ORIGINAL ARTICLE

CONTENTS

Comparison of the risk of complications in posterior fusion of the lumbar spine with cortical and transpedicular screw trajectories: A systematic review and meta-analysis

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ABSTRACT

Aim: To conduct a systematic review and meta-analysis to compare complication rates between CBT and PSF in lumbar spine fusion.

Materials and Methods: A systematic literature search was performed in major scientific databases. Fourteen studies were included: 3 meta-analyses and 11 clinical studies (2 randomized controlled trials and 9 cohort studies), involving 1,122 patients (542 with CBT, 580 with PSF). Complication rates were analysed using hazard ratios. Heterogeneity was assessed using χ^2 and I^2 statistics.

Results: No significant differences were found between CBT and PSF in terms of total complication rate, wound infection, dural sac injury, segment non-union, or revision surgeries. Adjacent segment disease was more frequently observed in PSF, with a 7% higher risk, though not statistically significant (p=0.28). Most results showed high homogeneity ($I^2 = 0\%$).

Conclusions: CBT and PSF show comparable safety profiles in lumbar spine fusion. CBT may offer a potential advantage in reducing adjacent segment disease. However, further high-quality clinical trials are needed to confirm these findings and determine the optimal fixation technique.

KEY WORDS: complication, screw trajectory, reoperation, non-union, cortical bone trajectory, pedicular screw fixation

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INTRODUCTION

The traditional pedicle screw (PS) fixation technique, first proposed by Boucher H.H. in 1959, is recognized as an effective and reliable method for achieving vertebral fusion, demonstrating a high union rate. This approach is widely used for lumbar spine fusion in the treatment of degenerative disorders and traumatic injuries that lead to spinal segment instability.

Pedicular screw fixation (PSF), involving screw placement along a transpedicular trajectory, is commonly employed for managing various spinal pathologies such as spondylolisthesis, fractures, deformities, tumors, and degenerative diseases of the lumbar spine. It consistently yields favorable postoperative outcomes and is still considered the gold standard for spinal fusion.

However, in patients with reduced bone density, this technique poses a risk of screw instability. Additionally, the insertion of pedicle screws requires extensive surgical exposure, which can result in significant soft tissue trauma [1].

Traditional PSF involves a lateral-to-medial screw trajectory [2]. To insert pedicle screws, substantial exposure of the posterior vertebral elements is required, often necessitating large surgical incisions. This can lead to considerable intraoperative blood loss, muscle and soft tissue damage, and increased risk of injury to facet joints, blood vessels, and spinal nerve branches [3].

To address these challenges, Santoni and colleagues introduced in 2009 an alternative technique — cortical bone trajectory (CBT) screw fixation — which enhances screw purchase strength, particularly in osteoporotic bone [4]. Several biomechanical studies have demonstrated that CBT screws exhibit favorable mechanical properties in lumbar spine specimens [5,6].

The cortical screw (CS) follows a medial-to-lateral trajectory, reducing the risk of facet joint violation, minimizing muscle trauma, and lowering the likelihood of neurovascular injuries [7].

Given these advantages, CBT fixation has attracted growing interest among spine surgeons as a potential alternative to traditional PSF. Both techniques are currently in use for lumbar spine fusion. However, the question of which method should be considered the optimal standard remains a topic of debate.

Although several systematic reviews and meta-analyses have compared these posterior fixation techniques—considering factors such as operative time, blood loss, and biomechanical stability—they

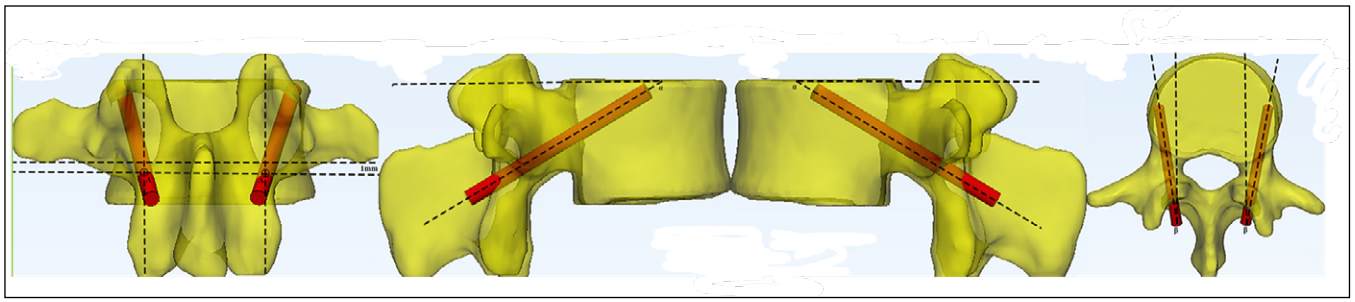

Fig. 1. Cortical trajectory

do not offer a conclusive answer regarding complication rates. Therefore, we conducted a systematic review and meta-analysis of available clinical studies to provide evidence-based insights into this ongoing controversy.

AIM

To conduct a systematic review and meta-analysis of the risk of complications associated with posterior fixation of lumbar spine segments using transpedicular and cortical screw trajectories.

MATERIALS AND METHODS

This study was conducted in accordance with Cochrane review methodology [8], and the reporting followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [9].

SEARCH STRATEGY

A comprehensive search was performed in scientometric databases including the Cochrane Library, PubMed, MedLine, ScienceDirect, and Semantic Scholar. The search covered a 10-year period. Search terms included: "cortical bone trajectory", "CBT", "TT", "PS", "pedicle screw", "traditional trajectory", and "lumbar", used in various combinations according to the search engine filters.

A preliminary search of existing systematic reviews and meta-analyses was conducted to assess the current level of evidence and verify the relevance of the data.

SELECTION OF STUDIES

INCLUSION CRITERIA

1. Randomized controlled trials and cohort studies comparing PSF with CBT in lumbar spine fusion.
2. Patients with degenerative lumbar spine conditions, such as herniated disc, spinal stenosis, spondylolisthesis, trauma, and fixation involving one or two segments.
3. Fixation method: instrumented posterior lumbar fusion.

EXCLUSION CRITERIA

1. Case reports, systematic reviews, meta-analyses, letters, cadaveric and animal studies.
2. Duplicate publications and studies lacking full-text access.
3. Fractures due to spinal tuberculosis, infections, or tumors.
4. Surgical procedures performed using special navigation systems.
5. Study groups with significant differences in age or clinical conditions.
6. Fixation method: transforaminal lumbar interbody fusion (TLIF), posterior lumbar interbody fusion (PLIF), or studies combining multiple fixation techniques or their modifications.

QUALITY ASSESSMENT

The quality of randomized controlled trials (RCTs) was assessed using the Cochrane Risk of Bias Tool [10]. Cohort study quality was evaluated using the Newcastle-Ottawa Scale [11].

SURGICAL TECHNIQUE

The point of entry for the screw in cortical bone trajectory (CBT) is located on the lateral aspect of the pedicle isthmus, specifically at the intersection of the midline of the superior articular facet and a horizontal line positioned 1 mm below the inferior border of the transverse process (Fig. 1a).

The direction of screw insertion is angled cranially at 25–30° in the sagittal plane (Fig. 1b, c) and approximately 10° posteromedially in the transverse plane (Fig. 1d).

The overall trajectory of the screw follows a caudo-cephalic orientation in the sagittal plane and a medial-to-lateral direction in the transverse plane [12,13].

The entry point for the screw in pedicle screw fixation (PSF) is typically located at the intersection

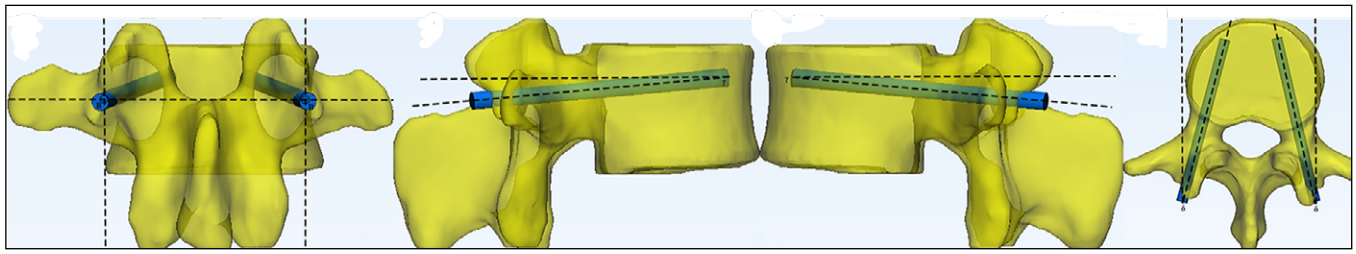

Fig. 2. Transpedicular trajectory

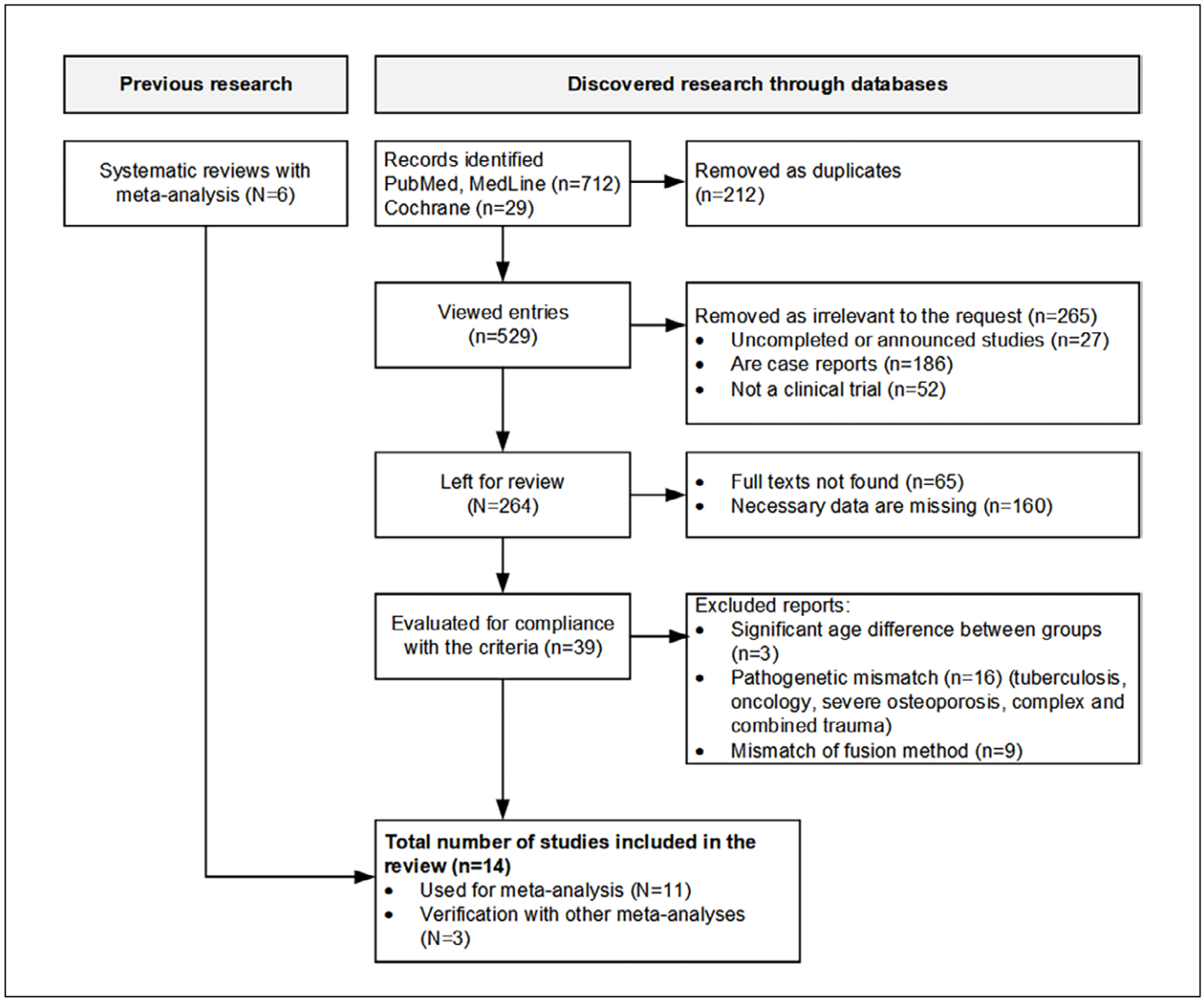

Fig. 3. Study selection flowchart

of a vertical line drawn from the lateral edge of the superior articular process and a horizontal line passing through the midpoint of the transverse process (Fig. 2a).

The screw insertion angle ranges from 0° to 30° in the sagittal plane (Fig. 2b, c) and is directed medially at an angle of 5° to 15° in the transverse plane (Fig. 2d).

The overall trajectory of the screw generally follows the axis of the vertebral pedicle [14].

STATISTICAL ANALYSIS

Meta-analysis was performed using R software version 4.2. The hazard ratio (HR) was used as the effect measure for dichotomous variables. Heterogeneity of outcome measures was assessed using the χ^2 test and the I^2 statistic.

Heterogeneity was considered insignificant when the χ^2 test yielded $p > 0.05$ and $I^2 < 50\%$. If these conditions were not met, the presence of heterogeneity in the data was assumed.

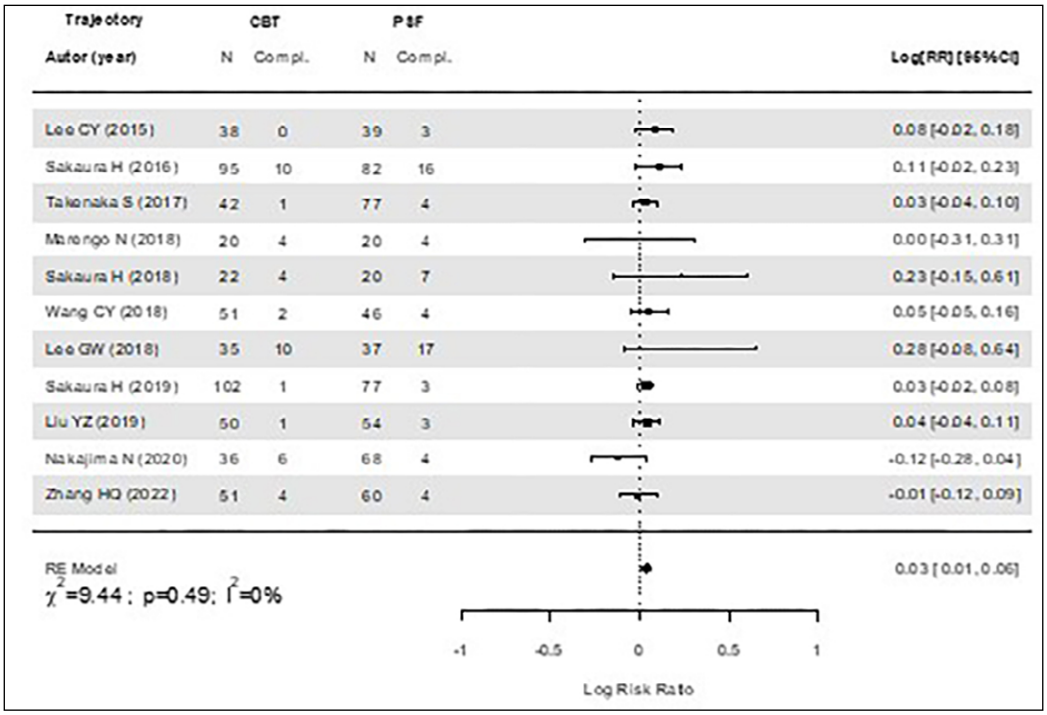

Fig. 4. Forest plot total number of complications.

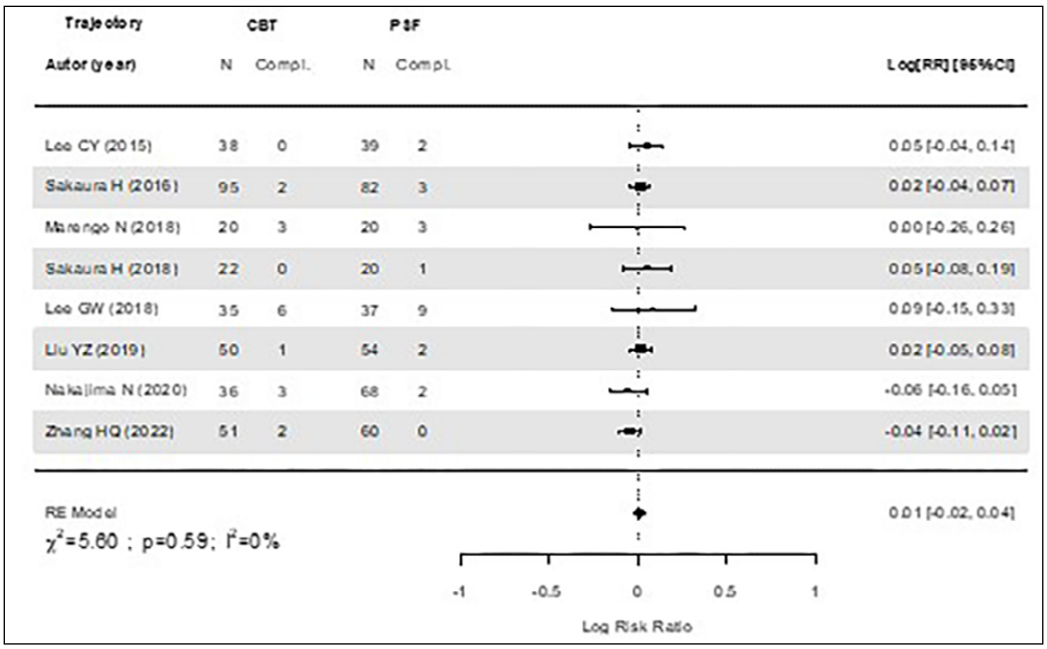

Fig. 5. Forest plot of impairment of stability of the structure

RESULTS

SELECTION OF STUDIES

To assess the current state of evidence regarding the comparative efficacy of fixation techniques, previously published systematic reviews with meta-analyses from the past 10 years were evaluated. A total of six reviews were identified (Fig. 3).

A total of 741 relevant literature sources were retrieved from the databases. After duplicate removal, initial screening, re-screening, and quality assessment, 14 studies were ultimately included: 3 meta-analyses and 11 clinical studies (including 2 randomized controlled trials and 9 cohort studies), involving a total of 1,122 patients — 542 treated with cortical bone trajectory (CBT) fixation and 580 with pedicle screw fixation (PSF).

The detailed study selection process is illustrated in Fig. 3. The main characteristics of the included studies are presented in Table 1.

RESULTS OF THE META-ANALYSIS

The meta-analysis included 11 comparative studies evaluating the efficacy of cortical bone trajectory (CBT) versus pedicle screw fixation (PSF). The objective of the meta-analysis was to assess the complications associated with these lumbar

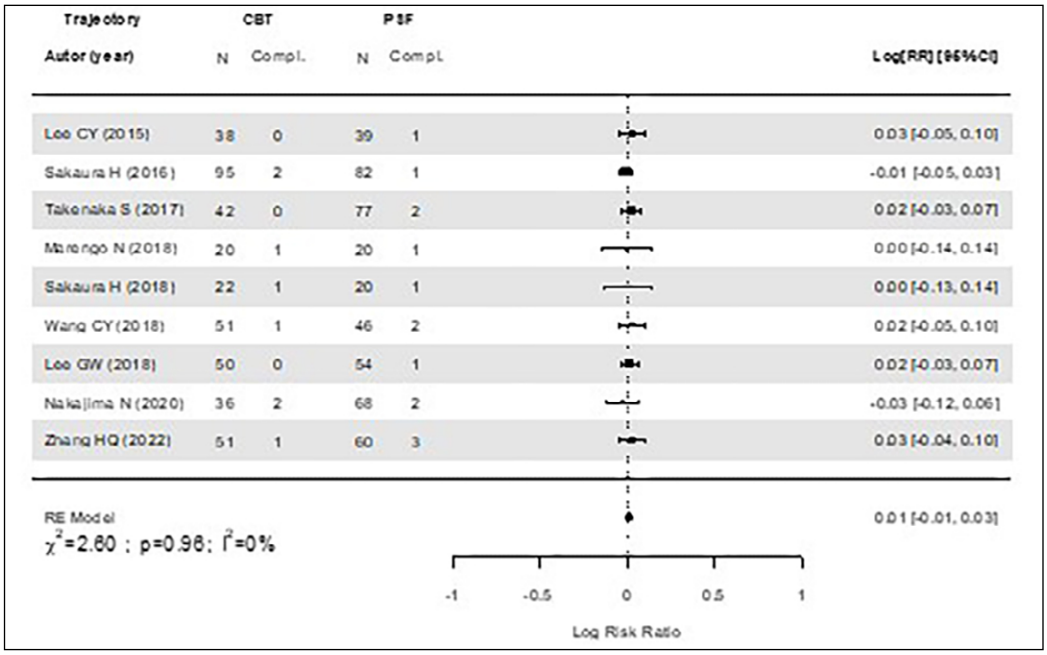

Fig. 6. Forest plot of wound infection

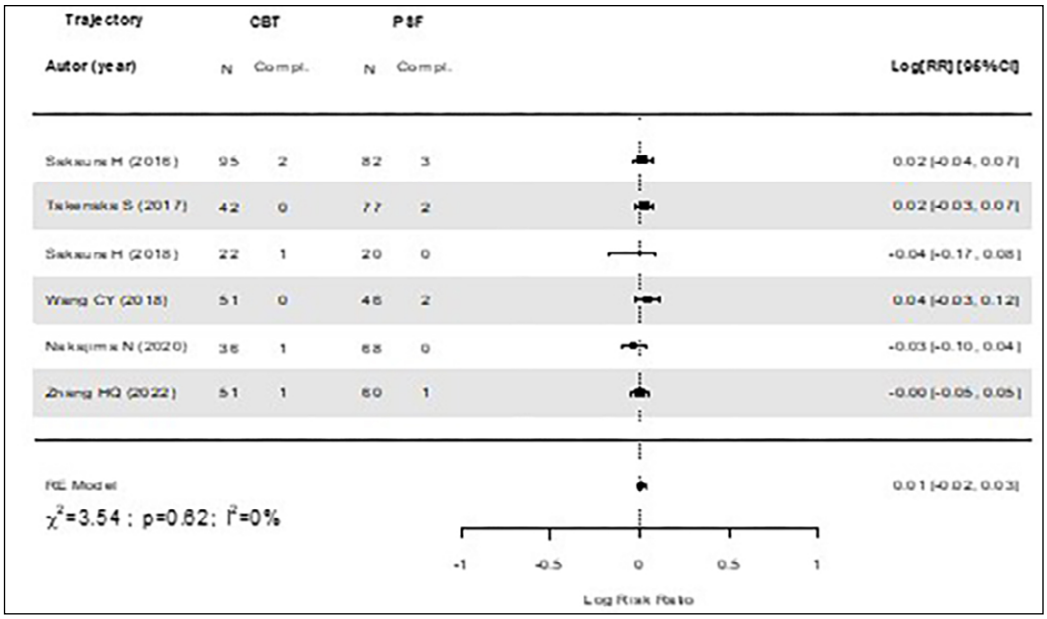

Fig. 7. Forest plot of risks of damage to the dural sac.

spine fusion techniques. A list of complications is presented in Table 1. The results of the meta-analysis are shown in Fig. 4.

Total number of complications (Fig. 4).

According to the forest plot, there is an average 3% shift (log RR = 0.03; 95% CI [0.01; 0.06]) in the number of complications in favor of PSF. The heterogeneity index ($I^2 = 0$) indicates no inconsistency among the data presented in the included studies.

Structural Stability Impairment (Fig. 5).

This category includes complications related to the stability or integrity of the screw system. These complications encompass screw loosening, migration, and breakage. However, not all authors differentiate between these types of complications. Therefore, for the purposes of this analysis, only screw migration and breakage were considered. Data on screw-related complications were reported in 8 studies.

According to the analysis, there was no significant difference in the risk of screw breakage or migration between CBT and PSF, with a difference of only 1%. The variability of data across studies was low ($I^2 = 0\%$).

Wound infection was reported in 9 studies (Fig. 6).

According to the analysis, no significant difference between the fusion techniques was identified; the studies demonstrated high homogeneity ($I^2 = 0\%$).

Dural sac injury is reported in 6 studies, while 2 additional studies explicitly state the absence of such complications (Fig. 7).

Dural sac injury is a relatively rare complication, especially with advancements in both transpedicular

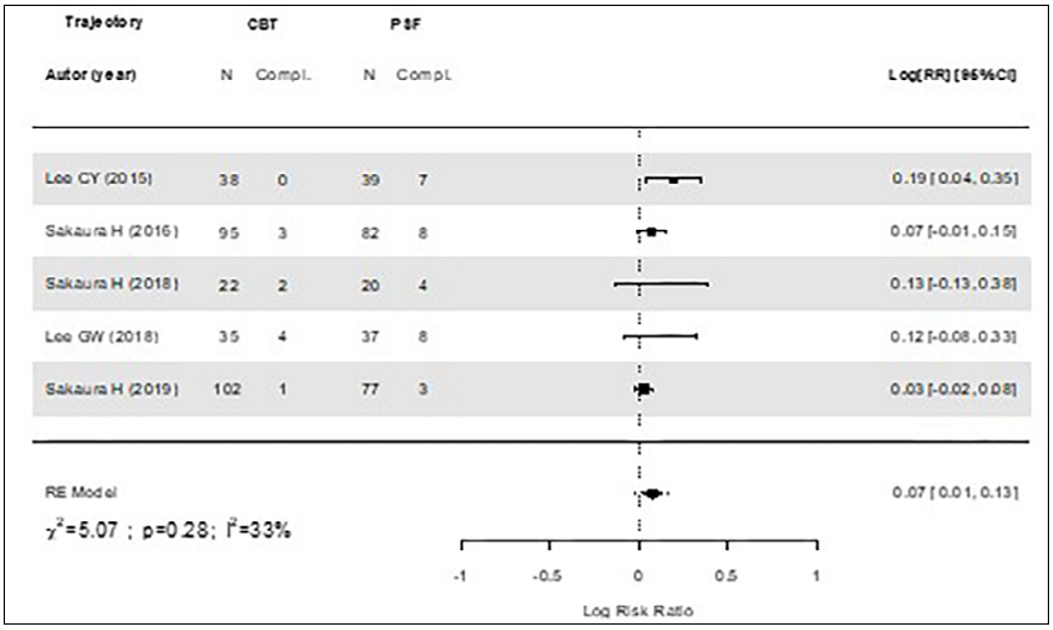

Fig. 8. Forest plot of disease risk of the adjacent segment

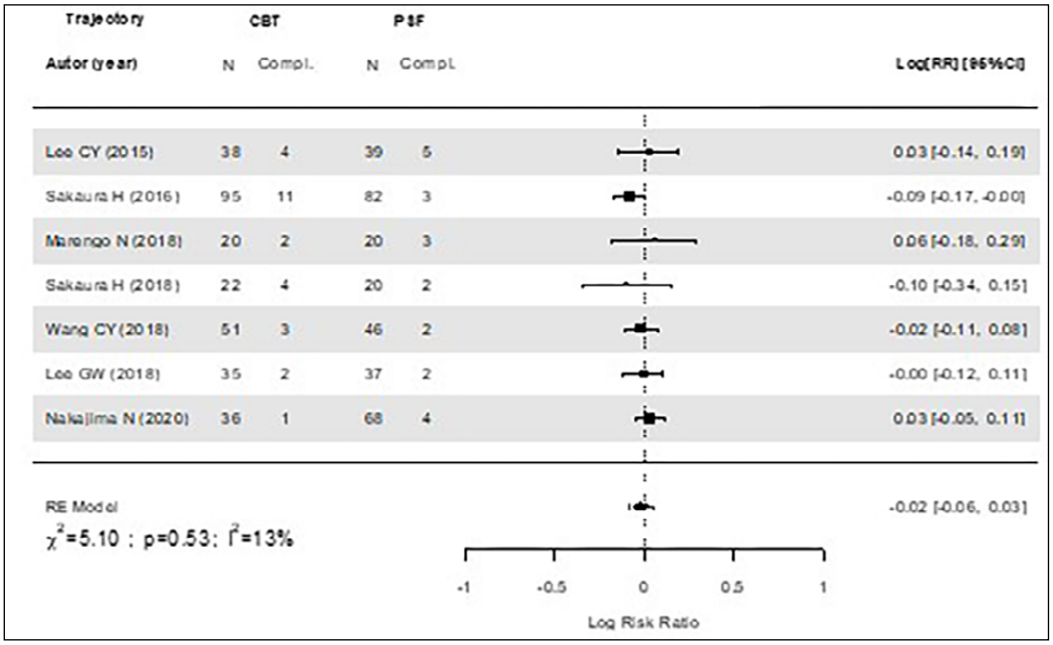

Fig. 9. Forest plot of the risk of non-union of segments.

and cortical screw insertion techniques. In the studies, the risk of this complication was comparable between groups ($I^2 = 0\%$).

Delayed complications include adjacent segment disease, nonunion, and revision surgical interventions.

Adjacent segment disease, most commonly affecting the superior segment, is reported by the authors in 5 studies (Fig. 8).

According to the meta-analysis, the risk of adjacent segment disease is 7% higher with transpedicular fixation, although the difference is not statistically significant ($p = 0.28$).

Nonunion of spinal segments is one of the major complications of spinal fusion. Failure to achieve fusion is reported in 7 studies (Fig. 9).

Nonunion of spinal segments may occur with a frequency of up to 10–15%. The outcome depends not only on the fusion technique but also on the patient's general condition, age, bone quality, and the underlying reason for surgery. According to our analysis, no significant difference was found in the risk of nonunion between the two fixation techniques ($p = 0.96$). The data reported in the literature are homogeneous.

The risk of revision surgical interventions is often associated with the aforementioned complications — most commonly, instability of the screw system, such as screw breakage or migration, and nonunion of segments, which may lead to pain, neurological deficits, spinal stenosis, and other issues. According to the meta-analysis (Fig. 10).

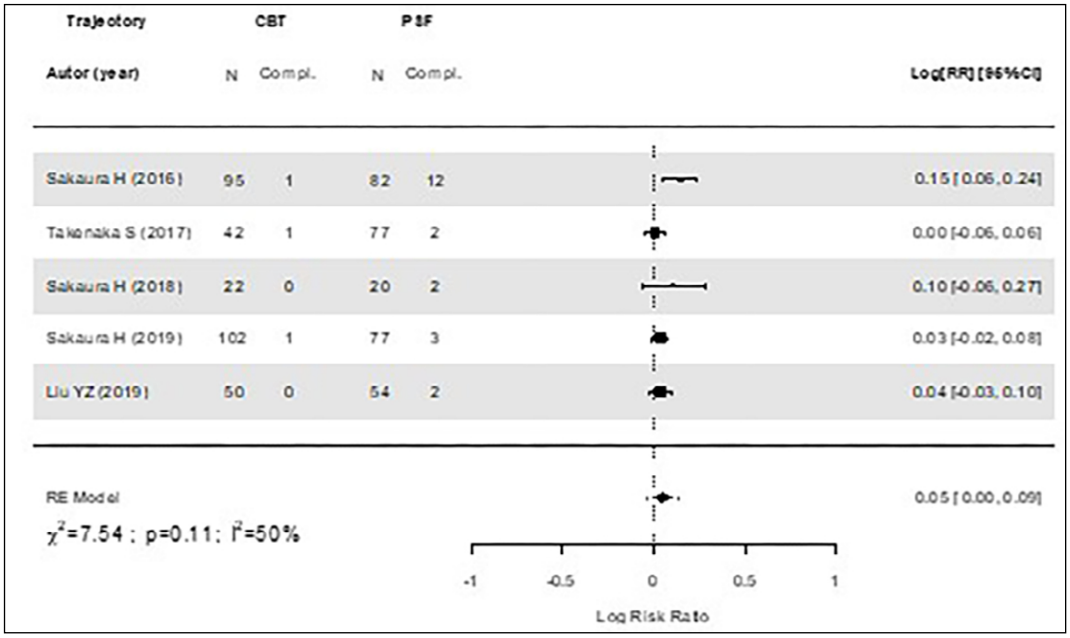

Fig. 10. Forest plot of the risk of revision surgical interventions

According to the meta-analysis, the risk of reintervention was 5% higher with transpedicular fixation. Regarding heterogeneity, $I^2 = 50\%$, which may indicate a moderate level of variability among the included studies that does not significantly affect the overall result. This variability is likely due to differences in how authors classify the reasons for reintervention.

For example, in the studies by Sakaura H [17, 20, 22], revision surgeries are reported as a consequence of instrumental complications, such as screw breakage, migration, or misalignment leading to segmental instability, as well as surgeries performed due to instability in adjacent segments. In contrast, other authors report reinterventions only in cases of complications occurring in the previously operated segment.

DISCUSSION

Posterior lumbar intervertebral fusion is widely used in the treatment of lumbar spine disorders. Indications for lumbar fusion include persistent lumbar pain associated with intervertebral disc herniation following the acute phase, chronic disc degeneration accompanied by lumbar pain, predisposition to segmental instability due to decompression, disc pathology combined with facet joint pathology, and overall segmental instability.

Pedicle screw fixation is employed in most fusion surgeries and is considered the gold standard due to its ability to provide rigid stabilization of the vertebral segment. The strength of screw fixation depends on vertebral geometry, bone mineral density, fixation system design, and mechanical properties [26].

However, the PSF technique carries certain risks, such as violation of the superior facet joint, injury to the medial branch of the spinal nerve, denervation of paravertebral muscles, and potential impairment of spinal segment mobility. These factors may lead to biomechanical alterations and chronic back pain. Moreover, placement of pedicle screws may result in injury to the superior facet joint, dura mater, or lumbar nerve roots during surgical access [27].

Reduced bone density may weaken pedicle screw anchorage and increase the risk of screw loosening [28]. Studies have shown that screw loosening occurs in 1% to 15% of patients with normal bone density, whereas in patients with osteoporosis, this rate can exceed 60% [29].

Cortical screws are inserted through the junction of the superior articular process and the pedicle isthmus, traversing the cortical bone of the vertebral body via a dorsal entry point. This trajectory increases the screw's contact with cortical bone and improves anchorage, thereby reducing the risk of loosening.

Studies have reported that even smaller and shorter CBT screws outperform traditional pedicle screws. Biomechanical analyses have demonstrated that, although CBT screws have denser threads than traditional pedicle screws, the trajectory itself is the primary factor influencing pullout strength. Theoretically, the increased contact with cortical bone is achieved through the caudocephalic trajectory in the sagittal plane and the laterally directed pathway in the transverse plane [30].

To date, several systematic reviews have been conducted to determine the clinical effectiveness of posterior lumbar spine fusion techniques.

One of the key indicators for evaluating clinical effectiveness is the rate of spinal fusion, while complication rates are crucial for assessing surgical safety. Additional

Table 1. Main Characteristics of Literature Included

Author (year)	Type of study	Group	Number of observations	Age M±SD	Sex M/F	Total complications	Impairments of structure stability	Diseases of the adjacent segment	Wound infection	Dural injury	Union	Revision	Period of observation (months)
Lee CY (2015) [17]	RCT	CBT	38	51.3±12.4	33/5	-	-		-		34		12
		PSF	39	51.9±11.7	34/5	3	2		1		34		12
Lee GW (2018) [18]	RCT	CBT	35	51.2±11.9	31/4	10	6	4			33		24
		PSF	37	51.7±10.4	33/4	17	9	8			35		24
Sakaura H (2016) [37]	Cohort	CBT	95	68.7±9.5	46/49	10	2	3	2	2	84	1	35
		PSF	82	67.0±8.7	36/46	16	3	8	1	3	79	12	40
Takenaka S (2017) [40]	Cohort	CBT	42	65.8±8.1	18/24	1			0	0		1	12
		PSF	77	66.0±11.2	31/46	4			2	2		2	12
Marengo N (2018) [23]	Cohort	CBT	20	45.75±9.63	12/8	4	3		1		18		12
		PSF	20	54.0±12.01	9/11	4	3		1		17		12
Sakaura H (2018) [38]	Cohort	CBT	22	70.7±7.3	4/18	4	0	2	1	1	18	0	39
		PSF	20	68.3±9.5	6/14	7	1	4	1	0	18	2	35
Wang CY (2018) [41]	Cohort	CBT	51	62.8±8.7	23/28	2			1	0	48		12
		PSF	46	61.9±11.3	18/28	4			2	2	44		12
Sakaura H (2019) [36]	Cohort	CBT	102	67.5±9.2	35/67	1		1				1	36
		PSF	77	66.4±10.5	28/49	3		3				3	36
Liu YZ (2019) [21]	Cohort	CBT	50	68±5	26/24	1	1		0			0	12
		PSF	54	67±5	27/27	3	2		1			2	12
Nakajima N (2020) [27]	Cohort	CBT	36	69.7±10.0	16/20	6	3		2	1	35		12
		PSF	68	69.1±10.8	25/43	4	2		2	0	64		12
Zhang HQ (2022) [43]	Cohort	CBT	51	57.08±9.70	18/33	4	2		1	1			34
		PSF	60	55.53±10.43	23/37	4	0		3	1			34

important factors include operative parameters such as surgical time, intraoperative blood loss, the accuracy of screw placement, and long-term screw stability.

Our literature search identified six systematic reviews with meta-analyses. Hu et al. (2019) [31] conducted a meta-analysis of 12 studies and found no statistically significant differences between CBT and PSF in terms of visual analogue scale (VAS), Japanese Orthopaedic Association (JOA) scores, Oswestry Disability Index (ODI), complication rates, fusion rates, or operative time.

However, in a systematic review by Zhang T. et al. (2019) [32], the authors reported that CBT was associated with shorter operative time, less intraoperative blood loss, fewer complications, lower nonunion rates, and better ODI scores compared to PSF. Although back and leg pain (VAS) and fusion rates were similar between the two techniques, the authors concluded that CBT could be considered a viable alternative to PSF for one- or two-level lumbar fusions.

Similar findings were reported earlier by Keorochana G. et al. (2017) [33], who found no difference in long-term outcomes regarding back and leg pain but reported a statistically significant lower complication rate with CBT compared to PSF.

In the study by Kim et al. (2021) [34], CBT demonstrated better functional recovery, lower surgical morbidity, fewer revisions, and fewer overall complications. However, both techniques showed similar fusion rates and comparable complication rates related to screw system instability (e.g., malposition, loosening, or screw extrusion) and wound infections.

The main conclusion of this meta-analysis emphasized the need to individualize the choice of surgical technique, taking into account the patient's bone mineral density, the condition of the facet joints, and the surgeon's level of expertise.

A systematic review with meta-analysis by Mao H. et al. (2023) [35] addressed a relatively narrow issue—the impact of fixation technique on the development of surgical site wound infections. Based on the analysis of 13 studies, no definitive conclusion was reached in favor of either fixation method. However, the authors emphasized a clear correlation between perioperative complications and the duration of surgery. Operative time itself is considered an independent risk factor for complications, including wound infections, pulmonary complications, and thromboembolism. Although no significant difference in operative time was found when one or two spinal levels were fused, the authors noted that prolonged surgery may pose a higher risk in cases involving fusion of more than two segments.

It should be emphasized that we did not identify any meta-analyses comparing the outcomes of fusion involving more than two spinal segments.

In a systematic review, Wang Y. et al. (2023) concluded that cortical bone trajectory (CBT) screw fixation is associated with lower overall complication rates, lower incidence of adjacent segment disease, fewer wound infections, and fewer revision surgeries compared to pedicle screw fixation (PSF). CBT was shown to reduce the incidence of both intraoperative and postoperative complications and may be considered a viable alternative for lumbar fusion.

Similar findings were reported in the review by Qiu L. et al. (2022) [36], where CBT was associated with reduced complication rates, shorter operative time, lower intraoperative blood loss, and better postoperative outcomes in terms of ODI and JOA scores. CBT achieved comparable fusion rates to PSF, while demonstrating improved clinical results.

These findings were further confirmed by the meta-analysis by Zheng J. et al. (2024) [37], which concluded that although there were no significant differences in postoperative complication rates between CBT and PSF, the CBT technique showed more favorable outcomes in terms of clinical scores, surgical trauma, and recovery parameters during follow-up. The authors noted that CBT screws provided better pain relief, improved functional outcomes, restored intervertebral alignment, reduced surgical trauma, and facilitated faster rehabilitation.

Based on the results of these systematic reviews comparing fixation methods in the lumbar spine, it can be concluded that as CBT technique continues to improve, it may offer a safer and more effective alternative to traditional pedicle screw fixation.

In our meta-analysis, we focused specifically on the risk of complications associated with CBT and PSF. We deliberately narrowed the inclusion criteria to studies describing only instrumented posterior lumbar fusion. Unlike the aforementioned meta-analyses, we excluded studies that included other types of fusion, extensive spinal pathologies, or specific conditions such as oncological lesions or spinal tuberculosis—factors that were not always clearly accounted for in previous reviews.

According to our analysis, no statistically significant differences were found between CBT and PSF in terms of overall complication rate, wound infection rate, risk of dural sac injury, risk of segment non-union, or revision surgery. However, adjacent segment disease was observed more frequently in the PSF group, with a risk difference of 7%.

Despite the substantial number of studies comparing lumbar fusion techniques, there remains a lack of high-quality randomized trials that clearly define fixation methods, minimally invasive modifications, the use of robotic navigation systems, anaesthesia protocols,

antibiotic prophylaxis, and other surgical parameters that may influence outcomes.

CONCLUSIONS

The meta-analysis of complication risks associated with lumbar spine segment fixation using cortical bone trajectory (CBT) and transpedicular screw fixation (PSF) demonstrated that the overall complication rate, risk of wound infection, dural sac injury, segment non-union, and related revision surgeries were statistically comparable between the two techniques. However, adjacent segment disease was more frequently observed in PSF than in CBT, with a risk difference of 7%.

The limited number of observations in the studies included in the analysis does not allow for a definitive conclusion regarding which method is safer in terms of complication development. Further research is needed to clarify these findings.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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