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A comparison of clinical outcomes following kyphoplasty for osteoporotic compression fractures of the thoracic and lumbar spine: a systematic review and meta-analysis

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Introduction: Kyphoplasty is a minimally invasive treatment for osteoporotic vertebral compression fractures (VCFs) aimed at restoring vertebral height and alleviating pain. However, despite its widespread use, kyphoplasty outcomes are typically analyzed without distinguishing between thoracic and lumbar regions. Given the anatomical and biomechanical differences between these regions, it is crucial to compare the efficacy and complication rates of kyphoplasty based on spinal location. This review seeks to evaluate these distinctions and explore their potential clinical implications to inform patient expectations and procedural understanding.

Methods: A comprehensive search strategy was developed using concepts of kyphoplasty, compression fractures, and spinal regions. Resulting literature underwent title, abstract, and full-text screening using the inclusion criteria: (1) Patients underwent kyphoplasty for osteoporotic VCFs of the thoracic and lumbar spine, (2) Clinical, perioperative, or postoperative outcome measures were available, and (3) Outcome measures were subcategorized into thoracic or lumbar spinal regions. Meta-analysis was performed using a random effects model. The ROBINS-I tool was used to evaluate bias.

Results: Twenty-five manuscripts were included in final analysis. Meta-analysis revealed operative time and injected cement volume were 43.07 minutes [95% CI (35.34, 50.79)] and 4.61 ml [95% CI (3.79, 5.43)] in the lumbar spine and 56.42 min [95% CI (41.03, 71.81)] and 4.25 ml [95% CI (3.56, 4.93)] in the thoracic spine, respectively. Likewise, the incidence of cement leakage and subsequent adjacent level fractures were 13% [95% CI (7%, 22%)] and 5% [95% CI (2%, 12%)] in the lumbar spine and 19% [95% CI (10%, 32%)] and 10% [95% CI (2%, 33%)] in the thoracic spine, respectively. Lastly, the post-operative decrease in visual analog scale pain was 5.59 [95% CI (5.23, 5.94)] in the lumbar spine and 5.49 [95% CI (4.79, 6.19)] in the thoracic spine. Across studies, the primary risk of bias was due to confounding variables, resulting in a serious risk of bias in 12 studies (48.0%).

Discussion: Kyphoplasty provides comparable outcomes in thoracic and lumbar VCFs, with no clinically significant differences in pain relief or procedural effectiveness. Despite anatomical differences, the procedure remains safe and effective in both regions, warranting further research on spinal region-specific outcomes.

KEYWORDS

kyphoplasty, osteoporotic compression fractures, thoracic compression fractures, lumbar compression fractures, clinical outcomes

Introduction

Vertebral fractures affect approximately 1.5 million Americans each year and can result from a variety of causes, including trauma, malignancy, infection, and most commonly, osteoporosis (1, 2). Osteoporotic spinal fractures are particularly prevalent among the elderly population who suffer from diminished bone density, which can be associated with a number of risk factors including female gender, prolonged corticosteroid use, low estrogen levels, tobacco and alcohol abuse, and kidney disease, among others (3–5). With the increasing age of the general population, the incidence of osteoporotic spinal fractures is expected to grow (6, 7). Similarly, the identification of red flag signs such as advanced age, trauma, and corticosteroid use, among others, has enhanced the screening and diagnosis of osteoporotic vertebral compression fractures (OVCFs) within the elderly population (8, 9). These fractures can give rise to a range of symptoms including back pain, kyphotic deformities, and neurological deficits that can result in pervasive loss of mobility and function, social isolation, and increased rate of mortality (7, 10–12). In numerous instances, these fractures have the potential to resolve spontaneously through conservative management or non-invasive therapeutic interventions (13, 14). However, surgical intervention is indicated in a subset of patients contingent on the severity of their symptoms, the extent of spinal deformity, and the presence of neurological impairment (7, 15–19). A variety of clinical and radiological outcomes are used to assess the management of OVCFs, including pain levels, vertebral body height restoration, spinal alignment, incidence of adjacent-level fractures, and surgical complications (18, 20–22). While specific clinical recommendations (i.e., the osteoporotic fracture classification score) have emerged to offer surgeons greater guidance in treatment decision-making (13, 23), the choice still remains heavily reliant on a surgeon's individual judgment, taking into account the unique characteristics of their patient such as age, comorbidities, and frailty, among others.

One minimally invasive surgical technique that has emerged as an effective vertebral augmentation treatment for OVCFs is kyphoplasty (24, 25). Kyphoplasty is a minimally invasive procedure that involves inserting a balloon into the fractured vertebra to restore its height, followed by injection of bone cement to stabilize the fracture and alleviate pain (26). In the evaluation of kyphoplasty for OVCFs, thoracic and lumbar fractures are frequently amalgamated into a single category with their outcomes collectively assessed (27–29). However, key anatomical and biomechanical differences exist between the thoracic and lumbar spine such as facet joint orientation, sagittal alignment, and spinal stability (30–32). These differences may significantly influence the manifestation of symptoms and subsequently affect treatment outcomes. While prior systematic reviews delineate variations in prevalence, biomechanical properties, bone density, blood flow, and subsequent fracture rate between osteoporotic fractures of the lumbar and thoracic regions, they do not provide a comprehensive characterization of the differences in clinical outcomes following kyphoplasty for differing regions of the spine (30). Insights into these differences could establish a more outcomes-based framework to guide surgical decision-making and management in older adults with OVCFs depending on whether the fracture is within the thoracic or lumbar spine. This systematic review and meta-analysis aims to provide an updated evaluation of perioperative, postoperative, and patient-reported outcomes of kyphoplasty for OVCFs, with a focus on differentiating outcomes between thoracic and lumbar regions. This review provides a comprehensive comparison of kyphoplasty outcomes between the thoracic and lumbar spine, assessing whether anatomical and biomechanical differences influence surgical outcomes and highlighting the need for further research.

Methods

Search strategy and data extraction

Published literature was searched using key phrases including: "kyphoplasty", "osteoporotic compression fractures", and "lumbar and thoracic spine", with related synonyms. Literature searches were executed in PubMed, Embase.com, Ovid-Medline, and Web of Science from database inception (Table 1). All database searches were completed on November 17, 2023. A total of 1,164 results were retrieved from the database literature search and imported to the Pico Portal systematic review platform (33). Duplicate citations (432) were identified and excluded. Four independent reviewers (M.R.K., C.C., S.L., T.Z.) performed title and abstract screening on the remaining 732 studies, with each manuscript title and abstract screened twice. If two reviewers disagreed on whether a manuscript should advance to full-text screening, a third reviewer (M.R.K.) provided the final decision. Full-text screening was conducted based on the following inclusion criteria: (1) patients undergoing kyphoplasty for osteoporotic compression fractures of the thoracic or lumbar spine, (2) reporting of clinical, patient-reported, perioperative, or postoperative outcome measures, and

TABLE 1 Complete literature review search strategy designed by a medical librarian.

Database	Result	Search terms
PubMed	226 results on 12/1/2,023; No limits/ filters used	("vertebral body fracture" OR "vertebral fracture" OR "spine fracture" OR "lumbar spine fracture" OR "thoracic spine fracture" OR "thoracolumbar fracture" OR "compression fracture") AND ("osteoporosis" OR "osteoporotic" OR "insufficiency fracture" OR "compression" OR "elderly" OR "geriatric patients") AND ("thoracic spine" OR "thoracic vertebrae" OR "thoracic vertebral body" OR "lumbar spine" OR "lumbar vertebrae" OR "lumbar vertebral body" OR "thoracolumbar spine" OR "thoracolumbar vertebrae" OR "thoracolumbar vertebral body") AND ("kyphoplasty" OR "balloon kyphoplasty")
Embase.com	559 results on 12/1/2023; No limits/ filters used	('vertebral body fracture' OR 'vertebral fracture' OR 'spine fracture' OR 'lumbar spine fracture' OR 'thoracic spine fracture' OR 'thoracolumbar fracture' OR 'compression fracture') AND ('osteoporosis' OR 'osteoporotic' OR 'insufficiency fracture' OR 'compression' OR 'elderly' OR 'geriatric patients') AND ('thoracic spine' OR 'thoracic vertebrae' OR 'thoracic vertebral body' OR 'lumbar spine' OR 'lumbar vertebrae' OR 'lumbar vertebral body' OR 'thoracolumbar spine' OR 'thoracolumbar vertebrae' OR 'thoracolumbar vertebral body') AND ('kyphoplasty' OR 'balloon kyphoplasty')
Ovid-Medline	226 results on 12/1/2023 (all from CENTRAL trials)	("vertebral body fracture" OR "vertebral fracture" OR "spine fracture" OR "lumbar spine fracture" OR "thoracic spine fracture" OR "thoracolumbar fracture" OR "compression fracture") AND ("osteoporosis" OR "osteoporotic" OR "insufficiency fracture" OR "compression" OR "elderly" OR "geriatric patients") AND ("thoracic spine" OR "thoracic vertebrae" OR "thoracic vertebral body" OR "lumbar spine" OR "lumbar vertebrae" OR "lumbar vertebral body" OR "thoracolumbar spine" OR "thoracolumbar vertebrae" OR "thoracolumbar vertebral body") AND ("kyphoplasty" OR "balloon kyphoplasty")
Web of science	153 results on 12/1/2023; No limits/ filters used	TS = ("vertebral body fracture" OR "vertebral fracture" OR "spine fracture" OR "lumbar spine fracture" OR "thoracic spine fracture" OR "thoracolumbar fracture" OR "compression fracture") AND TS = ("osteoporosis" OR "osteoporotic" OR "insufficiency fracture" OR "compression" OR "elderly" OR "geriatric patients") AND TS = ("thoracic spine" OR "thoracic vertebrae" OR "thoracic vertebral body" OR "lumbar spine" OR "lumbar vertebrae" OR "lumbar vertebral body" OR "thoracolumbar spine" OR "thoracolumbar vertebrae" OR "thoracolumbar vertebral body") AND TS = ("kyphoplasty" OR "balloon kyphoplasty")

(3) differentiation of outcomes by spinal region (thoracic vs. lumbar). Any reviews, case reports, conference abstracts, non-English manuscripts, animal studies, expert opinion, editorials, or non-original research were excluded. Data extraction included information regarding study aims, methods, patient population, spinal level at which the compression fracture occurred, surgical and clinical outcomes, and a description of main findings. The variability in reported data across studies posed challenges but did not preclude the feasibility of conducting a meta-analysis. The systematic review was conducted in accordance with PRISMA reporting guidelines.

Risk of bias assessment

Risk of bias was evaluated using the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool (34). Two reviewers (T.Z., S.L.) assessed the risk of bias as definitely low, moderate, serious, or critical using a series of signaling questions across seven domains including bias due to confounding, bias in selection of participants into the study, bias in classification of interventions, bias due to deviation from intended interventions, bias due to missing data, bias in measurement of outcomes, and bias in selection of reported result. A third reviewer (M.R.K.) facilitated consensus in cases where the two primary reviewers disagreed on the assessment of bias within a domain.

Statistical analysis

A meta-analysis was conducted for continuous outcome measures with data across individual studies converted to means and standard deviations using approximation techniques. If a study did not explicitly report the change between preoperative and postoperative values for a variable of interest, it was calculated using the provided mean and standard deviation distributions before and after surgery. If only the mean and range were provided for a specific outcome measure, the standard deviation was approximated by dividing the range by four. Likewise, if only the median and range were reported, the mean and standard deviation were approximated using the method described by Hozo et al. (35). Lastly, if only the mean was reported, the standard deviation was conservatively estimated as half of the mean. A meta-analysis of proportions was performed to calculate pooled rates for cement leakage and subsequent adjacent fracture with a forest plot created to visualize the results. For all meta-analyses, an effect size was computed for each study and a pooled effect size with 95% confidence intervals was calculated to summarize across studies. Heterogeneity among studies was evaluated using the Higgins I^2 statistic, with values exceeding 50% indicating substantial heterogeneity. A random effects model was employed across all meta-analyses as a more conservative approach, accounting for both intra-study and inter-study variability (36, 37). Similarly, a meta-analysis was conducted only for outcomes examined in at least five studies, as smaller sample sizes may produce unreliable estimates (36, 37). All statistical analyses were conducted using R and RStudio (Posit Software, PBC, Boston, MA) with the meta and metafor packages.

Results

Overview of included studies

A total of 1,164 results were initially retrieved from the database literature search and yielded 25 manuscripts after screening (Figure 1). All included manuscripts were published

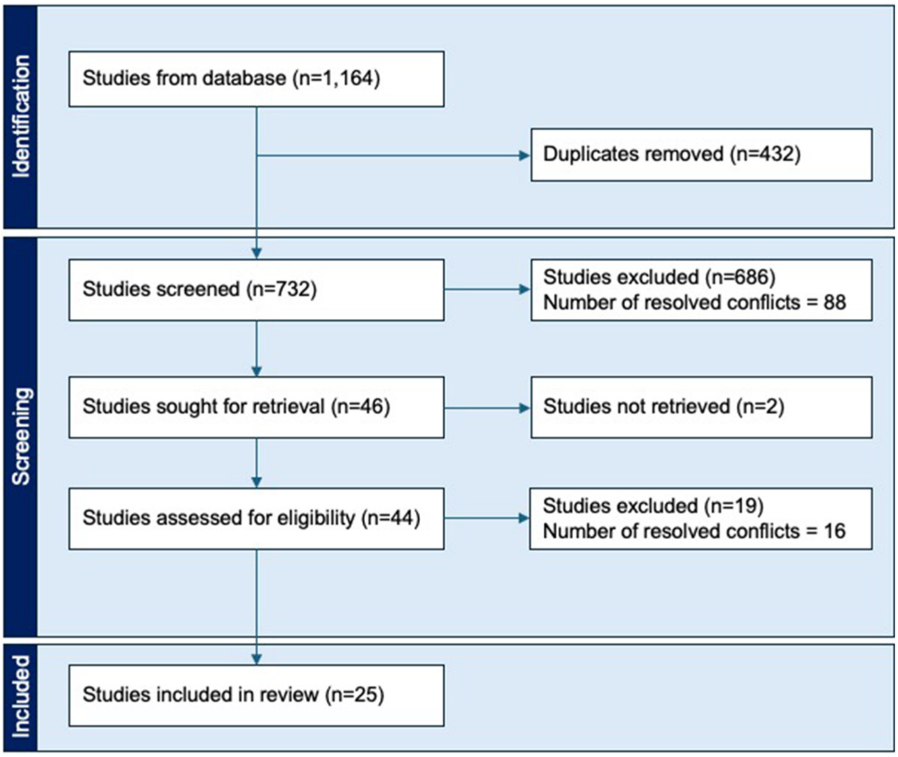

FIGURE 1
Flow diagram depicting the selection process for studies included within this systematic review.

between 2003 and 2023 and included both retrospective ($N = 18$, 92%) and prospective ($N = 7$, 28%) studies. Of these manuscripts, 7 (28.0%) reported on kyphoplasty outcomes for lumbar fracture patient cohorts, 8 (32.0%) reported on kyphoplasty outcomes for thoracic fracture patient cohorts, and 10 (40.0%) reported on kyphoplasty outcomes for lumbar and thoracic patient cohorts. An overview of all included studies is provided in Table 2.

Perioperative outcomes

The most commonly reported perioperative outcomes included injected cement volume (9 thoracic studies, 5 lumbar studies) and operative time (5 thoracic studies, 4 lumbar studies). Meta-analysis using a random effects model revealed an injected cement volume of 4.25 ml [95% CI (3.56, 4.93)] in the thoracic spine and 4.61 ml [95% CI (3.79, 5.43)] in the lumbar spine (Table 3). Likewise, meta-analysis using a random effects model found operative time in the thoracic spine to be 56.42 min [95% CI (41.03, 71.81)] and 43.07 min [95% CI (35.34, 50.79)] in the lumbar spine (Table 4). Other common perioperative outcomes reported included blood loss (1 thoracic study, 2 lumbar studies) and length of stay (3 thoracic studies, 2 lumbar studies). Across thoracic cohorts, the observed blood loss ranged from 6.2 to 7.9 ml and the lumbar studies showed a range of 5.46 to 50.0 ml (Supplementary Table S1). The length of stay ranged from 3.48 to 7.3 days following thoracic procedures and 2.0 to 4.9 days following lumbar procedures (Supplementary Table S2).

Postoperative outcomes

The most commonly reported postoperative outcomes included VAS (8 thoracic studies, 7 lumbar studies), kyphotic angle (5 thoracic studies, 4 lumbar studies), cobb angle (7 thoracic studies, 3 lumbar studies), anterior vertebral body height (8 thoracic studies, 7 lumbar studies), middle vertebral body height (6 thoracic studies, 3 lumbar studies), and posterior vertebral body height (5 thoracic studies, 5 lumbar studies). Using the VAS score from the last postoperative visit recorded in each study, meta-analysis using a random effects model revealed a decrease in VAS score of 5.49 [95% CI (4.79, 6.19)] following thoracic kyphoplasty and a decrease of 5.59 [95% CI (5.23, 5.94)] following lumbar kyphoplasty (Table 5).

Due to heterogeneity in measuring and reporting methods across studies, the findings for kyphotic angle, cobb angle, and anterior, middle, and posterior vertebral body heights were solely reported from studies that directly compared outcomes between thoracic and lumbar procedures. For kyphotic angle correction, Lee et al. reported a reduction of 8.6% in thoracic kyphotic angle compared to a 6.9% reduction in lumbar kyphotic angle (38). Hsieh et al. observed mean reductions of $18.30° \pm 5.45°$ in thoracic kyphotic angle and $19.07° \pm 5.53°$ in lumbar kyphotic angle (39). Regarding Cobb angles, Cao et al. reported a reduction in thoracic vertebrae from $25.1° \pm 14.2°$ preoperatively to $22.0° \pm 12.95°$ postoperatively, while lumbar vertebrae showed a slight increase from $27.5° \pm 21.8°$ to $30.96° \pm 21.6°$ (40). Phillips et al. reported a reduction in thoracic Cobb angle by 9.7° (range 0–29) and in lumbar Cobb angle by 7.9° (range 0–23) (41).

TABLE 2 Characteristics of 25 included articles.

Author, year	Study type	Follow up	Thoracic patients and levels	Lumbar patients and levels	Kyphoplasty technique	Perioperative outcomes assessed	Postoperative outcomes assessed	Main findings
Lee et al. (2007)	Retrospective	NR	• 21 patients • 21 vertebrae • T1-T12	• 17 patients • 17 vertebrae • L1-L5	BKP	Injected cement volume	• Posterior, middle, and anterior vertebral body height post-op • Kyphotic angle post-op	Following kyphoplasty, there was a greater vertebral height restoration and kyphotic angle restoration in the thoracic spine than the lumbar spine.
Wu et al. (2022)	Retrospective	Mean 1 year	• 42 patients • 42 vertebrae • T4-T9	N/A	BKP	Injected cement volume	• Posterior, middle, and anterior vertebral body height post-op and six months post-op • Kyphotic angle post-op and six months • Cobb angle post-op and six months post-op • VAS six months post-op • LOS • Cement leakage • Subsequent adjacent fractures	• BKP achieved sufficient pain relief, vertebral height restoration, and kyphotic angle correction. • LVC BKP was a safe and effective procedure for patients with symptomatic single level osteoporotic VCF of the mid thoracic level.
Qian et al. (2023)	Retrospective	2 years	N/A	• 160 patients • 160 vertebrae • L3-L5	Unipedicular and bipedicular PK	• Operative time • Blood loss	• Anterior, middle, and posterior vertebral body height post-op and 2 years post-op • Cement distribution • VAS post-op and 2 years • ODI post-op and 2 years • LOS • Cement leakage	• Unipedicular PK cohort had lower operative time and blood loss than bipendicular PK. • Both groups experienced a drastic two-year postoperative decrease in ODI and VAS, and vertebral height correction was similar across both groups.
Ge et al. (2019)	Retrospective	Mean 15 months (range 6–36)	• 50 patients • 55 vertebrae • T3–T12	N/A	BK (extrapendicular approach)	• Injected cement volume • Operative time	• Anterior and median vertebral body height post-op and final follow-up • Cobb angle post-op and final follow-up • VAS post-op and final follow-up • LOS • Cement leakage • Subsequent adjacent fracture	BK using the extrapendicular approach was found to be a safe procedure that was effective at pain reduction, vertebral height correction, and kyphotic/cobb angle restoration.
Liu et al. (2019)	Retrospective	Median 17 months (range 2–36)	• NR patients • 37 vertebrae • T5–T8	N/A	Unipedicular and bipedicular PK	None	• Cement leakage • Cement distribution	• PKP reduced pain and improved mobility. • PKP had lower rates of epidural cement leakage and improved cement distribution across the vertebrae compared to PVP.
Cao et al. (2020)	Retrospective	NR (2–3 days post-op)	• 9 patients • NR vertebrae • T1–T9	• 10 patients • NR vertebrae • L3–L5	PKP	None	• VAS post-op • Spinopelvic parameters post-op (PI, pelvic tilt (PT), sacral slope (SS), local kyphosis Cobb angle, TK, TLK, LL, PI-LL, SVA, spino-sacral angle (SSA), and T1 pelvic angle (TPA))	Key differences existed in the postoperative change in spinopelvic parameters and sagittal balance between individuals with fractures of the thoracic spine and the lumbar spine.

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10.3389/fmscd.2025.1597288

TABLE 2 Continued

Author, year	Study type	Follow up	Thoracic patients and levels	Lumbar patients and levels	Kyphoplasty technique	Perioperative outcomes assessed	Postoperative outcomes assessed	Main findings
Cho et al. (2011)	Retrospective	Mean 17.2 months (range 2–44)	N/A	• NR patients • 28 vertebrae • L3–L5	Unilateral single balloon extrapedicular kyphoplasty	None	• Anterior and middle vertebral body height post-op • Segmental kyphosis post-op • VAS post-op and every four weeks • Subsequent adjacent fracture	Kyphoplasty was an effective procedure for pain relief, vertebral height restoration, and kyphotic angle correction.
Fribourg et al. (2004)	Retrospective	Mean 8 months (range 14–868 days)	• NR patients • 18 vertebrae • T5–T12	• NR patients • 29 vertebrae • L1–L5	Bilateral transpedicular kyphoplasty	None	Subsequent vertebral fractures	The location of the compression fracture within the thoracic or lumbar spine did not correlate with the development of a subsequent fracture.
Jin et al. (2022)	Retrospective	1 year	N/A	• 45 patients PKP; 56 patients PKP and back rehab • 45 vertebrae PKP; 56 vertebrae PKP and back rehab • L1–L5	PKP	None	• VAS one, six, and twelve months post-op • ODI twelve months post-op • JOA twelve months post-op	PKP combined with back rehabilitation was more effective at decreasing long term pain and improving lumbar function compared to PKP alone.
Chen et al. (2022)	Retrospective	>6 months	N/A	• 55 patients • NR vertebrae • L1-L5	PKP	None	Subsequent vertebral fractures	Among 55 patients treated with PKP, 7 developed subsequent vertebral fractures.
Takahashi et al. (2019)	Prospective	>6 months	• 2 patients • 2 vertebrae • T7–T10	• 13 patients • 13 vertebrae • L3–L5	Bilateral transpedicular BKP	None	Subsequent adjacent vertebral fractures	• 1/2 thoracic and 1/13 lumbar patients developed subsequent adjacent levels fractures. • Across the entire cohort, comprised primarily of thoracolumbar spine fractures (T11-L2), the independent predictors for AVF were thoracic/thoracolumbar spine, old OVF presence, wedge angle greater than 25 degrees before surgery, and greater than 10 degrees correction. • Patients had significant pain relief and quality of life improvement kyphoplasty.
Yan et al. (2014)	Prospective	Mean 16.8 months (range 12–28)	N/A	• 309 patients • 309 vertebrae • L1–L5	Unilateral transverse process-pedicle vs. bilateral PKP	• Injected cement volume • Operative time • Radiation dose	• VAS preop, one, six, and twelve months post-op • SF-36 preop, one, six, and twelve months post-op • Anterior and posterior vertebral body height preop and twelve months post-op • Kyphotic angle preop and twelve months post-op • Cement leakage • Cement distribution • Subsequent vertebral fractures • Cost	• VAS, SF-36, vertebral height, and kyphotic angle drastically improved postoperatively • Injected cement volume and operative time was greater in the bilateral group. • There were extra-vertebral cement leakages in 7.6% of patients treated by unilateral technique and 14.6% of patients treated using bilateral technique. • Unilateral approach had a lower radiation dose, shorter operative time, lower rate of surgical complications, and a higher degree of deformity correction.

(*Continued*)

10.3389/fmscd.2025.1597288

TABLE 2 Continued

Author, year	Study type	Follow up	Thoracic patients and levels	Lumbar patients and levels	Kyphoplasty technique	Perioperative outcomes assessed	Postoperative outcomes assessed	Main findings
Kim et al. (2007)	Retrospective	>6 months	• 18 patients • 18 vertebrae • T5–T8	N/A	Extrapedicular approach BKP	Injected cement volume	• VAS preop, post-op, and six months post-op • Kyphotic angle preop and post-op • Cement leakage • Compression rate	• VAS score, compression rate, and kyphotic angle significantly improved postoperatively. • Mean volume of cement injected was 4.2+/-1.5 cc. • Cement leakage to the adjacent disc and paravertebral soft tissues in 3 cases.
Deng et al. (2023)	Retrospective	6 months	N/A	• 792 patients • NR vertebrae • L1–L5	PKP	• Injected cement volume • Operative time	• VAS six months post-op • Compression rate • Cement leakage	This study identified several variables as risk factors for chronic lower back pain following kyphoplasty of the lumbar spine, including multiple lumbar fractures, lumbar compression rate greater than 50%, and cement leakage.
Izadpanah et al. (2009)	Prospective	NR	• 17 patients • 17 vertebrae • T9–T12	• 13 patients • 13 vertebrae • L1–L5	BKP	• Operative time • Dose area product • Radiation time	None	• For both thoracic and lumbar compression fractures, use of computer navigation decreased dose area product and reduced radiation time without a significant increase in operative time. • The operative time and average radiation time was greater in the thoracic vertebrae while the applied DAP was greater in the lumbar vertebrae.
Korovessis et al. (2008)	Prospective	Mean 22 months (range 17–28)	N/A	• 18 patients • 18 vertebrae • L1–L4	BKP with calcium phosphate cement combined with posterior segmental short minimal invasive fixation	• Operative time • Blood loss • Injected cement volume	• ASIA post-op • VAS six months post-op • Anterior and posterior vertebral body height 6–8 months post-op • Gardner angle post-op • SF-36 six months post-op • Cement leakage • Spinal canal encroachment • Spinal canal clearance • LOS • Adjacent vertebral fractures	For lumbar compression fracture, BK with calcium phosphate cement combined with posterior segmental short minimal invasive fixation showed significant improvement in segmental kyphosis, reduction in spinal canal encroachment, vertebral height restoration, and post-operative improved in VAS and SF-36.
Pradhan et al. (2006)	Retrospective	<2 weeks	• 21 patients • 21 vertebrae • T6–T12	• 25 patients • 25 vertebrae • L1–L5	BAK, bilateral approach	None	• Anterior, middle, and posterior vertebral body height post-op • Sagittal angle post-op	• BKP was an effective treatment in reducing angular deformity and restoring vertebral height. • Angular restoration and height restoration was greater following BKP in thoracic patients than the lumbar patients.
Boszczyk et al. (2005)	Prospective	NR	• 27 patients • 48 vertebrae • T2–T8	N/A	Transcostovertebral KP	• Injected cement volume • Operative time • Blood loss	• Anterior and posterior vertebral body height post-op • Segmental kyphosis post-op • Cement leakage	Transcostovertebral KP for osteoporotic compression fractures of the thoracic spine improved vertebral body height, improved segmental kyphosis, had low cement leakage, and had low complications.

(*Continued*)

TABLE 2 Continued

Author, year	Study type	Follow up	Thoracic patients and levels	Lumbar patients and levels	Kyphoplasty technique	Perioperative outcomes assessed	Postoperative outcomes assessed	Main findings
Phillips et al. (2003)	Prospective	NR	• 15 patients • 26 vertebrae • T6–T12	• 18 patients • 26 vertebrae • L1–L5	BKP	None	Cobb angle post-op	Thoracic patients had a mean improvement in cobb angle of 9.7 degrees while the lumbar patients had a mean improvement of 7.9 degrees.
Lin et al. (2023)	Retrospective	NR	• 50 patients • 57 vertebrae • T4–T12	N/A	PKP	None	• VAS post-op and one month post-op • Anterior, middle, and posterior vertebral body height post-op and one month post-op • Cobb angle post-op and one month post-op	• This study evaluated 50 patients who had regional bilateral rib pain prior to PKP in treatment for OVCF in the thoracic region. • PKP as a treatment for thoracic OVCFs was supported due to the decrease in bilateral rib regional pain, restoration of vertebral height, and reduction in Cobb angle post-op.
Nguyen et al. (2020)	Prospective	3 months	• 65 patients • 73 vertebrae • T1–T12	N/A	BKP (fluoroscopic guidance)	• Injected cement volume • Infiltration of cement into vertebrae • Trocar insertion position	• VAS post-op and 3 months post-op • Cobb angle post-op • Cement leakage • Macnab's criteria	BKP is a minimally invasive procedure that can be used as a safe an effective method for treatment, regarding pain and spine deformity correction in the thoracic region.
Zhang et al. (2020)	Retrospective	Mean 14.4 months	• 44 patients • 44 vertebrae • T6–T9	N/A	PKP with O-arm navigation or fluoroscopy	• Operative time • Blood loss • Injected cement volume	• VAS post-op and final follow up • ODI post-op and final follow p • Anterior and middle vertebral body height post-op and final follow up • Kyphotic angle post-op and final follow up • LOS • Cement leakage	• PKP with O-arm navigation or fluoroscopy showed radiographic restoration and improvement on pain and quality of life scores. • O-arm navigation technique showed a statistically significant decrease in blood loss and complications, and it showed better volume of injected cement.
Zhang et al. (2019)	Retrospective	NR	• NR patients • 304 vertebrae • T6–T12	• NR patients • 244 vertebrae • L1–L5	PKP with c-arm x-ray or fluoroscopy	Injected cement volume	• PVWCD • VBSD • PVWCD/VBSD ratio • Bone mineral density • Cement leakage	• PVWCD deepened from T6-T12 but became shallower from L1-L5. VBSD increased from T6-L5. PVWCD/VBSD ratio was 16% from T6-T12 group and 3% from L1-L5 group. Thoracic group showed 10.1% cement leakage rate and lumbar group showed 3.7% leakage rate. • This case control study looked at differences in morphology of the posterior vertebral wall between the thoracic and lumbar spine, and also evaluated how these differences effect cement leakage in PKP. Overall, the study showed that the posterior thoracic spine was more concave and was associated with increased cement leakage when compared to the less concave lumbar spine.

(*Continued*)

10.3389/fmscd.2025.1597288

TABLE 2 Continued

Author, year	Study type	Follow up	Thoracic patients and levels	Lumbar patients and levels	Kyphoplasty technique	Perioperative outcomes assessed	Postoperative outcomes assessed	Main findings
Hsieh et al. (2013)	Retrospective	1 year	• 8 patients • 8 vertebrae • T10–T12	• 16 patients • 16 vertebrae • L1–L3	KP with PMMA	None	• VAS one year post-op • Anterior vertebral body height one year post-op • Kyphotic angle one year post-op • Subsequent vertebral fractures • Cement extravasation	• The study demonstrated that KP was an effective treatment for OVCFs between T10-L3. • While there is data on each individual KP case and vertebral level, the data was not compared between the lumbar and thoracic groups.
Tatsumi et al. (2010)	Retrospective	1 year	• 84 patients • 84 vertebrae • T1–T10	• 80 patients • 80 vertebrae • L3–L5	KP	Injected cement volume	• Preop Cobb angle • Subsequent adjacent vertebral fractures	• Patients treated with KP in the thoracic region were more likely to sustain an adjacent subsequent VCF (65%) while those with KP in the lumbar spine only showed 45% subsequent fractures. • Additionally, there was less time between original and subsequent thoracic fractures than between original and subsequent lumbar fractures.

BKP, balloon kyphoplasty; VAS, visual analog scale; LOS, length of stay; PK, percutaneous kyphoplasty; ODI, oswestry disability index; PKP, percutaneous kyphoplasty; PVP, percutaneous vertebroplasty; JOA, Japanese orthopedic association; SF-36, 36-tem short form health survey; NR, not reported.

Following kyphoplasty, Lee et al. reported an increase of 25%, 44%, and 6% in anterior, middle, and posterior vertebral body height in the thoracic spine, respectively, and an increase of 13%, 33%, and 3% in anterior, middle, and posterior vertebral body height in the lumbar spine (38). Similarly, Pradhan et al. observed an increase of 27%, 52%, and 3% in anterior, middle, and posterior vertebral body height in the thoracic spine following kyphoplasty, respectively, and an increase of 1%, 34%, and 11% in anterior, middle, and posterior vertebral body height in the lumbar spine (42). One year following the kyphoplasty procedure, Hsieh et al. reported a 5.64 ± 4.46 mm increase in anterior vertebral body height within the thoracic spine, and a 5.85 ± 7.82 mm increase in anterior vertebral body height within the lumbar spine (39).

Complications

Amongst the studies included, cement leakage (9 thoracic studies, 4 lumbar studies) and subsequent fractures (7 thoracic studies, 7 lumbar studies) were the most described complications (Tables 6, 7). In thoracic procedures, the pooled proportion of cases with cement leakage was 19% [95% CI (10%, 32%)] using a random-effects model, with significant heterogeneity observed ($I^2 = 89\%$) (Figure 2A). The fixed-effects model estimated a slightly higher proportion of 21% [95% CI (18%, 25%)]. For lumbar procedures, the pooled proportion of cement leakage was 13% [95% CI (7%, 22%)], with substantial heterogeneity ($I^2 = 85\%$). The fixed-effects model produced a comparable estimate of 14% [95% CI (12%, 17%)] (Figure 2B).

Regarding subsequent adjacent fractures, the pooled proportion for thoracic procedures was 10% [95% CI (2%, 33%)] under a random-effects model, with heterogeneity of $I^2 = 76\%$. The fixed-effects model estimated a higher proportion of 22% [95% CI (16%, 30%)] (Figure 2C). For lumbar procedures, the pooled proportion of adjacent fractures was 5% [95% CI (2%, 12%)] using a random-effects model, with $I^2 = 74\%$. The fixed-effects model yielded a slightly higher proportion of 7% [95% CI (5%, 11%)] (Figure 2D).

Risk of bias

Across all included studies, the primary risk of bias pertained to the risk of bias due to confounding factors. This resulted in a serious risk of bias in 12 studies (48.0%) and moderate risk of bias in 13 studies (52.0%) (Supplementary Figure S1).

Discussion

Kyphoplasty is a widely used surgical technique for the treatment of OVCFs in the thoracic and lumbar spine offering a safe option for fragile osteoporotic patients. This procedure is particularly advantageous because of its rapid onset of analgesia, ability to promote early mobilization without the need for

TABLE 3 Injected cement volume (ml).

Author, year	No. of pts (Vertebrae)	Thoracic	Author, year	No. of pts (Vertebrae)	Lumbar
Lee et al. (2007)	21 (21 vertebrae)	3.4, Approx: 3.4 ± 1.7	Lee et al. (2007)	17 (17 vertebrae)	5.2, Approx: 5.2 ± 2.6
Zhang et al. (2019)	NR (304 vertebrae)	4.2 ± 0.2	Zhang et al. (2019)	NR (244 vertebrae)	5.1 ± 0.5
Tatsumi et al. (2010)	84 (84 vertebrae)	3, Approx: 3 ± 1.5	Tatsumi et al. (2010)	80 (80 vertebrae)	4, Approx: 4 ± 2
Wu et al. (2022)	42 (42 vertebrae)	4.40 ± 1.71	Yan et al. (2014) Unilateral	158 (158 vertebrae)	3.4 ± 0.8
Ge et al. (2019)	50 (55 vertebrae)	4.44 ± 1.49	Yan et al. (2014) Bilateral	151 (151 vertebrae)	5.5 ± 0.7
Kim et al. (2007)	18 (18 vertebrae)	4.2 ± 1.5	Korovessis et al. (2008)[b]	18 (18 vertebrae)	3–6 grams
Boszczyk et al. (2005)	27 (48 vertebrae)	2.9 (range 1–5)[a] Approx: 2.9 ± 1			
Nguyen et al. (2020)	65 (73 vertebrae)	4.1 ± 1.1			
Zhang et al. (2020) O-arm	20 (20 vertebrae)	6.7 ± 1.2			
Zhang et al. (2020) Fluoroscopy	24 (24 vertebrae)	5.2 ± 1.3			
I^2 = 98.3%, Random Effects Model: 4.25 [95% CI (3.56, 4.93)]			I^2 = 99.4%, Random Effects Model: 4.61 [95% CI (3.79, 5.43)]		

[a]May not include strictly osteoporotic compression fractures.
[b]Not included within meta-analysis.
No., number; Pts, patients; NR, not reported; Approx., approximation.

TABLE 4 Operative time (min).

Author, year	No. of pts (Vertebrae)	Thoracic	Author, year	No. of pts (Vertebrae)	Lumbar
Wu et al. (2022)	42 (42 vertebrae)	39.05 ± 10.11	Qian et al. (2023) Unipedicular	82 (82 vertebrae)	32.01 ± 4.48
Ge et al. (2019)	50 (55 vertebrae)	77, Approx: 77 ± 38.5	Qian et al. (2023) Bipedicular	78 (78 vertebrae)	42.42 ± 6.01
Izadpanah et al. (2009)	17 (17 vertebrae)	61 ± 16	Yan et al. (2014) Unilateral	158 (158 vertebrae)	33.2 ± 5.1
Boszczyk et al. (2005)	27 (48 vertebrae)	30 (range 13–60) Approx: 30 ± 11.75	Yan et al. (2014) Bilateral	151 (151 vertebrae)	52.5 ± 10.9
Zhang et al. (2020) O-arm	20 (20 vertebrae)	66.3 ± 19.0	Izadpanah et al. (2009)	13 (13 vertebrae)	57 ± 20
Zhang et al. (2020) Fluoroscopy	24 (24 vertebrae)	71.4 ± 59.5	Korovessis et al. (2008)	18 (18 vertebrae)	45 (range 35–70) Approx: 45 ± 8.75
I^2 = 97.1%, Random Effects Model: 56.42 [95% CI (41.03, 71.81)]			I^2 = 99.4%, Random Effects Model: 43.07 [95% CI (35.34, 50.79)]		

No., number; Pts, patients; NR, not reported; Approx., approximation.

bracing, and the ability to treat multiple levels simultaneously (6). Thoracic and lumbar OVCFs are often analyzed together in clinical reports assessing kyphoplasty based outcome measures such as pain relief, radiographic improvement, and complication rates, potentially overlooking how the distinct anatomical and biomechanical differences between these regions may influence surgical and patient outcomes. For example, the thoracic vertebra have smaller, steeper pedicles, a narrower anterior border, and less angulation between the pedicle and vertebra compared to the lumbar region (43). These anatomical differences can make certain procedural steps, such as pedicle cannulation, balloon inflation, and cement distribution, more challenging. To our knowledge, this is the first systematic review to evaluate how such differences between the thoracic and lumbar spine may impact perioperative and postoperative outcomes in patients undergoing kyphoplasty for the treatment of OVCFs.

One of the primary outcomes we assessed in our study was post-procedural pain relief, as pain is one of the major indications for kyphoplasty. Approximately one third of patients with OVCFs experience chronic pain at the site of the fracture, which often results in limitations to their daily activities and lifestyle (44). Kyphoplasty frequently results in a significant pain reduction, and Mooney et al. demonstrated that, regardless of vertebral height improvement, the majority of patients who undergo kyphoplasty for vertebral compression fractures experience pain relief and enhanced quality of life (45). For example, Li et al. investigated kyphoplasty treatment of OVCFs at the mid thoracic vertebrae and found that the VAS pain score of patients decreased significantly from 8.34 ± 1.19 preoperatively to 2.49 ± 1.01 postoperatively (27). Likewise, Qian et al. investigated the treatment of lumbar vertebral compression fractures and reported a significant reduction in VAS scores from 7.30 ± 1.01 preoperatively to 2.39 ± 0.76 postoperatively in the unipedicular group and from 7.23 ± 0.88 preoperatively to 2.38 ± 0.72 postoperatively in the bipedicular group (46). Our study found similar pain relief, as measured through VAS, between patients undergoing kyphoplasty for OVCFs of the thoracic and the lumbar spine. Specifically, both groups showed significant improvement in pain levels from pre-procedural to post-procedural with no notable difference between the thoracic and lumbar groups in terms of pain relief.

The prevalence of kyphoplasty related surgical complications was another key variable examined in our study was. Cement leakage into the paravertebral soft tissues, veins, intradiscal space, or intraspinal canal is a common complication of kyphoplasty and can lead to severe complications such as neurological deficits, shortness of breath, wound infections, and adjacent segment fractures (47, 48). Prior studies have reported the overall

TABLE 5 Visual analog scale.

Author, year	Thoracic					Lumbar			
	No. of pts (Vertebrae)	Pre-op	Post-op (Duration)	Change	Author, year	No. of Pts (Vertebrae)	Pre-op	Post-op (Duration)	Change
Hsieh et al. (2013)	8 (8 vertebrae)	7.81 ± 0.75	1.88 ± 0.69 (1 year)	5.94 ± 0.78	Hsieh et al. (2013)	16 (16 vertebrae)	8.03 ± 0.56	2.19 ± 0.75 (1 year)	5.84 ± 1.09
Cao et al. (2020)	9 (NR vertebrae)	7.7 ± 1.0	2.2 ± 0.4 (post-op)	Approx: 5.5 ± 1.08	Cao et al. (2020)	10 (NR vertebrae)	7.4 ± 0.5	2.6 ± 0.7 (post-op)	Approx: 4.8 ± 0.86
Wu et al. (2022)	42 (42 vertebrae)	5.60 ± 1.53	2.17 ± 0.49 (6 mo.)	Approx: 3.43 ± 1.61	Qian et al. (2023) Unipedicular	82 (82 vertebrae)	7.30 ± 1.01	2.39 ± 0.76 (post-op) 1.75 ± 0.62 (2 year)	Approx: 4.91 ± 1.26 Approx: 5.55 ± 1.18
Ge et al. (2019)	50 (55 vertebrae)	8.87 ± 0.53	2.16 ± 0.57 (3 days) 2.93 ± 0.41 (final follow-up)	Approx: 6.71 ± 0.78 Approx: 5.94 ± 0.67	Qian et al. (2023) Bipedicular	78 (78 vertebrae)	7.23 ± 0.88	2.38 ± 0.72 (post-op) 1.68 ± 0.63 (2 year)	Approx: 4.85 ± 1.13 Approx: 5.55 ± 1.08
Kim et al. (2007)	18 (18 vertebrae)	7.9	3.0 (<48 hours) 3.0 (6 months)	Approx: 4.9 ± 2.45 Approx: 4.9 ± 2.45	Cho et al. (2011)	NR (28 vertebrae)	7.7 ± 1.01	2.0 ± 1.28 (post-op)	Approx: 5.7 ± 1.63
Lin et al. (2023)	50 (57 vertebrae)	7 med. (IQR 6–7) Approx: 7.0 ± 0.74	1 med. (IQR 1–2) (post-op) Approx: 1.0 ± 0.74 0 med. (IQR 0–1) (1 mo.) Approx: 0.0 ± 0.74	Approx: 6.0 ± 1.05 Approx: 7.0 ± 1.05	Jin et al. (2022) PKP	45 (45 vertebrae)	7.87 ± 1.23	4.02 ± 1.07 (1 mo.) 3.08 ± 0.63 (6 mo.) 1.75 ± 0.43 (12 mo.)	Approx: 3.85 ± 1.63 Approx: 4.79 ± 1.38 Approx: 6.12 ± 1.30
Nguyen et al. (2020)	65 (73 vertebrae)	7.7 ± 1.1	3.3 ± 0.6 (post-op) 1.2 ± 0.6 (3 mo.)	Approx: 4.4 ± 1.25 Approx: 6.5 ± 1.25	Jin et al. (2022) PKP + back rehab	56 (56 vertebrae)	7.89 ± 1.27	3.41 ± 0.78 (1 mo.) 1.87 ± 0.54 (6 mo.) 1.28 ± 0.45 (12 mo.)	Approx: 4.48 ± 1.49 Approx: 6.02 ± 1.38 Approx: 6.61 ± 1.34
Zhang et al. (2020) O-arm	20 (20 vertebrae)	7.0 ± 0.9	2.1 ± 0.8 (post-op) 2.0 ± 0.6 (final follow-up)	Approx: 4.9 ± 1.20 Approx: 5.0 ± 1.08	Yan et al. (2014) Unilateral	158 (158 vertebrae)	8.1 ± 1.4	3.7 ± 1.1 (1 mo.) 2.6 ± 1.3 (12 mo.)	Approx: 4.4 ± 1.78 Approx: 5.5 ± 1.91
Zhang et al. (2020) Fluoroscopy	24 (24 vertebrae)	7.0 ± 0.8	2.0 ± 0.7 (post-op) 2.0 ± 0.6 (final follow-up)	Approx: 5.0 ± 1.06 Approx: 5.0 ± 1.0	Yan et al. (2014) Bilateral	151 (151 vertebrae)	7.9 ± 1.3	4.0 ± 1.2 (1 mo.) 2.9 ± 1.4 (12 mo.)	Approx: 3.9 ± 1.77 Approx: 5.0 ± 1.91
					Korovessis et al. (2008)	18 (18 vertebrae)	7.6 ± 2.0	3.1 ± 2.3 (6 mo.)	Approx: 4.5 ± 3.05
I^2 = 96.7%, Random Effects Model: 5.49 [95% CI (4.79, 6.19)]					I^2 = 88.5%, Random Effects Model: 5.59 [95% CI (5.23, 5.94)]				

No., number; Pts, patients; NR, not reported; IQR, interquartile range; mo., months; yr, year; med., median; Approx., approximation.

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TABLE 6 Cement leakage.

Author, year	No. of Pts (Vertebrae)	Thoracic	Author, year	No. of Pts (Vertebrae)	Lumbar
Zhang et al. (2019)	NR (304 vertebrae)	31/304 (10.1%) (spinal canal)	Zhang et al. (2019)	NR (244 vertebrae)	9/244 (3.7%) (spinal canal)
Hsieh et al. (2013)	8 (8 vertebrae)	0/8 (0.0%) (cement extravasation)	Hsieh et al. (2013)	16 (16 vertebrae)	0/16 (0.0%) (cement extravasation)
Wu et al. (2022)	42 (42 vertebrae)	27/42 (64.28%) (location not specified)	Qian et al. (2023) Unipedicular	82 (82 vertebrae)	19/82 (23.1%) (6 vein, 5 intervertebral, 8 paravertebral)
Ge et al. (2019)	50 (55 vertebrae)	4/50 (8.0%) (bone cement leakage)	Qian et al. (2023) Bipedicular	78 (78 vertebrae)	20/78 (25.6%) (5 vein, 4 intervertebral, 10 paravertebral)
Liu et al. (2019)	NR (37 vertebrae)	20/37 (54.1%) (18 cement leakage, 2 epidural cement leakage)	Yan et al. (2014) Unilateral	158 (158 vertebrae)	12/158 (7.6%) (4 adjacent intervertebral disc, 7 paravertebral soft tissue, 1 spinal canal)
Cho et al. (2011)	NR (28 vertebrae)	3/28 (10.7%) (epidural)	Yan et al. (2014) Bilateral	151 (151 vertebrae)	22/151 (14.6%) (10 adjacent intervertebral disc, 4 paravertebral soft tissue, 8 spinal canal)
Kim et al. (2007)	18 (18 vertebrae)	3/18 (16.7%) (2 adjacent discal, 1 paravertebral soft tissue, 0 epidural, 0 venous)	Korovessis et al. (2008)	18 (18 vertebrae)	4/18 (22.2%) (adjacent superior disc)
Boszczyk et al. (2005)	27 (48 vertebrae)	8/54 (14.8%) (3 paravertebral, 3 adjacent disc, 1 lateral, 1 epidural)[a]			
Nguyen et al. (2020)	65 (73 vertebrae)	20/65 (30.8%) (location not specified)			
Zhang et al. (2020) O-arm	20 (20 vertebrae)	1/20 (5%) (location not specified)			
Zhang et al. (2020) Fluoroscopy	24 (24 vertebrae)	3/24 (12.5%) (location not specified)			

No., number; Pts, patients; NR, not reported.
[a]May not include strictly osteoporotic compression fractures.

TABLE 7 Subsequent adjacent fractures.

Author, year	No. of Pts (Vertebrae)	Thoracic	Author, year	No. of Pts (Vertebrae)	Lumbar
Tatsumi et al. (2010)	84 (84 vertebrae)	24/84 (adjacent)	Tatsumi et al. (2010)	80 (80 vertebrae)	12/80 (adjacent)
Takahashi et al. (2019)	2 (2 vertebrae)	1/2 (adjacent)	Takahashi et al. (2019)	13 (13 vertebrae)	1/13 (adjacent)
Wu et al. (2022)	42 (42 vertebrae)	3/42 (adjacent)	Yan et al. (2014) Unilateral	158 (158 vertebrae)	4/158 (adjacent) 15/158 (subsequent)[a]
Ge et al. (2019)	50 (55 vertebrae)	0/50 (adjacent)	Yan et al. (2014) Bilateral	151 (151 vertebrae)	5/151 (adjacent) 15/151 (subsequent)[a]
Cho et al. (2011)	NR (28 vertebrae)	0/28 (adjacent)	Korovessis et al. (2008)	18 (18 vertebrae)	0/18 (adjacent)
Fribourg et al. (2004)	NR (18 vertebrae)	8/18 (subsequent)[a]	Chen et al. (2022)	55 (NR vertebrae)	7/55 (subsequent)[a]
			Fribourg et al. (2004)	NR (29 vertebrae)	9/29 (subsequent)[a]

No., number; Pts, patients; NR, not reported.
[a]Fractures were not classified as adjacent or distal and were therefore not included within meta-analysis.

incidence of cement extravasation to be around 10% (49, 50). Cement extravasation occurs through pathways created by structural irregularities, including blood vessels, vertebral shell damage, fracture clefts, or improper instrument placement (51, 52). Performing kyphoplasty earlier after an OVCF has previously been shown to lead to better vertebral height restoration, reduced kyphotic deformity, and a lower incidence of cement leakage (53). Our review highlighted a higher mean rate of cement leakage in the thoracic spine compared to the lumbar spine. Although the substantial overlap in confidence intervals suggests that this difference is not clinically significant and that the risk of this complication is comparable between anatomical locations, the higher rate of cement leakage in the thoracic spine may be attributed to anatomical challenges, such as posterior wall morphology, which might complicate instrument placement or surgical view (54). Similarly, we investigated the prevalence of subsequent adjacent level fractures. The redistribution of biomechanical stress after kyphoplasty may place increased strain on adjacent vertebrae, increasing the risk for adjacent-level fractures that can worsen spinal deformity, exacerbate pain, and contribute to functional decline (55). Subsequent fractures are typically subacute or late complications, making them difficult to predict. According to a recent meta-analysis, they can occur between 7 and 52 months after percutaneous kyphoplasty (56). More than 50% of subsequent fractures occur adjacent to the treated vertebrae, reigniting the ongoing debate over whether kyphoplasty increases the incidence of subsequent vertebral fractures. Prior studies have estimated the incidence of adjacent-level fractures following vertebral augmentation to range between 7%–29% (57). Several risk factors have been identified for the development of an adjacent-level fracture, including age, vertebral body height loss, cement leakage, and vertebral angles, among

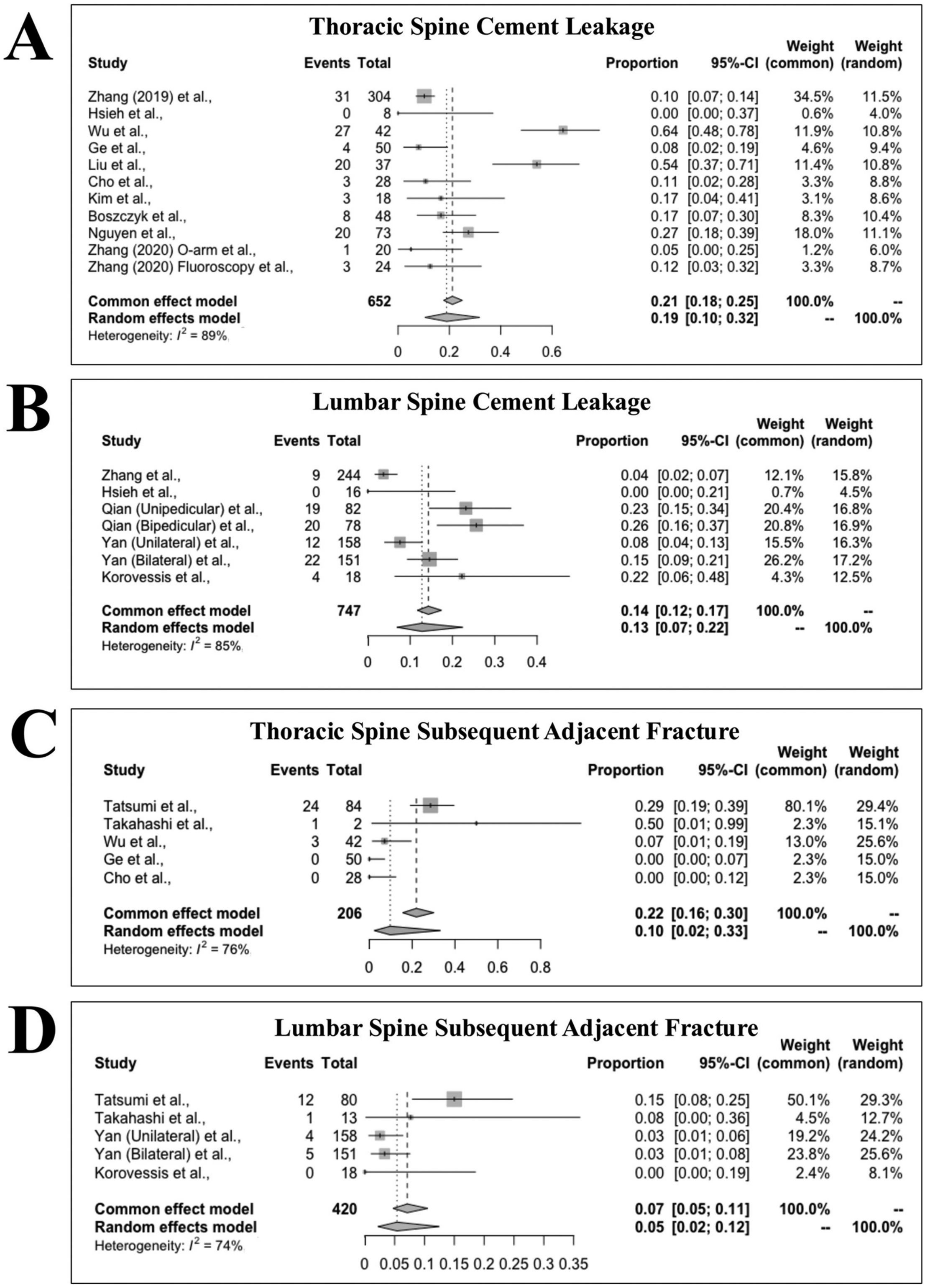

FIGURE 2
Forest plot analysis illustrating the proportion of cement leakage following kyphoplasty in the thoracic spine (A) and the lumbar spine (B). Forest plot analysis illustrating the proportion of subsequent adjacent fracture following kyphoplasty in the thoracic spine (C) and the lumbar spine (D).

others (55, 57–59). Within our study, the pooled proportion of adjacent-level fractures following kyphoplasty was higher in the thoracic spine compared to the lumbar spine. While the overlap within confidence intervals suggests this different may not be clinically significant, anatomical differences impacting biomechanical stress distribution in the thoracic spine may further increase its susceptibility to adjacent-level fractures. Further research is warranted to explore potential reasons for a higher likelihood of subsequent adjacent level fractures and cement leakage following kyphoplasty of the thoracic spine.

As larger volumes are thought to be associated with improved vertebral body height restoration and kyphotic angulation correction, we also investigated differences in the volume of cement injected during kyphoplasty (60). Prior studies have suggested that larger cement volumes may be a significant predictor of pain relief following the procedure, with volumes exceeding 4.5cc recommended for optimal outcomes (61). Given the anatomical differences between the thoracic and lumbar vertebrae, it was hypothesized that less cement would be required for thoracic vertebrae. While meta-analysis did reveal a decreased volume of cement injected during kyphoplasty of the thoracic spine compared to the lumbar spine, this difference was minimal and likely indicates that surgeons are using relatively similar volumes of cement regardless of the vertebral region being treated.

Operative time is another critical consideration in kyphoplasty, especially when treating thoracic OVCFs. The presence of ribs in the thoracic spine may increase the technical difficulty of the procedure due to challenges in balloon implantation, as well as the increased risk of pedicle fractures and neural dysfunction (43). Likewise, the thoracic spine has smaller pedicle size and increased kyphosis which leads to difficulty in needle placement and cannulation (62). We hypothesized that thoracic kyphoplasty would result in longer operative times compared to lumbar procedures. Previously reported operative times for lumbar kyphoplasty are between 52.5 and 120 min (29, 63–66). Our meta-analysis revealed a 13 min increase in operative time for kyphoplasty of the thoracic spine vs. the lumbar spine. Prolonged operative time elevates a patient's risk for infection, anesthesia-related complications, excessive blood loss, and increased surgical costs, among other potential complications. Nevertheless, further research is needed to better understand this difference in operative time and determine whether it has clinically significant impacts on the predominantly frail and elderly patients undergoing this operative procedure.

Our study highlights several key similarities in outcomes between thoracic and lumbar OVCFs treated with kyphoplasty, including cement volume injected, VAS pain scores, cement leakage rates, and the incidence of subsequent adjacent fractures. Despite the anatomical challenges associated with the thoracic spine, our findings support that kyphoplasty can be performed safely and effectively in both regions with comparable outcomes. Nevertheless, this review draws attention to longer operative times and a higher incidence of cement leakage and adjacent-level fractures in the thoracic spine. While these differences may not be clinically significant, they underscore the need for larger, more controlled prospective studies to further explore potential variations in outcomes based on fracture location. Likewise, these findings provide an outcomes-based framework for surgeons to inform surgical decision-making and optimize treatment strategies for elderly patients with OVCFs depending on the spinal region affected.

Limitations

This review was not registered. Although we conducted a thorough and systematic assessment of the literature across multiple databases using all key terms and search combinations deemed relevant, there remains a possibility that studies offering additional insights were unintentionally omitted. Similarly, any insights that could have been gained from reviews, case reports, conference abstracts, non-English manuscripts, animal studies, expert opinions, editorials, or non-original research were not captured due to the exclusion criteria employed in this review. The authors noted substantial variability in sample sizes, kyphoplasty techniques, and the demographic and clinical profiles of research participants across studies that may limit the generalizability of the findings. The most prevalent source of bias across studies arose from confounding variables. Most studies included in this review did not directly compare the outcomes of kyphoplasty performed on the thoracic and lumbar spine within the same study. Consequently, cross-study comparisons are inherently influenced by variations in surgeons, surgical techniques, patient populations, and hospital resources, which can impact the interpretation of results. Likewise, several studies included in this review did not clearly distinguish whether their patient populations consisted of individuals with acute and/or chronic OVCFs, representing another potential confounding variable. Lastly, to conduct meta-analysis, we converted the reported data from various studies to means and standard deviations using established statistical approximation methods whenever these metrics were not provided directly. As these techniques assumed an underlying normal distribution, the resulting estimates may be imprecise when that assumption is violated, potentially influencing our pooled outcomes. Nevertheless, all approximation used in analysis are documented in Tables 3–5. Future research on the effectiveness of different kyphoplasty techniques for osteoporotic fractures should incorporate spinal region-specific stratification, distinguishing between thoracic and lumbar fractures while evaluating their respective outcome measures. This direct approach would offer valuable insights into regional differences in outcomes within a controlled cohort, enhancing the understanding of treatment efficacy.

Conclusion

This systematic review and meta-analysis provided a comprehensive comparison of perioperative and postoperative outcomes of kyphoplasty between thoracic and lumbar regions of the spine, addressing a critical gap in the literature. Our findings suggest that despite the anatomic and biomechanical differences between the spinal regions, key outcome measures such as pain relief, cement leakage rates, and subsequent adjacent fracture rates remain comparable. While the literature suggests that kyphoplasty in the thoracic region poses technical challenges, including increased operative time and difficult deformity correction, the overall safety and success of the procedure remains consistent across the two spinal regions. The comparable outcomes support a broader adoption of kyphoplasty in the thoracic spine, challenging the prevailing notion that the procedure is more suitable for the lumbar spine. Future studies investigating kyphoplasty should subcategorize patient cohorts by operative spinal region to directly evaluate the impact of varying anatomical and biomechanical factors in the success of the kyphoplasty procedure between the thoracic and lumbar spine regions.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

MK: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. RR: Conceptualization, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. CG: Conceptualization, Investigation, Supervision, Writing – original draft, Writing – review & editing. TE: Writing – original draft, Writing – review & editing. CCi: Data curation, Investigation, Writing – review & editing. CCo: Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing. TZ: Data curation, Investigation, Writing – review & editing. SL: Data curation, Investigation, Writing – review & editing. JC: Investigation, Writing – original draft, Writing – review & editing. MS: Investigation, Supervision, Writing – review & editing. RW: Investigation, Supervision, Writing – review & editing. JL: Investigation, Supervision, Writing – review & editing. VS: Conceptualization, Investigation, Supervision, Writing – review & editing.

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Conflict of interest

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmscd.2025.1597288/full#supplementary-material

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