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Is Implant Removal After Thoracolumbar Fracture Fixation Truly Necessary? A Systematic Review and Meta-Analysis of Radiological, Functional and Safety Outcomes

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Abstract

Study Design: Systematic review and Meta-analysis.

Objective: To compare radiological, functional and safety outcomes of implant removal vs implant retention following posterior fixation of thoracolumbar (TL) fractures.

Methods: Following PRISMA guidelines, we searched PubMed, Embase, Scopus, Web of Science, and Cochrane library from inception to October 2025. Randomised controlled trials (RCT) and comparative cohort studies comparing outcomes between planned implant removal and retention were considered. Primary outcome measures were Cobb angle correction, Oswestry Disability Index (ODI) and surgical site infection (SSI). Secondary outcomes included pain scores, kyphosis progression, reoperation rates, and patient reported outcome measures (PROM). Random effects models generated pooled mean differences (MD) and odds ratio (OR).

Results: Eight studies with 571 patients met the inclusion criteria. Radiological outcomes were comparable between the groups. Improvements in Cobb angle were similar for the 2 groups [MD: 5.04°, 95% CI: 0.03-10.05 (implant removal group) vs MD 6.38°, 95% CI: 1.89-10.87 (implant retention group); $P = .70$]. Kyphosis progression also did not differ between the groups (MD: 0.41°; $P = .37$). Functional outcomes improved significantly within both groups; however, pooled ODI analysis demonstrated no between-group difference ($P = .81$). SSI rates were low across all studies, with no significant difference between the 2 groups [Odds ratio (OR)-1.42; $P = .30$). Pain scores improved similarly in both the cohorts, and the reoperation rates were infrequent and comparable.

Conclusion: Implant removal after healed TL fractures provides no radiological or functional advantage over implant retention for most patients. Both strategies demonstrate meaningful improvements in pain, spinal alignment and disability, with low complication rates. Implant removal may benefit in select young and symptomatic individuals; however, routine removal may not be recommended. Individualized decision-making remains essential.

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Level of Evidence: II.

Keywords
thoracolumbar fracture, pedicle screw, implant removal, implant retention, kyphosis, ODI, systematic review, meta-analysis

Introduction

Thoracolumbar (TL) fractures represent one of the most common spinal injuries encountered in trauma practice, and account for approximately 90% of all spinal fractures.[1–5] These injuries predominantly affect the T11-L2 transitional zone, where the biomechanical stresses under routine physiological forces are the largest.[6] Pedicle screw fixation remains the most-widely employed surgical treatment for unstable TL fractures, allowing for immediate stability, restoration of sagittal alignment and early mobilization.[3,7] Although advancements in surgical techniques, such as percutaneous fixation and short-segment instrumentation, have substantially enhanced the postoperative outcomes[8,9]; an important and yet unresolved question persists regarding the optimal postoperative management of implanted hardware once the bony union has been achieved.

Posterior instrumentation is frequently conceptualized as a temporary internal fixator (especially in percutaneous or non-fusion approaches), which may be removed after fracture consolidation so as to restore segmental motion, mitigate long term implant-related irritation, as well as reduce theoretical risks of adjacent segment degeneration (ASD), metal fretting, allergic reactions and stress-shielding induced

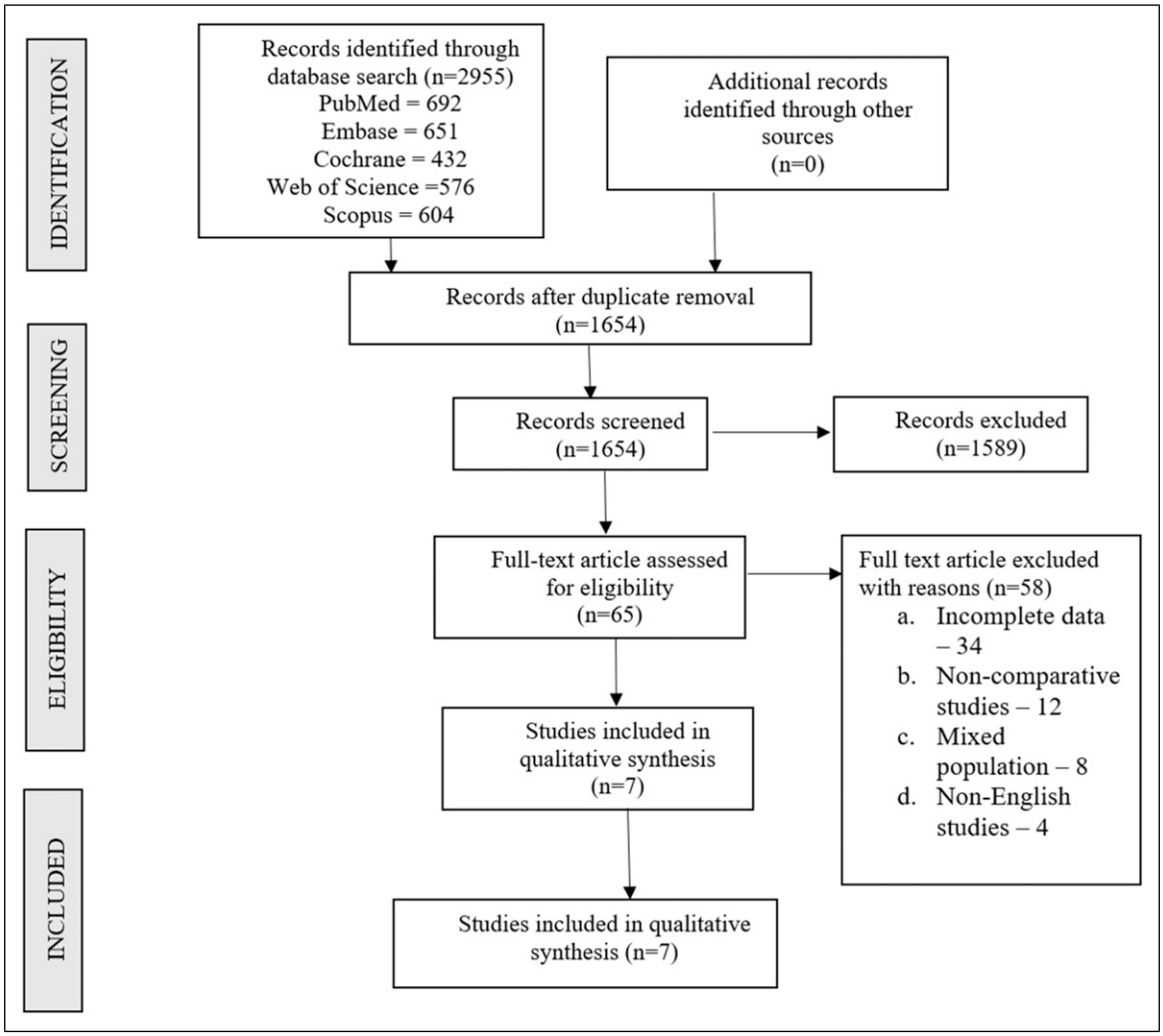


Figure 1. PRISMA flow diagram of inclusion of studies for analysis

Table 1. Characteristics of Studies Included in the Analysis

First author (year)	Country	Study design	Total sample size	Retention group (n)	Removal group (n)	Age mean (SD)	Sex (Male %)	Fracture type (%)	Levels treated	Surgical approach	Fusion performed	Time to implant removal (months)	Follow up (months)	Indication for removal	RoB grade
El Saman et al (2024)	Germany	RCS	87	44	43	45	59.8	A: 77.0; B: 19.5; C: 3.5	T11–L2	Open posterior	Retention group: No fusion removal group: Mixed	12	40.8	Symptom relief/ standard removal recommendation	Moderate
Zhang et al (2025)	China	RCS	57	27	30	Removal: 63.3 ± 3.2; retention: 67.7 ± 2.3	42.1	A1: 29.8; A2: 10.5; A3: 50.9; B1: 5.3; B2: 3.5	T11-L2	MIS	No	10-15	NR	Fracture healing/ implant-related irritation	Low
Chou et al (2016)	Taiwan	RCS	69	22	47	Removal: 44.7 ± 9.8; retention: 46.6 ± 10.6	63.7	NR	T11-L3	Open posterior	No	10.3	66.2 ± 13.4	Routine removal after union/patient preference/screw breakage risk	Low
Jeon et al (2015)	Korea	RCS	90	45	45	Removal: 39.7 ± 14.9; retention: 42.2 ± 15.6	Removal: 55.5; control: 62.2	Thoracolumbar burst fractures	T11-L4	Open posterior	Yes	18.3 ± 17.6	24	Removal after CT-union	Moderate
Ibrahim et al (2025)	Egypt	RCT	52	26	26	Removal: 33.0 ± 13.6; retention: 35.2 ± 12.3	Removal: 57.69; Retention: 65.38	AO type A/B single-level	T11–L2	Open	No	≥12 months	12	CT-confirmed fracture consolidation	Low
Xu et al (2022)	China	RCS	96	50	46	Removal: 69.8 ± 2.5; retention: 69.1 ± 1.9	46.9	AO A3–A4 burst fractures	T11-L4	Open/MIS	No	16.8	48.5	Pain/irritation/surgeon recommendation	Low
Zhang et al (2017)	China	RCS	61	30	31	Removal: 48.2 ± 2.4; retention: 50.1 ± 1.7	67.2	Thoracolumbar fractures (A1–A3/B1)	T11–L4	Open	Yes (retention group)	6	28.8	Healing of fracture	Low
Hoppe et al (2017)	Switzerland	RCS	59	30	26	Removal: 41.7 ± 15.4; retention: 43.2 ± 13.2	62.7	Thoracolumbar burst fractures (AO A3.1–A3.2.1)	T12-L3	Open	Yes	9.8	12	Patient preference/ routine removal	Moderate

RCS, retrospective cohort study; RCT, randomized controlled trial; NR, not reported; MIS, minimally invasive surgery; CT, computed tomography; RoB, risk of bias.

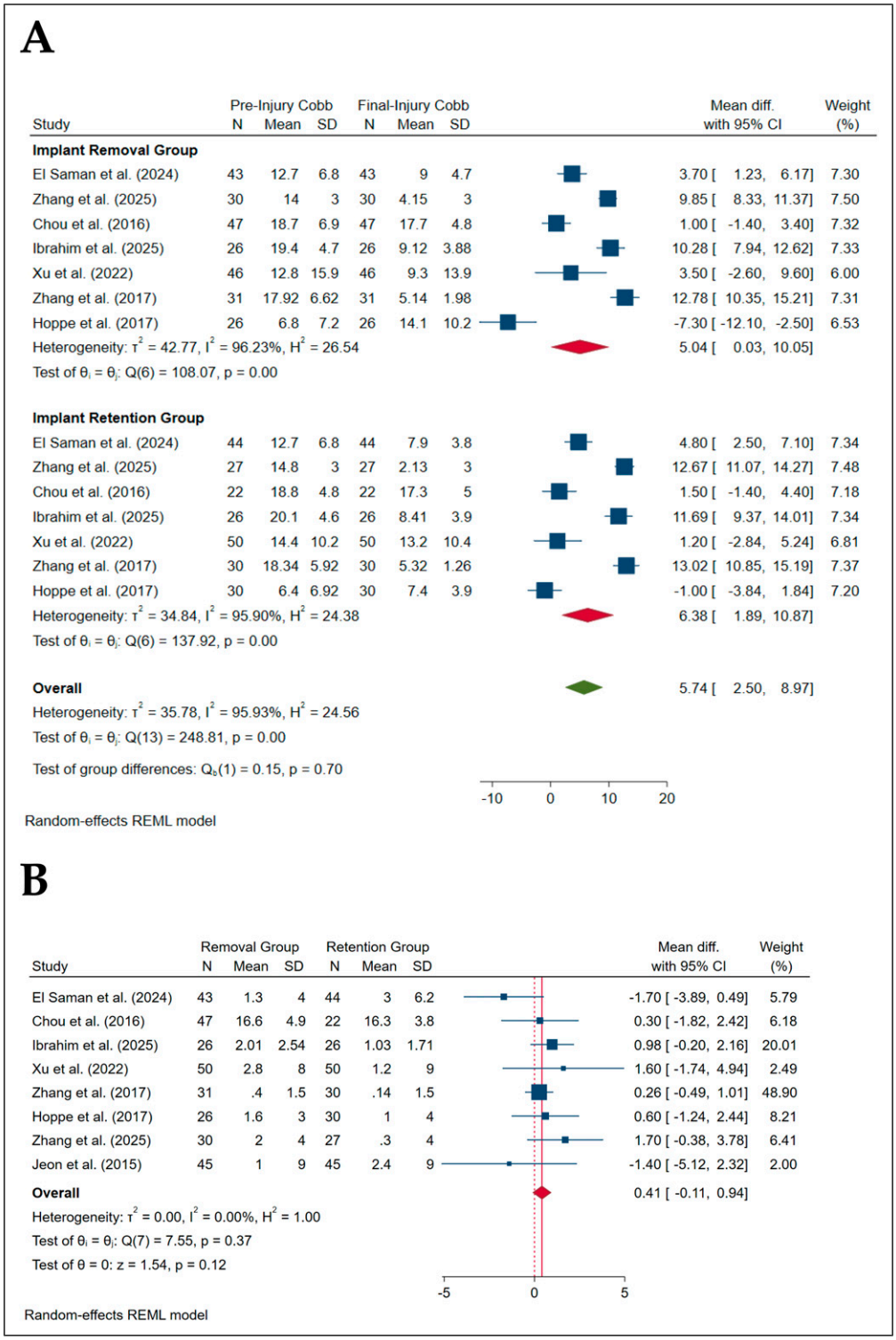


Figure 2. Forest plot comparing (A), the implant removal group to the implant retention group for radiological correction (Cobb angle change) at final follow-up compared to preoperative status; (B), advancement of kyphosis post-implant removal compared to the implant retention group

osteopenia.[1,3,5–26] The advocates of implant removal argue that hardware retention beyond the period necessary for fracture healing confers minimal biomechanical advantage while exposing the patients to potential long-term complications.[5,10,21,24] Diverse retrospective studies and observational cohorts have suggested that implant removal may lead to enhanced function, range of motion (ROM) and mitigated pain, especially in the context of young, active individuals; and can potentially reduce screw loosening or implant failure rates.[18,23,27] On the other hand, the disadvantages of routine implant removal include the need for a second surgery, surgical site infection (SSI), neurovascular complications, refractures, and loss of deformity correction (and potential spinal malalignment), especially in the absence of an anterior column support.[28,29] While some studies have reported clinically insignificant or non-measurable improvements in PROMs following removal; others have demonstrated kyphosis progression or loss of disc integrity.[2,12,25,30–32] In the elderly individuals, the physiological burden of reoperation and limited need for motion restoration further challenge the rationale for routine implant removal.[5,18] Consequently, current clinical practice varies widely across diverse institutions and surgeons, with no available consensus or guidelines.

Existing literature is characterized by heterogeneity in study designs, fracture patterns, fixation strategies, fusion status, timing of implant exit and outcome measures.[4,33] A majority of the studies are retrospective, with small sample sizes and variable follow-up, thereby limiting the generalizability of the conclusions.[34–41] Until recently, high-quality evidence including RCTs on this subject was limited; and the balance between the benefits and risks of routine implant removal in the backdrop of spinal fracture fixation was fairly unexplored.[18,19,23,42,43] Thus, a comprehensive synthesis of comparative studies evaluating implant removal vs retention was deemed necessary to clarify the impact on radiological alignment, functional recovery, pain outcome, and complication rates. This systematic review and meta-analysis were thus undertaken to evaluate the clinical and radiological outcomes following implant removal, in comparison with implant retention in patients treated surgically for TL fractures. By pooling contemporary evidence (including RCTs and comparative cohort studies), this review aims to provide clarity on whether implant removal confers any meaningful benefits, identify the patient subgroups who may benefit most; as well as develop evidence-based strategy for decision-making within spine trauma practice.

Methods

Study Design

This systematic review and meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-

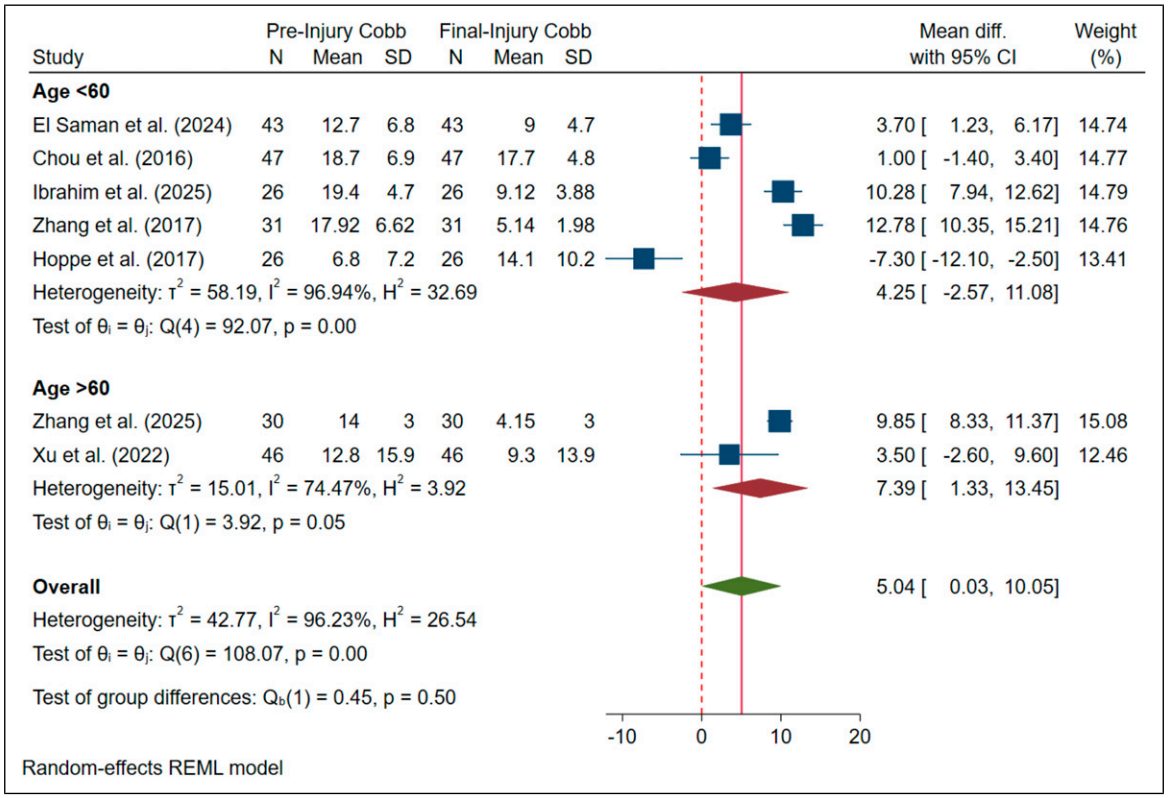


Figure 3. Forest plot of subgroup analysis of the implant removal cohort among the included studies based on the age group categories and radiological correction (Cobb angle change) at final follow-up, as compared to preoperative status

analysis (PRISMA) guidelines[44] and adhered to Cochrane collaboration standards for comparative effectiveness research.[45] The review evaluated clinical and radiological outcomes of implant removal vs implant retention following surgical fixation of TL fractures.

Eligibility Criteria

We included RCTs and comparative cohort studies that assessed outcomes in patients who underwent spinal fixation for traumatic fractures of the TL spine.

Inclusion Criteria

Study Population. Patients undergoing posterior spinal instrumentation for traumatic TL fractures

Intervention. Elective or planned implant removal (I_{REM} group) after radiological or clinical evidence of healing.

Comparator. Patients in whom the spinal implants were retained in-situ (I_{RET} group).

Outcomes. Primary outcomes were radiological correction (Cobb angle), functional improvement [Oswestry Disability Index (ODI)], safety outcome [surgical site infection (SSI)]. Secondary outcomes included pain scores [visual analog scale (VAS)], reoperation rates and additional patient-reported outcomes.

Exclusion Criteria

Case reports, narrative reviews, editorials, non-comparative studies, studies lacking extractable quantitative data and non-English full-text articles were excluded.

Search Strategy

A comprehensive search was performed across PubMed, Embase, Cochrane Central Register of Controlled Trials (CENTRAL), Scopus, and Web of Science from inception to October 2025. Trial registries, including ClinicalTrials.gov and WHO ICTRP, were also searched using a combination of Boolean operators in key words such as "thoracolumbar fracture," "implant removal," "hardware retention," "posterior

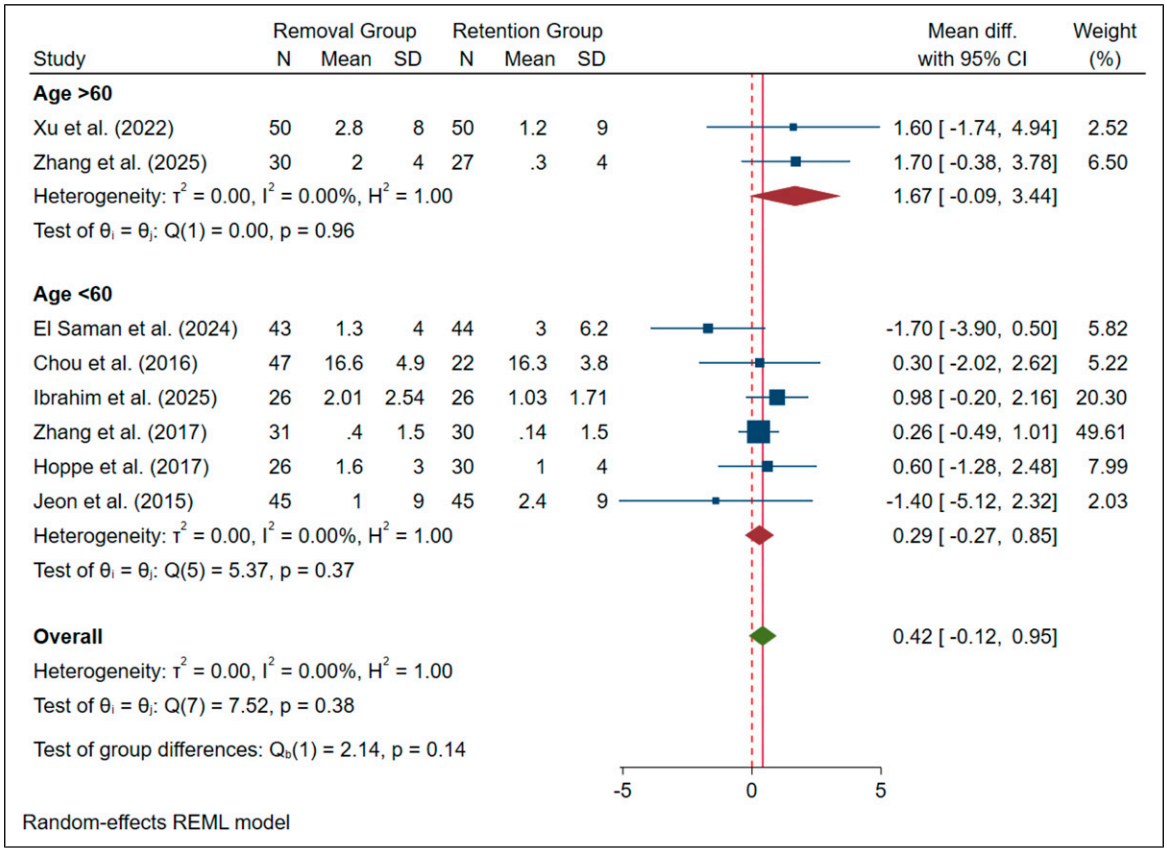


Figure 4. Forest plot of subgroup analysis among the included studies based on the age group categories and advancement of kyphosis (post-implant removal compared to the implant retention group)

fixation," "kyphosis," "ODI," and "VAS." Grey literature was explored through conference proceedings of major spine and orthopaedic societies. Reference lists of included studies and relevant systematic reviews were hand-searched to identify additional eligible reports. The search strategy combined controlled vocabulary and free-text terms for spinal instrumentation, implant removal, implant retention, and outcomes of interest. No restrictions were applied regarding year of publication; however, only full-text articles in English were considered.

Study Selection

All retrieved records were imported into Zotero for deduplication and screened using Rayyan software. Two reviewers independently screened titles and abstracts, followed by a full-text review of potentially eligible articles. Disagreements were resolved by consensus or adjudication by a third reviewer. A PRISMA flow diagram was constructed to depict the number of records identified, screened, excluded, and included, along with reasons for exclusion (Figure 1).

Data Extraction

Data extraction was performed independently by 2 reviewers using a standardised form. Extracted variables included study characteristics (author, year, country, design), participant demographics (sample size, mean age, sex distribution), intervention details (timing of implant removal, retention protocol), comparator details, and outcomes (Cobb angle, ODI, SSI, pain scores). Where outcomes were reported in heterogeneous formats (mean ± SD, mean + range, or descriptive statistics), harmonization was performed to ensure comparability. Missing standard deviations were estimated from ranges using established statistical methods.

Risk of Bias Assessment

Risk of bias was assessed independently by 2 reviewers. For randomised trials, the Cochrane Risk of Bias 2.0 tool was used, and for cohort studies, the Newcastle-Ottawa Scale (NOS) was applied. Disagreements were resolved by consensus.

Statistical Analysis

Continuous outcomes (Cobb angle, ODI, pain scores) were synthesised as mean differences (MD) with 95% confidence intervals (CI). Binary outcomes (SSI incidence) were synthesised as log odds ratios (OR) with 95% CI. Meta-analyses were conducted using random-effects models with restricted maximum likelihood (REML) estimation. Heterogeneity was

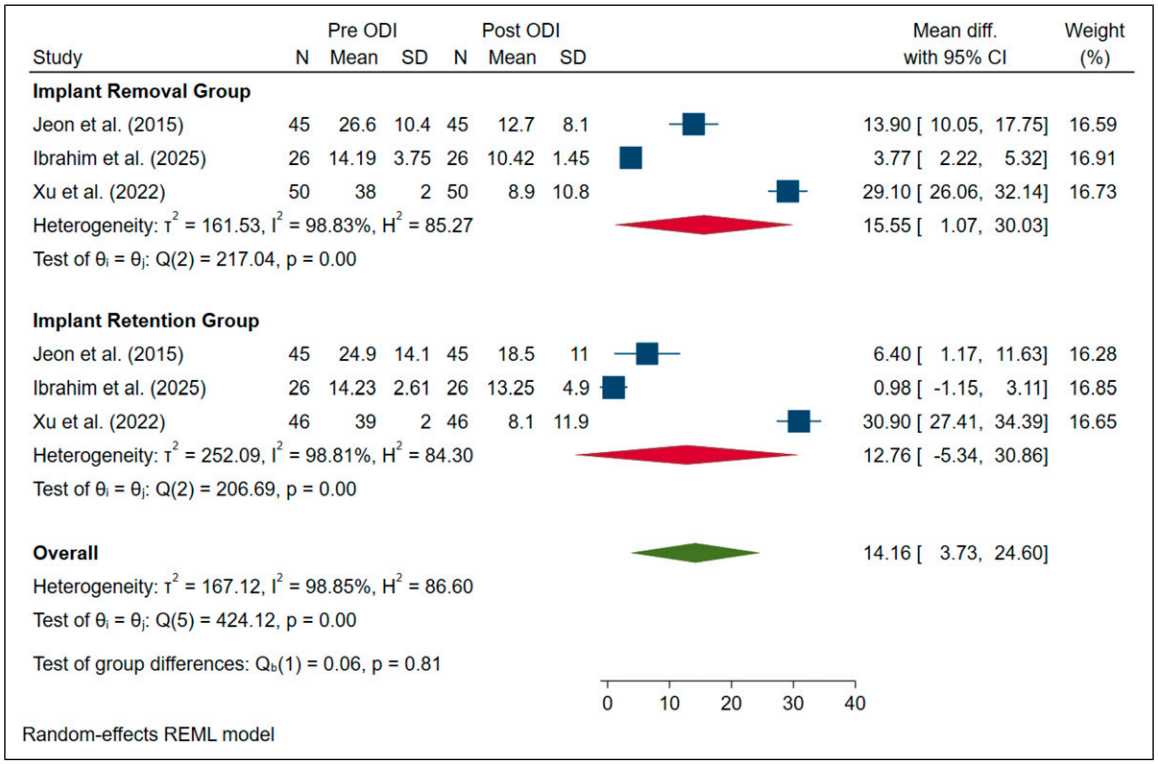


Figure 5. Forest plot comparing the implant removal group to the implant retention group for functional outcome (ODI) at final follow-up compared to preoperative status

quantified using I^2 and H^2 statistics along with the Galbraith plot, and explored through subgroup analyses comparing implant removal vs retention groups. Sensitivity analyses included leave-one-out meta-analysis and exclusion of studies at high risk of bias. Publication bias was assessed using funnel plots and Egger's regression test. The certainty of evidence was evaluated using the GRADE approach, considering risk of bias, inconsistency, indirectness, imprecision, and publication bias. Data synthesis and statistical analyses were conducted using Stata version 17 (StataCorp LLC, College Station, TX, USA). Statistical significance was set at $P < .05$ as a priori.

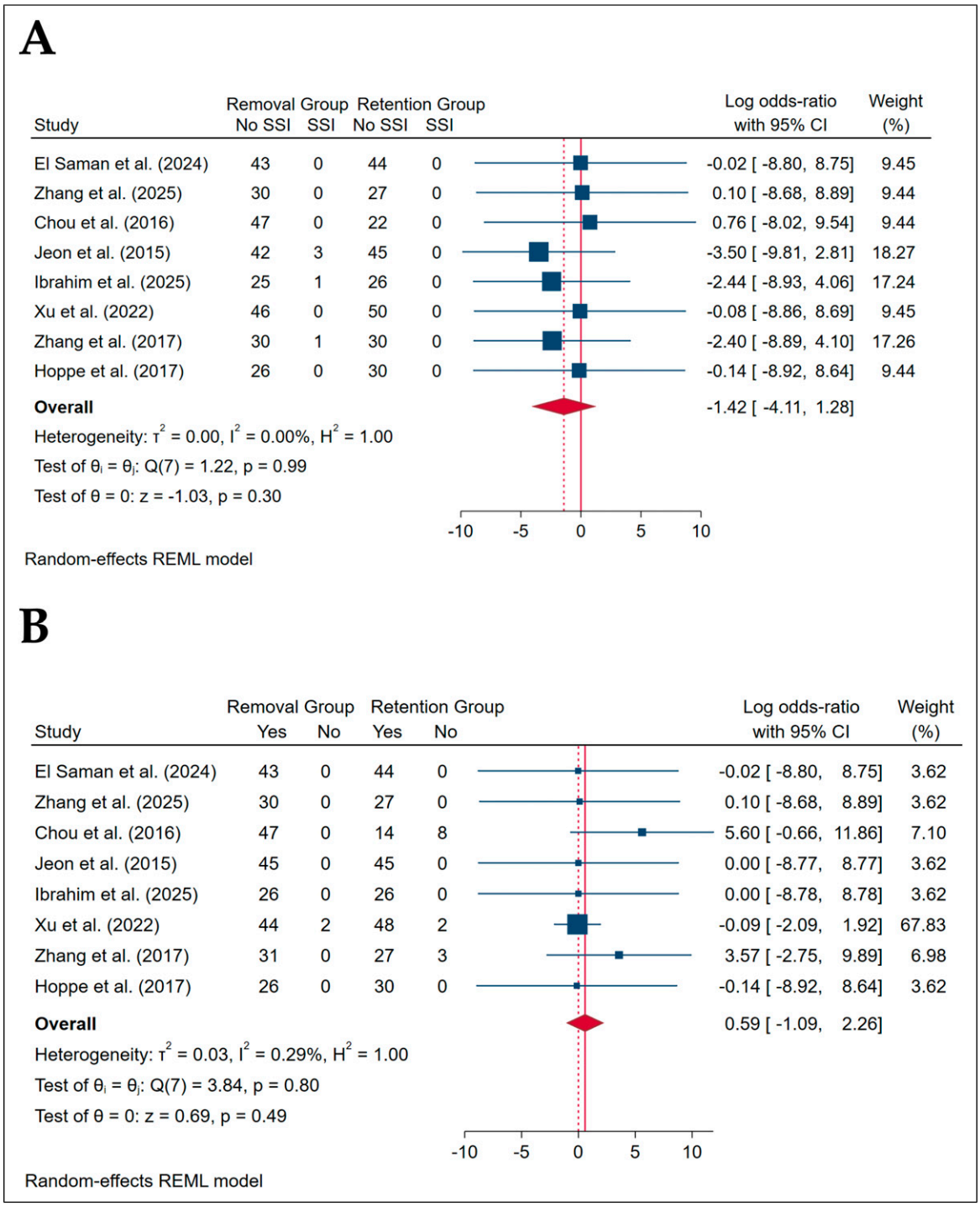


Figure 6. Forest plot comparing the implant removal group to the implant retention group for (A), surgical site infection; (B), screw related complication

Subgroup Analysis

A subgroup meta-analysis of the included studies was planned based on the fracture location (thoracic vs lumbar levels), age, and fusion status. Most studies focused on T11-L2 transitional fractures and did not report outcomes separately for thoracic and lumbar levels that prevented a subgroup analysis based on fracture location. Similarly, the data regarding the fusion status and overall outcome were also not consistently reported across the studies. However, subgroup analysis was performed to analyse the association between the overall outcome and age distribution of patients, wherever feasible.

Results

Study Selection

A total of 2955 articles were identified. After deduplication, 1.654 records were screened and 65 full-text articles underwent eligibility assessment. Eight studies met the inclusion criteria (one RCT and 7 comparative cohort studies). The included studies (spanning multiple geographic regions including China, Germany, Taiwan, Korea, Egypt, and Switzerland) were published between 2015 and 2025, comprising 571 total patients, with 26-50 participants per group. Seven studies contributed data on Cobb angle, 3 on ODI, 8 on SSI outcomes. Follow-up durations ranged between 12 months to >3 years. The summary of characteristics of individual studies has been presented in Table 1.

Characteristics of Included Studies

A. Study designs and populations: The only RCT (by Ibrahim et al,[15] 2025) provided strong internal validity, while the rest of the studies were retrospective. The patient demographics varied widely, with the mean ages ranging between 33 and 70 years (indicating different fracture populations).

B. Fracture types and levels: A majority of fractures were TL burst injuries (AO types A3/A4), extending between T11 and L4 levels. Six of 8 studies predominantly involved T11-L2 transitional fractures; no study reported outcomes stratified by pure thoracic vs lumbar levels.

C. Surgical approaches and fusion: Open posterior fixation was the predominant surgical approach. The fusion practices varied: while some studies performed no fusion in both groups; some studies (eg, Zhang et al,[26] 2017) performed fusion only in the retention cohort.

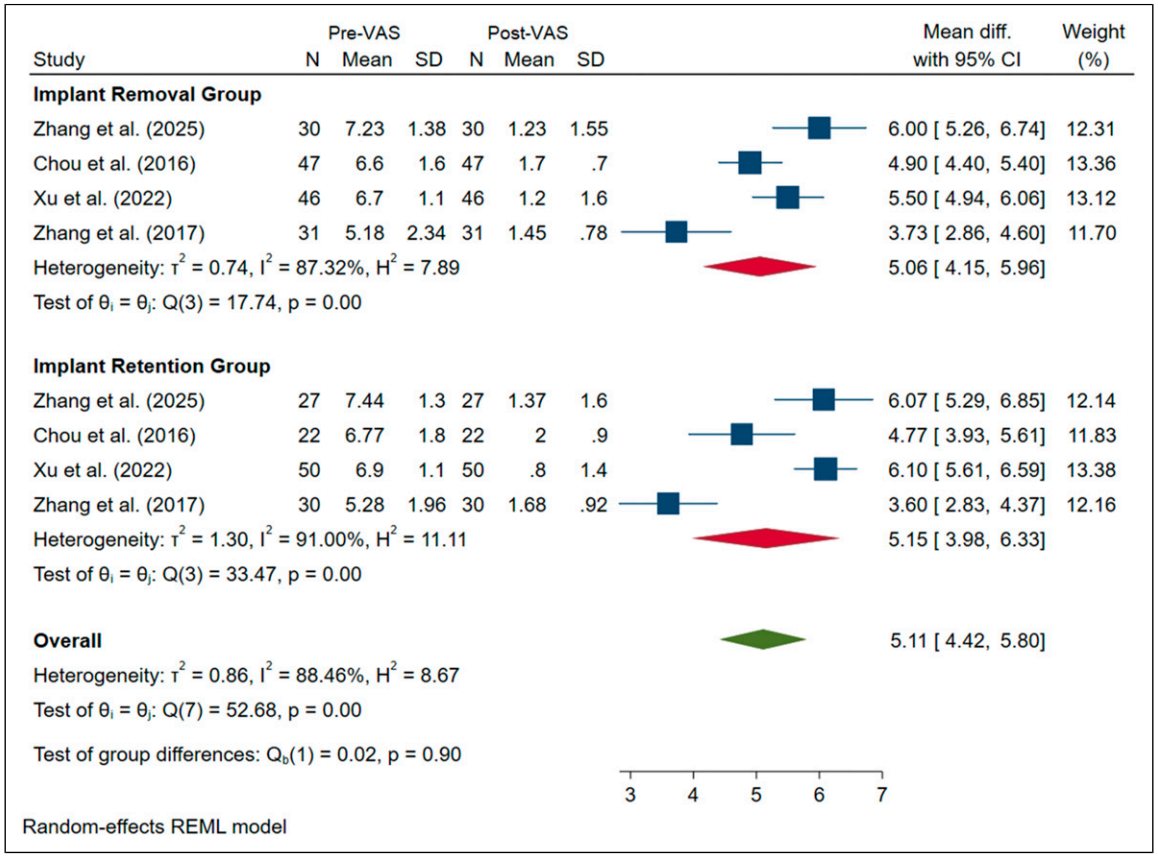


Figure 7. Forest plot comparing the implant removal group to the implant retention group for pain improvement (VAS change) at final follow-up compared to preoperative status

D. Timing and Indications for Implant Removal: The typical removal timing ranged from 6 to 18 months, with some variability. The indications for implant removal in the reviewed studies were routine removal after union, painful or irritable hardware, surgeon recommendation and CT-confirmed union.

Risk of Bias Assessment

Five studies were rated low risk,[5,12,25,26] including the RCT by Ibrahim et al[15] (2025), which demonstrated a strong methodological rigour (in terms of selection, comparability and outcome assessment). Three studies (El Saman et al,[14] 2024; Jeon et al,[27] 2015; and Hoppe et al,[16] 2017) were graded moderate risk, primarily due to baseline group imbalances, incomplete reporting of confounders and concerns regarding outcome measurements). No study was excluded for high risk of bias. Sensitivity analyses, excluding moderate risk studies, demonstrated no material change in pooled effect estimates.

Radiological Outcomes

A. Cobb angle correction: Seven studies reported changes in Cobb angle between preoperative and final followup assessments. In the $\boldsymbol{I_{REM}}$ group, the pooled mean difference (MD) was *5.04° (95% CI: 0.03-10.05, P = .049; I^2: 96.2%;* Figure 2A). In the $\boldsymbol{I_{RET}}$ group, the pooled MD) was *6.38° (95% CI: 1.189-10.87, P = .005; I^2: 95.9%)*. There was no statistically significant difference between the 2 groups *(P = .70)*; demonstrating that both strategies yielded overall meaningful radiological improvement, with no superiority of one strategy over the other. Subgroup analysis was conducted on the Cobb angle correction in the $\boldsymbol{I_{RET}}$ group. No significant difference was noted among the groups based on their age distribution (as shown in Figure 3).

B. Kyphosis Progression: Based on the 8 studies which reported on the kyphosis progression after implant removal; there was no statistically significant increase in the post-surgical kyphosis (at final followup) in $\boldsymbol{I_{REM}}$, as compared to $\boldsymbol{I_{RET}}$ group *[MD = 0.41° (95% CI: –0.11 to 0.94; P = .37; I^2: 0%);* Figure 2B]. No significant difference was noted among the groups when subgroup analysis was done based on their age distribution, as shown in Figure 4.

Functional Outcomes [Oswestry Disability Index (ODI)]

Three studies contributed data on ODI. While in the $\boldsymbol{I_{REM}}$ group, the pooled MD was *15.55 (95% CI: 1.07-30.03, P = .008; I^2: 98.8%;* Figure 5); pooled MD in the $\boldsymbol{I_{RET}}$ group was *12.76 (95% CI: −5.34-30.86, P = .002; I^2: 98.8%)*. There was no statistically significant difference between the 2 groups *(P = .81)*; demonstrating that both strategies yielded overall clinically significant functional improvement, and $\boldsymbol{I_{REM}}$ did

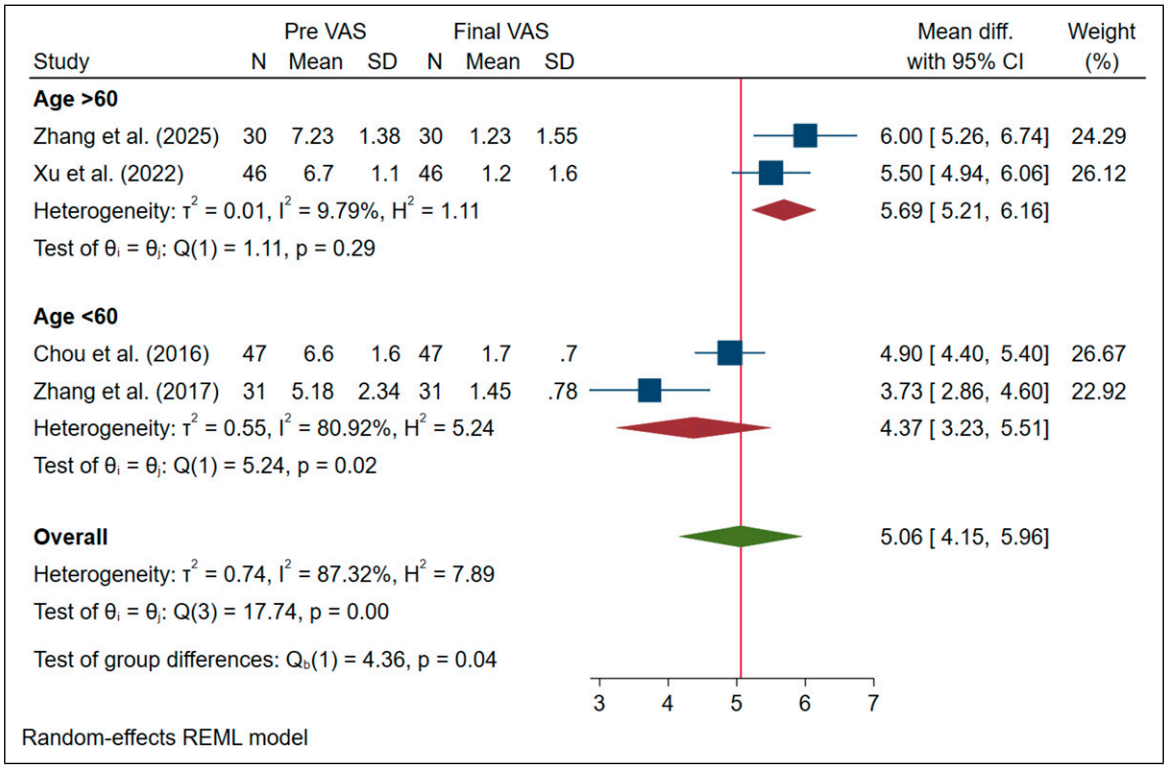


Figure 8. Forest plot of subgroup analysis of the implant removal cohort among the included studies based on the age group categories for VAS outcome at final follow-up compared to preoperative status

not outperform the I_{RET} group. Although high heterogeneity reflected variability in baseline ODI scores and follow-up durations, the consistency of pooled estimates across groups was evident from our analysis.

Safety Outcomes

A. Surgical Site Infection (SSI): Eight studies reported SSI rates. The pooled log odds ratio (OR) was *–1.42 (95% CI: –4.11-1.28; P = .30; I^2: 0%;* Figure 6A). Thus, based on our analysis, it was evident that implant removal was not associated with enhanced risk of SSI. The events were rare, with a majority being superficial infections in the I_{REM} group, resolving with conservative treatment.

B. Screw-related Complications: Eight studies reported on mechanical (screw-related) complications. The pooled log OR was *0.59 (95% CI: –1.09-2.26; P = .80; I^2: 29%;* Figure 6B). Thus, the overall incidence of screw-related complications (screw loosening, implant breakage or back-out etc.) was not significantly higher with long-term retained implants ***(I_{RET})***.

Secondary Outcomes

Pain Scores (VAS). Both the groups showed significant within-group improvement (5-point reduction in pooled MD); with significant reduction in pain for both $I_{RET\ and}$ I_{REM} groups (*P < .0001;* Figure 7). There was no statistically significant difference between the 2 groups (*P* = .90). The heterogeneity in the reporting of pain scores was high (*I^2 ~ 90%)*, reflecting difference in pain measurement and variability in follow-up intervals. To explore the heterogeneity, a subgroup analysis was conducted stratifying the studies based on age. Studies with patients aged >60 years demonstrated significantly higher pain reduction compared to those studies with patients aged <60 years (*P* = .04) as shown in Figure 8.

Reoperation rates. The reoperation rates were infrequently reported (<5%), with no clear difference between $I_{RET\ and}$ I_{REM} groups. A majority of reoperations were related to adjacent segment disease (ASD) or complications/pathologies unrelated to implant retention or removal.

Other patient-related outcome measures (PROMs). A minority of studies reported on additional PROMs (such as SF-36 physical (PCS) and mental component scores (MCS). These demonstrated improvements were consistent with ODI findings; with statistically significant within-group changes and non-significant intergroup ($I_{RET\ and}$ I_{REM}) differences.

Publication Bias and Certainty of Evidence

The funnel plots for Cobb angle and ODI outcomes were symmetric, and Galbraith plot for heterogeneity indicated no

Table 2. GRADE Summary of Findings Table

Outcome	No. of studies	Pooled effect (MD/OR with 95% CI)	I^2 (%)	Certainty of evidence	Interpretation
Cobb angle correction	7 (1 RCT, RCS)	Removal: MD 5.04° (0.03, 10.05; *P* = .049) Retention: MD 6.38° (1.89, 10.87; *P* = .005) Intergroup *P* = .70	96.2/95.9	●●○○ moderate	Both groups improved radiological alignment; no significant difference between removal and retention.
Oswestry disability index	3 (1 RCT, 2 RCS)	Removal: MD 15.55 (1.07, 30.03; *P* = .008) Retention: MD 12.76 (−5.34, 30.86; *P* = .002) Intergroup *P* = .81	98.8	●●○○ moderate	Both groups showed clinically meaningful functional improvement; no difference between groups.
Surgical site infection (SSI)	8 (1 RCT, 7 RCS)	Log OR −1.42 (−4.11, 1.28; *P* = .30) Intergroup *P* = .300	0	●●●● high	Very low incidence overall; no difference in infection risk between removal and retention.
Pain scores (VAS)	4 (4 RCS)	MD 5 points; *P* < .001 within groups Intergroup *P* = .900	87-91	●●○○ moderate	Pain improved significantly in both groups; no superiority of removal.
Reoperation rates	3 (3 RCS)		Not estimable	●○○○ low	Rare events; no clear difference between groups.

Risk of bias: Most studies were moderate quality; no exclusions for high risk; Inconsistency: Downgraded for Cobb angle and ODI due to very high heterogeneity (I^2 >95%); Indirectness: None; outcomes directly relevant to population and interventions; Imprecision: SSI estimates precise with narrow CI; Cobb and ODI estimates wide, downgraded; Publication bias: Funnel plots symmetric; Egger's test non-significant. MD, mean difference; CI, confidence interval; OR, odds ratio; Log OR, logarithmic odds ratio; VAS, visual analogue scale; I^2, Inconsistency statistic (percentage of variation due to heterogeneity); ●●●●, High certainty of evidence; ●●○○, Moderate certainty of evidence; ●○○○, Low certainty of evidence.

Table 3. Summary of Review Articles Published on the Role of Implant Removal After Thoracolumbar Fracture Fixation

Study	Type of review	Aim/focus	Key findings	Conclusion
Danison et al, 2017	Narrative review: Temporary stabilization strategy	Evaluate temporary instrumentation without fusion and the role of implant removal in restoring motion	- Temporary fixation preserves motion and avoids fusion morbidity - Correction loss occurs over time regardless of fusion status - Removal restores segmental mobility; functional outcomes equal or superior to fusion - MIS lowers morbidity of removal	Temporary fixation with planned removal is a viable motion-preserving strategy, but requires radiological monitoring
Kweh et al, 2022	Systematic review & meta-analysis (13 studies, 673 patients)	Compare radiological, biomechanical, and functional outcomes after implant removal vs retention following TL burst fracture fixation	- Cobb angle correction loss similar between groups (10°) - ODI improvement greater after removal (7.8 points at 1 year; 11.1 at final follow-up) - VAS improvement more pronounced after removal (mean 3.32) - No difference in kyphosis progression	Implant removal may offer functional benefit (especially in younger patients) but no radiological superiority
Wang et al, 2023	Systematic review (35 studies)	Evaluate necessity of implant removal after TL burst fracture fixation	- Potential benefits: Increased ROM, less pain and disability - Risks: Kyphosis progression, infection, neurovascular injury, worsening pain, revision surgery - High heterogeneity and conflicting results	No strong evidence for routine removal Removal decisions should be individualized
Visagan et al, 2023	Systematic review + case–control study (percutaneous fixation)	Determine whether removal of percutaneous pedicle screws improves outcomes	Systematic Review: - Back pain improved in most studies - ODI: 3 studies improved; 1 unchanged - Radiological stability maintained - Complications rare (1.7%) Case–Control Study: - 68.6% felt better after removal - Improved return-to-work (OR = 5.0) - ODI similar, but subjective benefit high	Removal after MIS percutaneous fixation is safe, improves symptoms, and does not compromise stability
Prandzhev et al, 2024	Narrative review on pedicle screw removal explantation	Describe indications, techniques, benefits, and risks of pedicle screw removal across all spinal pathologies	- Indications: Pain, infection, prominence, loosening, breakage, corrosion/allergy, pediatric growth issues - Benefits: Pain relief, restored motion - Risks: Secondary kyphosis, instability, disc herniation - Techniques vary depending on screw design and complications	Implant removal is not benign Careful patient selection is necessary Evidence mainly observational

(continued)

Table 3. (continued)

Study	Type of review	Aim/focus	Key findings	Conclusion
Bloemers et al, 2024	Narrative review of operative trauma management	Summarize indications, timing, and considerations for implant removal within the broader context of TL fracture surgery	- Removal considered for symptomatic implants, restoring motion, young active patients - Impact varies by fixation type (short vs long segment) - MIS allows safer removal - Loss of correction/kyphosis a concern without anterior support	Implant removal may be appropriate in selected patients; evidence insufficient to create universal guidelines

small-study effects (Figure 6). The Egger's regression test did not reveal any significant publication bias *(P = .543)*. The certainty of evidence (GRADE assessment) was rated moderate for Cobb angle and ODI (downgraded for inconsistency due to high heterogeneity); and high certainty for SSI outcome (consistent, precise, and free of heterogeneity), as detailed in Table 2.

Discussion

This systematic review and meta-analysis synthesized the best available comparative evidence evaluating implant removal vs retention following posterior fixation of TL fractures. Across the 8 studies encompassing 571 patients including the first RCT[15] on this subject, several clinically important findings emerge. Overall, implant removal and retention produced similar

Table 4. Integrated Synthesis of Observations From Prior Review Articles on Implant Removal vs Retention in Thoracolumbar Fractures

Domain	Synthesis of findings across all reviews	Implications
Radiological outcomes	- Kyphosis correction loss occurs in both removal and retention groups - No consistent radiological advantage for removal - Typical correction loss ranges ~8-12° over follow-up	Implant removal does not improve radiological alignment and should not be performed for deformity correction
Functional outcomes	- Kweh (2022) and Visagan (2023): ODI and VAS improve more with removal, especially in younger patients - Wang (2023): Conflicting evidence; heterogeneity; lack of RCTs	Functional gains after removal are possible but not universal; benefits are age- and population-dependent
Pain relief	- Consistently reported improvement in symptomatic patients after removal - Most prominent in MIS percutaneous constructs where hardware irritation is common	Pain relief is a valid indication for removal, particularly in MIS cases or hardware-related discomfort
Safety profile	- Complications after removal are rare (superficial SSI, temporary nerve irritation, screw breakage) - Kyphosis progression mild and comparable to retention	Removal is generally safe; but kyphosis risk, though small, must be discussed during counselling
Motion preservation	- Removal restores segmental mobility in motion-preserving constructs (non-fusion) - Benefits most notable in younger and physically active patients	Motion restoration is a reasonable rationale for removal in non-fusion constructs when mobility is a priority
Consensus position across reviews	- No major guideline endorses routine removal - Greatest benefit seen in: Young active patients Non-fusion constructs Symptomatic hardware irritation Percutaneous (MIS) screw systems	Implant removal should be selective and patient-specific, not routine Shared decision-making is essential
Final summary statement	- Evidence demonstrates no radiological advantage with implant removal, but potential functional and symptomatic benefit in selected subgroups - Complication rates are low, supporting a tailored approach	Routine removal is not recommended Selective removal is appropriate for younger, symptomatic, or MIS-treated patients

radiological and functional outcomes, with no significant differences in Cobb angle correction, kyphosis progression, ODI improvement, VAS pain scores, and SSI. These findings challenge the long-held assumption that routine implant removal necessarily confers superior recovery; and instead support a more nuanced, patient-focussed, decision-making approach.

Radiological Outcomes: Stability Without Fusion is Predictable in Most Patients

Radiological correction improved significantly in both $I_{RET\ and}$ I_{REM} groups, with no demonstrable difference in final Cobb angle or kyphosis progression. This is consistent with prior reports suggesting that once fracture consolidation is achieved, the anterior and middle columns provide sufficient stability to prevent recurrent deformity, irrespective of the hardware status.[5,10,14–16,18,23,27,31,33,42]

Importantly, kyphosis progression following implant removal, a major concern historically, was not observed in the pooled data (MD 0.41°, P = .37). Only one included study (Hoppe et al[16]) demonstrated a measurable increase (~6°) following implant removal, particularly in younger patients and junctional fractures; however, even this radiological aberration did not translate into inferior clinical outcomes. Collectively, the evidence suggests that, in the absence of severe preoperative kyphosis, comminution or structural anterior column deficiency, implant removal does not predispose to clinically significant loss of correction.

Functional Outcomes: Meaningful Improvement Occurs Regardless of Hardware Status

Both implant removal and retention groups demonstrated significant improvements in ODI from baseline to final followup. The magnitude of improvement exceeded established minimal clinically important differences (MCID) in nearly all studies, reflecting the natural recovery trajectory after TL fractures. The absence of between-group differences implies that implant removal is not required for functional improvement in the general patient population. Although some individual studies, especially those involving younger or more active cohorts, reported superior pain or disability outcomes following implant removal; these findings were not consistently reproduced across the broader evidence base. The RCT by Ibrahim et al[15] reported statistically superior EQ-5D-5L and ODI scores in the implant removal group; however, the pooled data revealed no overall functional superiority attributable to implant removal.

Pain Outcome and Motion Restoration: Benefits Are Highly Context-Dependent

Pooled VAS pain scores improved substantially within both treatment groups. Despite claims that implant removal alleviates hardware-associated irritation or restores segmental motion; our analysis did not demonstrate a significant between-group difference. Nonetheless, motion restoration remains a biologically plausible mechanism for symptom relief, especially in non-fusion constructs, supported by biomechanical studies and selected clinical cohorts.[4,23,27,41] Younger patients, individuals with high physical demands and those treated with minimally-invasive percutaneous fixation, are most likely to experience symptomatic improvement following implant removal. This aligns with findings from Visagan et al[23] and Jeon et al,[27] who reported subjective benefit in 60-70% of individuals after screw removal. These subgroup effects, while clinically relevant, were insufficiently consistent or large in magnitude to influence the pooled outcome.

Safety and Complications: Removal Is Safe, but Not Risk-Free

SSIs, screw-related complications and reoperations were rare in both the groups. The pooled OR of SSI were low and equivalent between $I_{RET\ and}$ I_{REM} groups (OR: −1.42, P = .30). The low complication profile reflects contemporary surgical practice, where implant removal is typically performed after radiological union and with meticulous technique. Nonetheless, implant removal is not entirely benign. The reported risks include wound complications, neurovascular injury, screw breakage during extraction and unnecessary surgical morbidity.[1,8,20,23,24,33] Conversely, implant retention carries long-term risks of screw loosening, metal fretting, implant breakage and adjacent segment degeneration, although these complications were infrequently reported.[14,15,18] These comparable safety profiles highlight that neither strategy presents a compelling advantage, reinforcing the need for individualized decision making.

Interpretation in the Context of the Current Literature

Our findings integrate and expand upon several recent systematic reviews, which have reached similar conclusions regarding implant removal after TL fracture fixation (Tables 3 and 4 summarize the findings from the prior review articles, hitherto published on this subject). Prior reviews (Kweh et al[18] and Wang et al[8,24]) have described improved pain and function following implant removal in selected populations but also reported substantial heterogeneity and lack of consistent radiological superiority. By incorporating new comparative data, including a well-designed RCT, our analysis provides stronger certainty that routine implant removal is not justified, especially when functional recovery and deformity maintenance are the primary goals.

Importantly, emerging evidence in elderly patients (Xu et al[5]) questions the utility of removal in populations with limited mobility demands or greater operative risk. In contrast,

younger individuals, patients with symptomatic implants and those seeking maximal segmental mobility may derive more meaningful improvement, supporting a more selective, instead of a universal approach.

Regional Considerations: Thoracic vs Lumbar Fractures

Biomechanical differences between the thoracic and lumbar spine may theoretically influence outcomes following implant removal. The thoracic spine benefits from rib cage stabilization and reduced motion, whereas the lumbar spine is characterized by greater segmental mobility and axial loading. These differences could potentially impact kyphosis progression, motion restoration and pain outcomes following hardware removal.

However, the majority of included studies primarily involved fractures within the T11-L2 transitional zone, and outcomes were not reported separately for thoracic vs lumbar levels. As a result, regional subgroup analysis was not methodologically feasible. Future prospective trials with stratified reporting by anatomical region are warranted to clarify whether lumbar fractures derive greater functional benefit from implant removal compared with thoracic injuries.

Clinical Implications of Our Observations

Based on the current evidence, the following principles may guide clinical decision making:

a. Routine implant removal is not indicated for a majority of healed TL fractures
b. Selective removal is reasonable in younger, active patients or those with symptomatic implants or motion preserving constructs (non-fusion, MIS/percutaneous fixation)
c. Radiological Safety of implant removal procedure (if indicated) is reliable, with minimal risk of kyphosis progression in well-healed fractures
d. Elderly patients may not benefit substantially and may be better managed with implant retention
e. Shared decision making must incorporate patient expectations, activity level, surgical risk profile and fracture morphology. Table 5 summarizes the gap in the existing literature; and how the findings of the current study address the concerns and ambiguity on this subject.

It is important to distinguish between routine implant removal and symptom-driven removal. While routine removal after union is not supported by pooled evidence, removal for symptomatic hardware irritation remains a valid indication. Patients with implant prominence, paraspinal muscle irritation, or discomfort during activity, particularly after minimally invasive percutaneous fixation, may experience meaningful subjective improvement following removal. Thus, removal should be individualized rather than protocolized.

Table 5. Gap in the Existing Literature and Contribution of the Present Study

Gap in the literature	How the present study addresses the gap
Lack of high-quality comparative evidence: Most existing studies are small, retrospective, and heterogeneous, limiting generalizability	Integrates the highest-quality evidence to date, including the first randomized controlled trial and 7 comparative cohorts, offering the most robust comparative dataset available
Inconsistent reporting of radiological and functional outcomes: Prior studies used variable metrics and follow-up intervals	Provides standardized pooled analyses of cobb angle, kyphosis progression, ODI, VAS, and SSI using harmonized outcome definitions across studies
No clarity on optimal timing or indications for implant removal: Decisions historically based on surgeon preference rather than evidence	Demonstrates through meta-analysis that removal does not confer radiological or functional superiority, informing clearer, evidence-based decision-making
Narrow focus in previous reviews: Earlier reviews often restricted to young patients, MIS constructs, or removal-only cohorts without true comparison groups	Offers the broadest and most inclusive synthesis, covering diverse ages, fixation strategies (open/MIS; fusion/non-fusion), and both removal and retention groups
Absence of pooled comparative data: No prior review combined outcomes quantitatively across both strategies	Provides the largest pooled evaluation of radiological, functional, and safety outcomes directly comparing removal vs retention
No previous assessment of evidence certainty: Past literature lacked formal evaluation of evidence strength	Applies GRADE methodology to rate certainty (moderate–high) across key outcomes, strengthening clinical applicability
Lack of an evidence-based clinical framework: Current practice varies widely with no consensus on routine vs selective removal	Demonstrates that routine removal is not supported by evidence, while suggesting a selective, patient-specific approach (younger, symptomatic, MIS constructs)
Overall impact	Establishes the most comprehensive, contemporary, and clinically actionable evidence base on implant removal vs retention, with potential direct impact on spine trauma practice and shared decision-making

Importantly, the present metaanalysis primarily evaluates routine elective removal after fracture union rather than symptom-driven removal. While several individual studies report subjective improvement in patients with hardware irritation, these outcomes were not consistently quantified across comparative cohorts and could not be pooled. Thus, conclusions regarding removal for clearly symptomatic hardware should be interpreted separately from routine removal strategies (Figure 9).

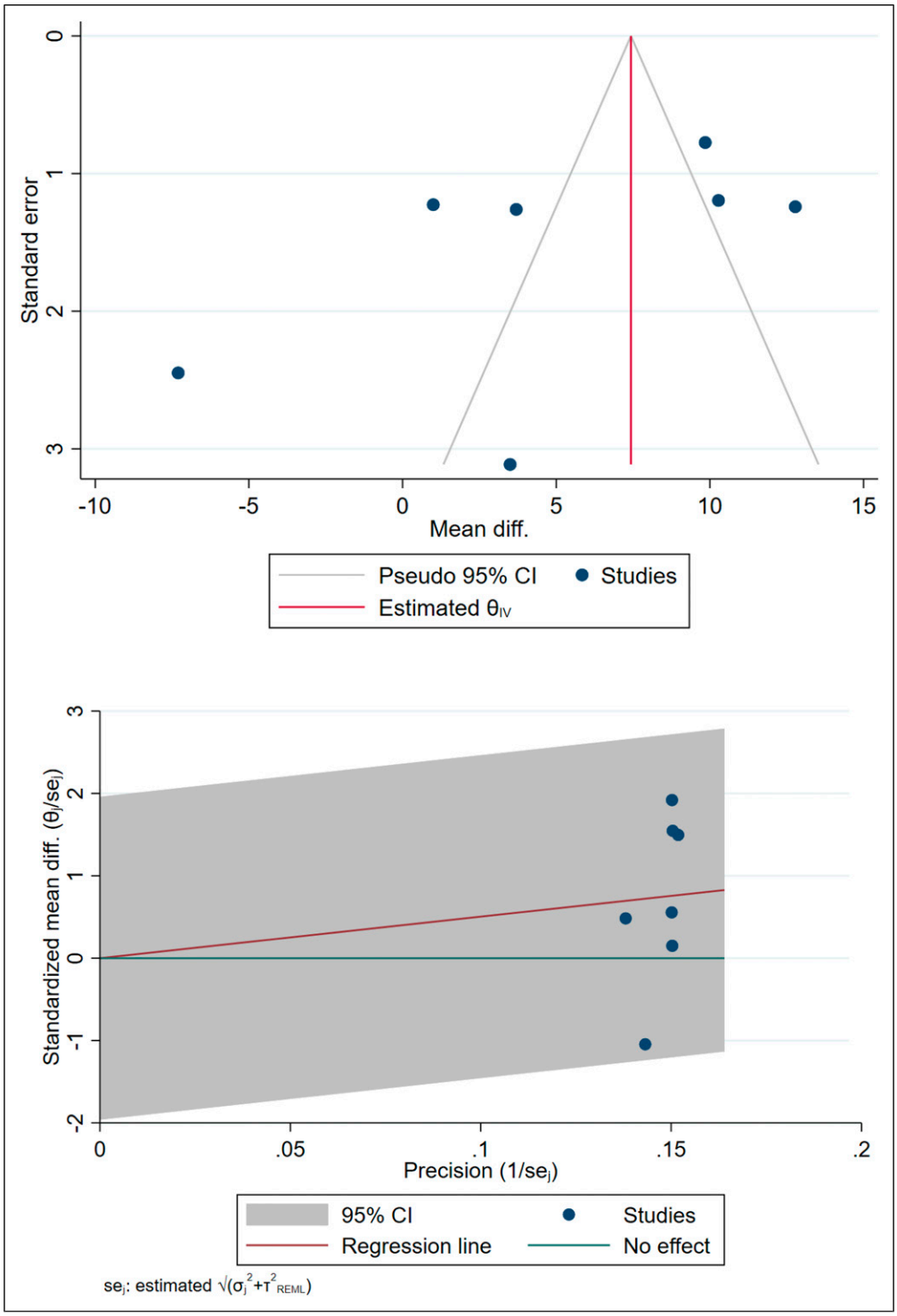


Figure 9. Funnel plot for Cobb angle and Galbraith plot to explore the publication bias and heterogeneity in included studies for analysis, respectively

Strengths and Limitations

This review is strengthened by comprehensive methodology, adherence to PRISMA standards, inclusion of the highest-quality evidence; and the ability to quantify pooled radiological and clinical outcomes.

Some of the crucial limitations include the predominance of retrospective data, heterogeneity in fracture patterns and fixation strategies, inconsistent followup intervals, and variation in removal timing. The high heterogeneity in ODI analyses reflects these differences. Subgroup analyses were limited by insufficient granular data, particularly regarding fusion status, anterior column integrity and physiologic age.

An additional limitation is the inability to perform subgroup analyses by fracture localization (thoracic vs lumbar) or anterior column integrity due to lack to granular reporting in the included studies. Most studies pooled transitional T11-L2 fractures without stratified outcome data, limiting region-specific conclusions.

The present analysis was limited by lack granular subgroup reporting across included studies. Specifically, outcomes were not consistently stratified by fusion status, anterior column integrity, or fracture comminution severity. These variables may influence biomechanical behaviour and functional recovery following implant removal and warrant prospective investigation.

Long-term outcomes beyond 3 years were inconsistently reported, limiting assessment of late adjacent segment degeneration or delayed mechanical complications. Additionally, cost-effectiveness analyses comparing removal vs retention strategies were not available in the included literature.

Future Directions

Future research should prioritize adequate powered randomized controlled trials stratified by fracture localization (thoracic vs lumbar), construct type (fusion vs non-fusion), and patient activity level. Particular attention should be directed toward younger, high-demand populations treated with motion preserving constructs, where the potential functional benefits of implant removal may be more pronounced. Long-term followup beyond 3 to 5 years is required to evaluate adjacent segment degeneration, disc health and delayed mechanical changes. Additionally, formal cost cost-effectiveness and health economic analyses are needed to better define the economic and functional implications of selective implant removal strategies.

Conclusion

Implant removal after posterior TL fracture fixation offers no radiological or functional superiority over implant retention for the general patient population. Both strategies achieve stable sagittal alignment, meaningful recovery, and low complication rates. Removal may benefit carefully selected patients, particularly younger, symptomatic individuals treated with non-fusion constructs, but the routine practice of implant removal cannot be recommended. Individualized, evidence-informed, decision-making remains essential.

Author Contributors

Dr SMuthu and Dr VKV contributed to the conceptualization and design of the research goals and aims. Dr SMuthu developed the methodology and statistical framework. Dr SM, DVKP carried out the data collection. Data validation and ensuring the accuracy of results were undertaken by Dr SMuthu and Dr VKV. Writing the original draft of the manuscript was managed by Dr SMuthu, and Dr VKV, with Dr KS, Dr SKRC, Dr LH, Dr ST providing critical revisions and editing. Visualization and creation of figures were executed by Dr SMuthu. Supervision and coordination of the project were led by Dr SMuthu. Dr KS, Dr LH, Dr ST and Dr SKRC helped in the revision of the manuscript. All the authors approved the final version of the manuscript.

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Data Availability Statement

Data generated in the study will be made available upon reasonable request to the authors.

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