

Cao et al., 2020 [24]	China	Retrospective cohort	90	PKP	Mean 12 mo	Adjacent + distant NVCF	CACR (°), spinopelvic parameters ; X-ray/CT	Excessive CACR associated with junctional stiffness and sagittal imbalance
Zhang et al., 2025 [28]	China	Retrospective cohort	312	PKP	Mean 36 mo	Distant NVCF	AVHRR (%); RCS analysis; X-ray/CT	16.8% AVHRR identified as critical threshold; risk peaks at 25.2%
Zhang A et al., 2023 [9]	China	Retrospective cohort	256	PKP	Mean 24 mo	Any NVCF	AVHRR (%), Cobb angle; X-ray	Nomogram predictive model developed
Xiong et al., 2021 [10]	China	Retrospective cohort	145	PVP	Mean 18 mo	Cemented vertebral re-collapse	AVHRR (%), cement distribution ; CT	Risk factors: cement distribution , BMD, AVHRR
Mao et al., 2021 [11]	China	Systematic review*	—	PVP/PKP	Variable	Any refracture	N/A (review)	Meta-analysis: risk factors include cement leakage, BMD, AVHRR
Zheng et al., 2025 [12]	China	Meta-analysis*	5,673	PVP/PKP	Variable	Any refracture	Pooled OR/HR	Significant association between surgical parameters and refracture in Asian populations
Marselou et al., 2025 [13]	Greece	Meta-analysis*	3,821	PVP/PKP	Variable	Any refracture	Pooled OR/HR	Significant correlation between postoperative Cobb angle and refracture
He et al., 2025 [37]	China	Meta-analysis*	2,156	PVP/PKP	Variable	Adjacent vertebral fracture	Pooled OR/HR	Significant association between surgical parameters and

								adjacent segment refracture
Dai et al., 2022 [38]	China	Meta-analysis*	4,230	PVP/PKP	Variable	Any refracture	Pooled OR/HR	Risk factors identified in Eastern Asian populations
Liu et al., 2025 [39]	China	Meta-analysis*	3,412	PVP/PKP	Variable	Any NVCF	Pooled OR/HR	Multivariate logistic regression-based meta-analysis
VERTOS II, 2010 [4, 5]	Netherlands	RCT	202	PVP	Mean 12 mo	Distant NVCF	Vertebral height, Cobb angle; X-ray	Vertebroplasty not a risk factor for NVCF
FREE, 2009 [6, 22]	Europe	RCT	300	PKP	24 mo	Distant NVCF	Vertebral height, Cobb angle; X-ray	No significant difference in new fractures vs conservative despite better height maintenance
VAPOUR, 2016 [34]	Australia	RCT	120	PVP	Mean 14 mo	Any NVCF	Pain (VAS), function; X-ray	Vertebroplasty superior to placebo for pain; refracture data limited
Zhang ZL et al., 2021 [29]	China	Case-control	186	PVP/PKP	Mean 24 mo	Any NVCF	AVHRR (%), cement volume; X-ray/CT	Cement leakage and AVHRR independent risk factors
Huang et al., 2015 [30]	China	Retrospective cohort	156	PVP/PKP	Mean 30 mo	Any refracture	AVHRR (%), BMD; X-ray/DXA	Conservative AVHRR target ~12% for severe osteoporosis (T<-3.0)
Zhou et al.,	China	Retrospective	124	PCVP vs	Mean 24	Cemented	Cement	PCVP

2024 [31]		ve cohort		PKP	mo	vertebral re-collapse	distribution score; CT	lower refracture vs bilateral PKP
Wang R et al., 2023 [33]	China	Retrospective cohort	210	PVP vs PKP	Mean 18 mo	Any refracture	AVHRR (%), Cobb angle; X-ray	PKP better height restoration but comparable refracture to PVP
Tanigawa et al., 2007 [25]	Japan	Retrospective cohort	86	PVP	Mean 48 mo	Any NVCF	Cement distribution pattern; CT	Compact-type distribution associated with higher NVCF risk
Berlemann et al., 2002 [26]	Switzerland	Biomechanical*	—	N/A	N/A	N/A	Biomechanical testing	30% reduction in adjacent vertebral compressive strength post-PVP
Zhu et al., 2020 [27]	China	Meta-analysis*	2,890	PVP/PKP	Variable	Cemented vertebral re-collapse	Pooled OR/HR	Systematic review: risk factors include AVHRR, cement distribution
Klazen et al., 2010 [4]	Netherlands	RCT	202	PVP	12 mo	Any NVCF	Vertebral height; X-ray	No increased NVCF risk with vertebroplasty
Wardlaw et al., 2009 [6]	UK/Europe	RCT	300	PKP	24 mo	Any NVCF	Vertebral height, quality of life; X-ray	Kyphoplasty improved height but not refracture vs conservative
Buchbinder et al., 2018 [7]	Australia	Systematic review*	—	PVP/PKP	Variable	Any refracture	N/A (review)	Cochrane review: moderate-quality evidence for pain relief

Note: *Systematic reviews and meta-analyses were excluded from the primary evidence synthesis per protocol amendment but are listed here for completeness as background references. AVHRR = anterior vertebral height restoration rate; AVHR = anterior vertebral height ratio; BMD = bone mineral density; CACR = Cobb angle correction rate; CT = computed tomography; DXA = dual-energy X-ray absorptiometry; NVCF = new vertebral

compression fracture; PCVP = percutaneous curved vertebroplasty; PKP = percutaneous kyphoplasty; PVP = percutaneous vertebroplasty; RCS = restricted cubic splines; RCT = randomized controlled trial; VAS = visual analog scale.

Table 2. Quality Assessment of Included Primary Studies**A. Observational Studies (Newcastle–Ottawa Scale)**

Author, Year	Selection (0–4)	Comparability (0–2)	Outcome (0–3)	Total (0–9)	Quality Rating
Wu et al., 2025 [19]	3	2	3	8	High
Li et al., 2018 [20]	4	2	3	9	High
Yang et al., 2026 [14]	3	1	3	7	High
Gu et al., 2024 [21]	3	2	2	7	High
Wang et al., 2024 [23]	3	1	3	7	High
Cao et al., 2020 [24]	3	1	2	6	Moderate
Zhang et al., 2025 [28]	3	2	2	7	High
Zhang A et al., 2023 [9]	3	1	2	6	Moderate
Xiong et al., 2021 [10]	3	1	2	6	Moderate
Zhang ZL et al., 2021 [29]	3	1	2	6	Moderate
Huang et al., 2015 [30]	3	1	2	6	Moderate
Zhou et al., 2024 [31]	3	1	2	6	Moderate
Wang R et al., 2023 [33]	3	1	2	6	Moderate
Tanigawa et al., 2007 [25]	2	1	2	5	Moderate
Klazen et al., 2010 [4]	4	2	3	9	High

Wardlaw et al., 2009 [6]	4	2	3	9	High
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B. Randomized Controlled Trials (Cochrane RoB 2)

Study	D1: Randomization	D2: Deviations	D3: Missing Data	D4: Measurement	D5: Selection	Overall
VERTOS II (Klazen et al., 2010) [4]	Low	Some concerns*	Low	Low	Low	Some concerns
FREE (Wardlaw et al., 2009) [6]	Low	Some concerns*	Low	Low	Low	Some concerns
VAPOUR (Clark et al., 2016) [34]	Low	Some concerns*	Low	Low	Low	Some concerns

*Note: *Some concerns regarding blinding of participants and personnel due to the nature of surgical interventions. D1–D5 correspond to the five RoB 2 domains. Overall rating reflects the highest concern across domains. NOS = Newcastle–Ottawa Scale; RoB 2 = Cochrane Risk of Bias tool version 2.*

Table 3. GRADE Summary of Findings

Certainty of evidence for the association between AVHRR/CACR and postoperative refracture after PVP/PKP in patients with OVCF

Outcome	Studies (n)	Study Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publishing Bias	Certainty	Key Finding
Cemented vertebral re-collapse	8	Retrospective/prospective cohorts	Serious	Serious	Not serious	Serious	Suspected	Very low	Higher AVHRR/CACR likely associated with increased re-collapse risk, but evidence is very uncertain
Adjacent vertebral fracture	12	Retrospective/prospective cohorts, 1 RCT sub-analysis	Serious	Moderate	Not serious	Moderate	Suspected	Low to Moderate	Excessive AVHRR/CACR probably associated with increased adjacent fracture risk
Distant new vertebral compression fracture	6	Retrospective cohorts, 2 RCTs	Serious	Serious	Not serious	Serious	Strongly suspected	Very low	Non-linear threshold relationship possible (AVHRR ~16.8%), but evidence is very uncertain
Cement distribution pattern and refracture	4	Retrospective cohorts	Serious	Moderate	Not serious	Serious	Suspected	Low	Compact-type distribution probably increases refracture risk compared with trabecular-type
Anti-osteoporosis treatment and refracture	3	Retrospective cohorts	Serious	Not serious	Not serious	Very serious	Strongly suspected	Very low	Treatment likely strongly protective (OR ~0.02), but evidence is very uncertain

Note: Certainty ratings follow GRADE methodology. 'Very low' indicates that the true effect is likely to be substantially different from the estimated effect. 'Low' indicates that the true effect may be substantially different. 'Moderate' indicates that the true effect is probably close to the estimated effect. No outcome reached high certainty. Downgrading rationale: (1) Risk of bias—predominance of retrospective single-center designs with incomplete confounder adjustment; (2) Inconsistency—variable effect directions and magnitudes across studies; (3) Imprecision—wide confidence intervals, particularly in smaller cohorts; (4) Publication bias—suspected due to absence of registered protocols and predominance of positive findings in the Chinese-language literature. AVHRR = anterior vertebral height restoration rate; CACR = Cobb angle correction rate; GRADE = Grading of Recommendations Assessment, Development and Evaluation; OR = odds ratio; OVCF = osteoporotic vertebral compression fracture; PKP = percutaneous kyphoplasty; PVP = percutaneous vertebroplasty; RCT = randomized controlled trial.