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SYSTEMATIC REVIEW **Open Access**

Clinical efficacy and complications of 10 surgical interventions for cervical ossification of the posterior longitudinal ligament: an updated systematic review and network meta-analysis

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Abstract

Background The optimal surgical techniques for cervical ossification of the posterior longitudinal ligament (OPLL) remain controversial due to insufficient high-level evidence. We investigated the following surgical approaches for cervical OPLL: anterior decompression and fusion (ADF), anterior cervical corpectomy and fusion (ACCF), anterior controllable antedisplacement fusion (ACAF), anterior cervical discectomy and fusion (ACDF), posterior decompression with instrumented fusion (PDIF), posterior decompression and fusion (PDF), laminectomy (LC), laminoplasty (LP), laminectomy with fusion (LF), and vertebral body sliding osteotomy (VBSO).

Methods We systematically searched PubMed, Embase, Ovid, the Cochrane Library, and Web of Science from database inception through October 30, 2024. Our search identified both randomized and non-randomized controlled trials compar ing the following surgical interventions: ACDF, ADF, ACCF, ACAF, PDIF, PDF, LC, LP, LF, and VBSO. The extracted data were subjected to network meta-analysis. Our analysis included the following outcome measures: Patient demographic characteristics, Japanese Orthopaedic Association (JOA) scores, JOA improvement rates, overall complication rates, excellent/good recovery rates, cervical lordosis characteristics, Visual Analog Scale (VAS) scores, Neck Disability Index (NDI) scores, surgical duration and intraoperative blood loss.

Results In our analysis of 50 studies involving 8705 patients, ACAF demonstrated the most significant improvements in JOA scores, cervical lordosis, VAS scores, and NDI scores. ADF showed the greatest increase in JOA improvement rate, while VBSO had the highest rate of excellent and good postoperative recovery. ACDF was associated with the fewest total complications and the shortest surgical duration. Finally, LC resulted in the lowest intraoperative blood loss.

Conclusion This studies demonstrate that ACAF significantly improves JOA scores and cervical lordosis while reducing VAS and NDI scores. Additionally, it achieves higher postoperative JOA improvement rates and excellent/good recovery rates, with fewer total complications and reduced intraoperative blood loss. Based on these findings, ACAF can be one of the preferred options for clinicians treating cervical OPLL, but it requires high surgical experience

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and strict indication selection. Additionally, the surgical team need to develop the best surgical plan based on imaging features and patient functional needs.

Keyword Ossification of the posterior longitudinal ligament; surgical; systematic review; network meta-analysis

Introduction

OPLL is a type of heterotopic ossification that primarily affects the cervical spine, resulting in neurological dysfunction due to spinal cord and nerve root by the ossified ligament [1, 2]. While most prevalent in East Asia—particularly Japan and South Korea, with a reported incidence of 1.9% to 4.3%—OPLL is less common in North America and Europe, where prevalence ranges from 0.1% to 1.5% [3–7]. Notably, its occurrence is increasing among younger populations [8]. Although OPLL typically progresses slowly, it can lead to motor deficits, and severe cases may result in paralysis, significantly impairing patients' daily functioning and work capacity [9]. As a result, OPLL has become an important public health issue [10].

While conservative management—including medication, physical therapy, and lifestyle modifications, may provide temporary symptomatic relief for cervical OPLL patients [11], it fails to alleviate underlying spinal cord compression [2]. Surgical intervention has emerged as the primary treatment for: asymptomatic patients demonstrating severe posterior longitudinal ligament ossification with abnormal spinal cord MRI signals, and (2) patients presenting with significant neurological deficits or those unresponsive to conservative therapies [12–14]. Surgery aims to decompress the spinal cord, restore the physiological curvature and intervertebral height of the cervical spine, and reconstruct spinal stability. These objectives help slow disease progression and create favorable conditions for neurological recovery. With advancements in spinal surgery, various techniques have been applied to OPLL treatment, including anterior approaches (ACDF, ACCF, ACAF, ADF) and posterior approaches (PDIF, PDF, LC, LP, LF, VBSO) [15–19]. Anterior surgical approaches enable direct removal of ossified lesions, providing complete neural decompression while offering superior restoration of cervical spine alignment. Comparative studies demonstrate that ACCF achieves better functional improvement in OPLL patients than ACDF. Kong et al. found that ACAF results in postoperative axial symptom rates and CSF leakage incidence comparable to or lower than posterior approaches [20]. Posterior techniques are preferred for multisegmental OPLL cases with K-line positivity. Among these, LP demonstrates both lower complication rates and higher patient satisfaction compared to LF [21]. However, a 2022 multicentre study by the JMSOLOS group ($n = 27$ institutions) demonstrated equivalent JOA scores and recovery rates between LP and LF at the 2-year follow-up [22]. Posterior approaches mitigate characteristic anterior approach complications such as dysphagia, vocal cord paralysis, and anterior structural compromise. They also exhibit lower rates of dural injury and CSF leakage. However, posterior procedures carry increased risk of C5 palsy, particularly with LF [14]. While each technique has distinct advantages and specific indications, current evidence remains insufficient to definitively identify an optimal approach that maximizes efficacy while minimizing complications.

A rigorous evaluation of these surgical methods' efficacy and safety is clinically essential. However, current research presents notable limitations: (1) most of studies have only examined pairwise method comparisons [13, 23–26]; and (2) while a limited number of investigations [14, 27, 28] have grouped procedures into broad "anterior versus posterior" a categories, they fail to account for substantial technical variations among significant subtype within each approach. This oversimplification precludes meaningful analysis by treating heterogeneous techniques as uniform categories. For instance, posterior approach techniques demonstrate significant technical and outcome differences between PDF, LP, and LC. The common practice of grouping these distinct methods as a single "posterior approach" category introduces considerable analytical bias. To date, only Li et al.'s investigation [12] has systematically compared five major surgical techniques. Notably, no existing study has conducted a comprehensive comparative analysis of all available anterior and posterior surgical options for cervical OPLL management. Therefore, we designed this study to conduct comprehensive comparisons and generate clinically meaningful findings. Given that network meta-analysis enables simultaneous evaluation of multiple interventions within a single analytical framework, we e employed this methodology to rigorously assess the efficacy and safety profiles of all ten surgical procedures. This study aims to provide definitive evidence regarding the relative advantages and limitations of each technique, thereby offering evidence-based guidance for surgical decision-making in cervical OPLL cases.

Methods

This study strictly complies with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [29, 30], to ensure methodological rigor and transparent reporting. We have additionally implemented the AMSTAR 2 (A Measurement Tool to Assess Systematic Reviews) criteria [31] to guarantee the highest quality standards for our systematic review. Furthermore, our network meta-analysis protocol was prospectively registered on PROSPERO data base (Registration number: CRD42024592798), ensuring transparency and minimizing reporting bias.

Data sources

Two independent investigators (the first and second authors) conducted a comprehensive systematic literature search using predefined criteria. w To ensure methodological rigor, all discrepancies in study selection were adjudicated by a third senior researcher (the corresponding author). The screening process involved rigorous evaluation at three levels: (1) initial title screening, (2) abstract review, and (3) full-text manuscript assessment for final eligibility determination.

We systematically searched multiple electronic database (PubMed, Embase, Ovid, the Cochrane Library, and Web of Science) from their inception through October 30, 2024. The search strategy encompassed both randomized controlled trials (RCTs) and non-randomized controlled clinical studies that: (1) enrolled patients with confirmed cervical OPLL diagnoses, and (2) evaluated comparative outcomes of surgical interventions. The search included the following indexed terms: "ossification of the posterior longitudinal ligament", "OPLL", "cervical", "anterior decompression and fusion", "ADF", "anterior cervical corpectomy and fusion", "ACCF", "anterior controllable antedisplacement fusion", "ACAF", "anterior cervical discectomy and fusion", "ACDF", "posterior decompression with instrumented fusion", "PDIF", "posterior decompression and fusion", "PDF", "laminectomy", "LC", "laminoplasty", "LP", "LAMP", "laminectomy with fusion", "LF", vertebral body sliding osteotomy" and "VBSO". Google Scholar was also searched to identify additional relevant literature. The reference lists of identified studies were systematically reviewed f to locate further pertinent publications. Our meta-analysis included only English-language studies, with the complete search strategy detailed in Table 1 (demonstrated using PubMed as an example).

Eligibility criteria

The inclusion criteria for this study are as follows: (1) Participants: Adults aged ≥ 18 years with multilevel cervical OPLL, regardless of race, gender, or nationality; (2) Study types: Clinical studies comparing the efficacy and complications of the following surgical procedures: ACDF, ADF, ACCF, ACAF, PDIF, PDF, LC, LP, LF, and VBSO. Eligible study designs include randomized controlled trials (RCTs), cohort studies, and case–control studies; (3) Interventions: Clinical studies comparing at least two of the 10 aforementioned surgical procedures. (4) Outcomes: Primary outcomes: Japanese Orthopaedic Association (JOA) scores and JOA improvement rate. Secondary outcomes: overall complications, excellent/good recovery rate, cervical lordosis, Visual Analog Scale (VAS) scores, Neck Disability Index (NDI) scores, surgical duration, and intraoperative blood loss.

The following studies were excluded: (1) Non-Clinical or Non-Relevant Study Types: Case reports, systematic reviews, meta-analyses, editorials, letters to the editor, protocols, biomechanical analyses, and animal or cadaveric experiments; (2) Inadequate Follow-Up: Studies with a follow-up period of < 6 months; (3) Hybrid Surgical

Table 1 Search strategy on PubMed

#1	Search: ((ossification of the posterior longitudinal ligament) OR (ossification of the posterior longitudinal ligament[MeSH Terms])) OR (OPLL) Sort by: Most Recent	2572
#2	Search: cervical Sort by: Most Recent	741894
#3	Search: (((ossification of the posterior longitudinal ligament) OR (ossification of the posterior longitudinal ligament[MeSH Terms])) OR (OPLL)) AND (cervical) Sort by: Most Recent	1889
#4	Search: ((((((((((((((((((((Anterior decompression and fusion) OR (ADF)) OR (anterior cervical corpectomy and fusion)) OR (ACCF)) OR (anterior controllable antedisplacement fusion)) OR (ACAF)) OR (Anterior cervical discectomy and fusion)) OR (ACDF)) OR (posterior decompression with instrumented fusion)) OR (PDIF)) OR (posterior decompression and fusion)) OR (PDF)) OR (Laminectomy)) OR (LC)) OR (Laminoplasty)) OR (LP)) OR (LAMP)) OR (laminectomy with fusion)) OR (LF)) OR (vertebral body sliding osteotomy)) OR (VBSO) Sort by: Most Recent	340824
#5	Search: ((((ossification of the posterior longitudinal ligament) OR (ossification of the posterior longitudinal ligament[MeSH Terms])) OR (OPLL)) AND (cervical)) AND (((((((((((((((((((((Anterior decompression and fusion) OR (ADF)) OR (anterior cervical corpectomy and fusion)) OR (ACCF)) OR (anterior controllable antedisplacement fusion)) OR (ACAF)) OR (Anterior cervical discectomy and fusion)) OR (ACDF)) OR (posterior decompression with instrumented fusion)) OR (PDIF)) OR (posterior decompression and fusion)) OR (PDF)) OR (Laminectomy)) OR (LC)) OR (Laminoplasty)) OR (LP)) OR (LAMP)) OR (laminectomy with fusion)) OR (LF)) OR (vertebral body sliding osteotomy)) OR (VBSO)) Sort by: Most Recent	992

Approaches: Studies combining different surgical techniques (e.g., ACDF with LP); (4) Incomplete Data: Studies lacking essential outcome measures or methodological details; (5) Revision Surgeries: Studies focusing on revision procedures rather than primary interventions; (6) Duplicate Publications: Redundant or overlapping studies published by the same author(s) across multiple journals.

Data extraction

A custom-designed extraction form was used to collect essential data from each registered study. The extracted data included: (1) General information: such as principal investigator, publication year, study design, country, study timeline, and follow-up duration; (2) Patient demographics, including the number of participants, male-to-female ratio, age at diagnosis, and total patient count; (3) Surgical details, covering interventions and comparisons; (4) Clinical outcome, including JOA scores, JOA improvement rates, overall complications rates, excellent/good recovery rates, cervical lordosis, VAS scores, NDI scores, operative duration and intraoperative blood loss. When standard deviations were not reported, they were estimated using methods specified methods in the Cochrane Handbook:

(1) When group standard deviations were not directly reported, the formula outlined in Sect. 6.5.2.2 of the Cochrane Handbook was used to calculate them from either the standard error of the mean (SEM) or 95% confidence intervals (CIs);

(2) When study data were reported as medians and interquartile ranges, we converted these values to mean ± standard deviations using the method described by Wan et al. in Sect. 6.5.2.5 of the Cochrane Handbook;

$$\left[\mathrm{SD} = \mathrm{SEM} \times \sqrt{n} \text{ or } \mathrm{SD} = \sqrt{n} \times (\text{upper limit} - \text{lower limit})/3.92\right]$$

(3) For unreported values, we used the Follmann et al. formula to estimate the standard deviations (SDs) of changes from baseline, assuming a correlation coefficient of 0.50 between baseline and post-intervention values [Cochrane Handbook Sects. 6.5.”Methods”.8, “Methods”].

$$\left[SD_{E,change} = \sqrt{SD^2_{E,baseline} + SD^2_{E,final} - \left(2 \times 0.50 \times SD_{E,baseline} \times SD_{E,final}\right)}\right]$$

Quality assessment

For randomized controlled trials, we assessed quality using the Cochrane Risk of Bias tool. Two investigators (the first and second authors) evaluated the risk of bias according to the Cochrane Handbook criteria, which encompassed randomization, allocation concealment, blinding of participants and personnel, blinding of outcome assessors, completeness of outcome data, selective reporting, and other biases. Each domain was classified as low risk, unclear risk, or high risk. The methodological quality of non-randomized controlled trials was evaluated using the ROBINS-I tool, which was also applied by the same two investigators. The ROBINS-I assessment covers seven critical domains: confounding, selection bias, classification of intervention, deviations from intended interventions, missing data, outcome measurement and selective reporting. Following ROBINS-I guidelines, we graded studies on five levels of bias risk: low, moderate, serious, critical, or no information. Studies were considered high quality when most domains were well-documented and demonstrated low risk of bias. Any scoring discrepancies were resolved through consensus discussions among the investigators.

Statistical analysis

For our comprehensive network meta-analysis, we employed STATA 17.0 software with the “Network” and “mvmeta” statistical packages. We analyzed dichotomous variables (overall complications and excellent/good recovery rate) using odds ratios (ORs) with 95% confidence intervals (CIs). Continuous variables—including JOA scores, JOA improvement rates, cervical lordosis, VAS scores, NDI scores, surgical duration and intraoperative blood loss—were evaluated using weighted mean differences (WMDs) with 95% CIs. Results were considered statistically non-significant when the 95% CI for either ORs or WMDs included the value 1.

For direct comparisons, we performed conventional pairwise meta- analyses using random-effects models, which also served as sensitivity analyses. The network meta-analysis was conducted using a frequentist random-effects model to simultaneously evaluate both direct and indirect treatment comparisons. The primary objective was to determine whether any intervention demonstrated superior outcomes relative to others. To evaluate potential discrepancies between indirect and direct comparisons, we evaluated global inconsistency, local inconsistency (using a node-splitting approach), and loop inconsistency. Statistical significance for global inconsistency was determined using *P*-values, with $P>$ 0.05 indicating no significant global inconsistency. Local inconsistency was evaluated via node-splitting analysis, where $P>$ 0.05 suggested no significant local inconsistency. Heterogeneity within each closed loop was quantified using the inconsistency factor (IF); a 95% confidence interval CI for IF encompassing zero indicated no statistical significance inconsistency. For each pre-specified outcome, a global network diagram was constructed to visualize direct comparisons among interventions. The size of each nodes in the diagram represented the number of participants assigned to the corresponding treatment. Directly compared treatments were connected by lines, with line thickness proportional to the number of trials assessing each specific comparison.

In the Results section, we presented the ranking probabilities of interventions using a cumulative probability ranking graphs. These graphs included the Surface Under the Cumulative Ranking Curve (SUCRA) values, which provide a composite measure of ranking probabilities. SUCRA value range from 0 to 100%, with higher values indicating better intervention rankings (either more favourable or less favourable effects, depending on the outcome direction). We ranked all interventions according to their SUCRA values (equivalent to the area under the curve), generating a complete hierarchy of treatment efficacy.

To evaluate the potential publication bias, we employed comparison-adjusted funnel plots. This method assessed whether evidence existed for either small-study effects or publication bias across the intervention network.

Results

Search results

Initially, 2,698 studies were identified from PubMed (*n* =992), Embase (*n* =824), Ovid (*n* =382), Web of Science (*n* =500), and the Cochrane Library (*n* =0). Using the “Find Duplicates” feature in EndNote software, we excluded 857 duplicate studies. After screening titles and abstracts, we further excluded 1708 non-relevant studies. The full texts of the remaining 133 studies were then assessed for eligibility. Ultimately, 50 studies [20, 22, 32–79], involving 8,705 patients—including 2 randomized controlled trials (RCTs) [32, 33] and 48 non-RCTs [20, 22, 34–79] —met the inclusion criteria for this network meta-analysis. The study selection process is summarized in Fig. 1, and the baseline characteristics of the included studies are presented in Table 2.

Risk of bias and quality assessment

The quality of the included RCTs was assessed using the Cochrane Collaboration’s “Risk of Bias” tool, with results presented in Table 2. For non-RCTs, the risk of bias was evaluated using the ROBINS-I checklist, as detailed in Table 3.

Evidence network

This study analyzed twelve surgical interventions: ACDF, ADF, ACCF, ACAF, PDIF, PDF, LC, LP, LF, and VBSO. The evidence network is presented in Fig. 2, where solid lines indicate direct head-to-head comparisons between interventions. Interventions without direct connections were evaluated through indirect comparisons within the network meta-analysis framework. In the network diagram, line width is proportional to the number of available trials for each comparison, while node size represents the cumulative sample size for each intervention across all included studies.

Inconsistency test

Figure 3 presents the inconsistency plot evaluating heterogeneity across closed loops of our network meta-analysis. We identified 38 closed loops spanning multiple outcome measures: JOA scores (6 loops), JOA improvement rates (4 loops), total complications (7 loops), excellent/good recovery rate (1 loop), cervical lordosis (7 loops), VAS scores (3 loops), NDI scores (1 loop), surgical duration (4 loops), and intraoperative blood loss (5 loops). The inconsistency factor (IF) from 0.06 to 17.19 across these comparisons. Most 95% CIs for the closed loops included zero, with only four exceptions where 95% CIs approached zero: ACCF ~ ACAF ~ LP loop for total complications, ACCF ~ LP ~ LF loop for excellent/good recovery rate, ADF ~ LP ~ LF loop for VAS scores, and ACDF ~ ACCF ~ LP loop for surgical duration. This pattern of results demonstrates good consistency across the network meta-analysis.

Results of network meta-analysis

Primary outcomes

The JOA scores

A pooled analysis of 38 studies ($n=$ 3,482 patients) assessed JOA scores across ten surgical interventions: ACDF, ADF, ACCF, ACAF, PDIF, PDF, LC, LP, LF, and VBSO. Network meta-analysis revealed no statistically significant differences in JOA scores between interventions (see Table 4 and Fig. 4A).

Figure 5A presents the ranking graph depicting the probability distributions for postoperative JOA scores across surgical interventions. The SUCRA analysis yielded the following hierarchy: ACAF (67.7%), ACCF (64.6%), VBSO (61.5%), ACDF (60.1%), LP (52.6%), LC (48.0%), LF (41.6%), PDF (37.9%), ADF (34.9%), PDIF (31.0%). These results indicate that ACAF demonstrated the highest likelihood of improving JOA scores, while

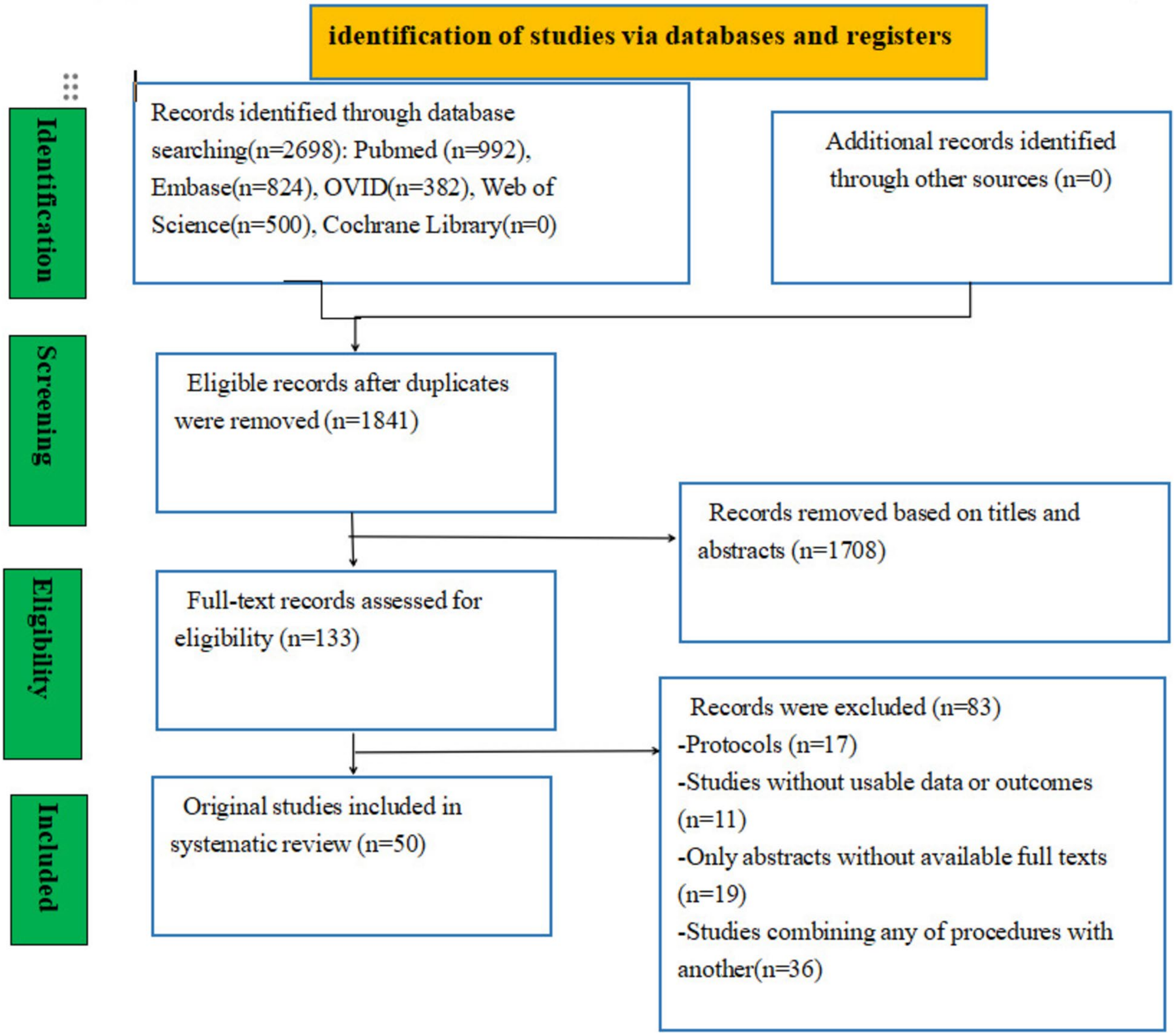


Fig. 1 Flow chart of included studies

PDIF showed the lowest probability. Accordingly, the surgical interventions were ranked in descending order of efficacy for JOA score improvement as follows: ACAF > ACCF > VBSO > ACDF > LP > LC > LF > PDF > ADF > PDIF.

The JOA improvement rates

Thirty studies comprising 2,731 patients evaluated JOA improvement rates across ten surgical interventions: ACDF, ADF, ACCF, ACAF, PDIF, PDF, LC, LP, LF, and VBSO. Network meta-analysis demonstrated statistically significant differences in JOA improvement rates for several pairwise comparisons: ADF showed superior improvement rates versus LC, LP, and LF; ACCF demonstrated better outcomes compared to LP and LF; ACAF achieved higher improvement rates than LP and LF. No other comparisons reached statistical significance (Table 4 and Fig. 4B).

Figure 5B displays the ranking probabilities for JOA improvement rates across surgical interventions. SUCRA analysis revealed the following hierarchy of effectiveness: ADF (87.6%), ACDF (71.2%), PDF (68.2%), ACCF (67.6%), ACAF (63.2%), VBSO (58.0%), PDIF (28.3%), LP (23.1%), LC (17.7%), LF (15.1%). These results indicate that ADF had the highest likelihood of improving postoperative JOA scores, while LF showed the lowest probability of improvement. The interventions were therefore ranked in descending order of efficacy for JOA improvement as follows: ADF > ACDF > PDF > ACCF > ACAF > VBSO > PDIF > LP > LC > LF.

Table 2 Baseline characteristics of the included studies

Author	Country	Study design	Interventions	Sample size	Sex (M/F)	Age (years)	FU (months)	Outcome
Cao 2023 [33]	China	RCT	ACCF	22	11/11	52.91 ± 7.41	24	JOA recovery rate; JOA scores; VAS; NDI; cervical lordosis; surgical duration; blood loss; overall complications;
			LF	18	15/3	57.17 ± 7.97		
Chen T 2023 [36]	China	RS	ACCF	74	26/48	56.1 ± 9.8	23.3 ± 5.2(12–36)	JOA recovery rate; JOA scores; VAS; cervical lordosis; surgical duration; blood loss; overall complications;
			ACDF	77	37/40	56.1 ± 8.1		
Chen Y 2011 [34]	China	RS	ACCF	22	14/8	57.2(43–71)	≥ 48	JOA recovery rate; JOA scores; excellent and good recovery rate; overall complications;
			LP	25	16/9	54.2(32–66)		
			LF	28	19/9	55.3(48–69)		
Chen Y 2012 [35]	China	RS	ACCF	91	63/28	48.7 ± 1.4	≥ 48	JOA recovery rate; JOA scores; overall complications;
			LP	41	33/8	46.3 ± 2.5		
			LF	32	19/13	52.6 ± 1.7		
Chen Y 2020 [32]	China	RCT	ACAF	39	23/16	54.6 ± 11.2	18.6 ± 4.5	JOA recovery rate; JOA scores; VAS; NDI; cervical lordosis; surgical duration; blood loss; overall complications;
			LP	38	20/18	57.2 ± 10.4		
Fujimori 2014 [38]	Japan	RS	ADF	12	7/5	55.6 ± 7.8	121.2(24–264)	JOA recovery rate; JOA scores; VAS; excellent and good recovery rate; cervical lordosis; surgical duration; blood loss; overall complications; reoperation rate
			LP	15	12/3	58.7 ± 9.1		
Ha 2019 [80]	South Korea	RS	LP	49	33/16	59.12 ± 8.53	38.6(27.8–46.2)	JOA recovery rate; JOA scores; VAS; NDI; cervical lordosis; surgical duration; blood loss; overall complications;
			LF	42	36/6	62.21 ± 7.81		
Hou 2017 [39]	China	RS	ACCF	150	86/64	47.8(29–79)	35.4(29–38)	JOA scores; VAS; cervical lordosis; surgical duration; blood loss; overall complications;
			LP	102	61/41	45.9(30–77)	36.1(28–40)	
Inoue 2022 [45]	Japan	PS	ADF	39	31/8	62.1 ± 10.8	24	JOA recovery rate; JOA scores; VAS; cervical lordosis; overall complications;
			LP	39	29/10	62.4 ± 10.9		
Kang 2019 [42]	South Korea	RS	LP	36	25/11	50.1 ± 8.0	37.6 ± 16.8	cervical lordosis;
			LF	14	10/4	54.7 ± 9.5	28.9 ± 20.8	
Kim 2015 [41]	South Korea	RS	ADF	71	51/20	57.3(35–76)	48(12–68)	JOA recovery rate; JOA scores; excellent and good recovery rate;
			LP	64	49/15	56.4(35–76)	41(24–64)	
Koda 2016 [40]	Japan	RS	ADF	15	10/5	57.7(49–69)	58.6(13–134)	JOA recovery rate; JOA scores; cervical lordosis; surgical duration; blood loss; overall complications;
			LP	16	12/4	60.3(36–82)	46.0(12–131)	
			PDIF	17	14/3	65.0(35–82)	42.0(12–103)	
Kong 2021 [20]	China	RS	ACAF	21	13/8	60.7 ± 7.2	26.7 ± 1.6	JOA recovery rate; JOA scores; cervical lordosis; surgical duration; blood loss; overall complications;
			LP	32	17/15	57.6 ± 6.3	28.5 ± 2.3	

Table 2 (continued)

Author	Country	Study design	Interventions	Sample size	Sex (M/F)	Age (years)	FU (months)	Outcome
Lee DH 2019 [81]	Korea	RS	ACCF	38	28/10	53.8 ± 10.1	32.4 ± 7.8	excellent and good recovery rate; cervical lordosis; overall complications;
			VBSO	24	19/5	56.3 ± 10.6	33.7 ± 7.8	
Lee DH 2021 [44]	Korea	RS	LP	44	33/11	63.2 ± 9.9	41.3 ± 11.7	JOA recovery rate; JOA scores;
			VBSO	33	24/9	57.6 ± 10.9	34.56 ± 11.4	
Lee DH 2022 [46]	Korea	RS	LP	57	44/13	62.2 ± 9.9	32.6 ± 11.3	JOA recovery rate; JOA scores; cervical lordosis; surgical duration; overall complications;
			VBSO	40	29/11	58.6 ± 10.9	35.56 ± 12.4	
Lee JJ 2021 [49]	Korea	RS	LP	188	137/51	56.80 ± 8.32	40.36 ± 16.69	JOA recovery rate; JOA scores; cervical lordosis; surgical duration; blood loss; overall complications;
			LF	85	63/22	59.42 ± 8.82	39.39 ± 18.40	
Lee SH 2008 [47]	South Korea	RS	ACCF	20	15/5	56.8(42–72)	21.8(6–61)	cervical lordosis; overall complications;
			LP	27	26/1	54.7(30–70)	29.1(11–64)	
Li JH 2024 [51]	China	RS	ACCF	30	17/13	56.37 ± 10.14	17.93 ± 2.86	JOA scores; NDI; cervical lordosis; surgical duration; blood loss; overall complications
			LP	44	22/22	56.18 ± 9.50	18.20 ± 3.54	
Li YC 2022 [50]	China	RS	ADF	40	27/13	64.5	12	JOA scores; VAS; cervical lordosis; blood loss; overall complications
			LF	15	14/1	67.73	12	
Lin 2012 [48]	China	RS	ADF	26	15/11	54.7 ± 13.2	36.3 ± 6.4	JOA scores; excellent and good recovery rate; surgical duration; blood loss; overall complications
			PDIF	30	17/13	56.2 ± 14.1	37.6 ± 6.7	
Liu HC 2013 [52]	China	RS	ACCF	68	36/32	54.4 ± 12.8	81.6(60–120)	cervical lordosis;
			LP	59	25/34	57.9 ± 9.5	81.6(60–120)	
Liu JW 2023 [56]	China	RS	ACCF	62	/	60.1 ± 3.8	26.8 ± 3.1	JOA recovery rate; JOA scores; overall complications
			LP	60	/	60.1 ± 3.8	26.8 ± 3.1	
Liu T 2024 [57]	China	RS	LP	31	26/5	59.97 ± 8.07	≥ 24	JOA recovery rate; JOA scores; VAS; NDI; cervical lordosis; surgical duration; blood loss; overall complications;
			LF	36	25/11	58.53 ± 9.55	≥ 24	
Liu XW 2017 [53]	China	RS	LP	32	26/6	59 ± 10	38 ± 13	JOA recovery rate; JOA scores; VAS; NDI; cervical lordosis; overall complications;
			LF	35	25/10	60 ± 8	42 ± 9	
Iwasaki 2007 [82]	Japan	RS	ADF	27	15/12	58(41–74)	72(24–120)	JOA recovery rate; JOA scores; excellent and good recovery rate; surgical duration; blood loss; overall complications;
			LP	66	51/15	57(41–75)	122.4(60–240)	
Ma 2024 [58]	China	RS	LP	40	24/16	61.3 ± 1.4	31.9 ± 2.0	JOA scores;VAS; NDI; cervical lordosis; excellent and good recovery rate; surgical duration; blood loss; overall complications;
			LF	40	29/11	60.0 ± 1.6	27.4 ± 2.0	
Masaki 2007 [55]	Japan	RS	ADF	19	14/5	51.8 ± 6.6	≥ 12	JOA recovery rate; JOA scores; excellent and good recovery rate;
			LP	40	30/10	62.6 ± 10.3	≥ 12	

Table 2 (continued)

Author	Country	Study design	Interventions	Sample size	Sex (M/F)	Age (years)	FU (months)	Outcome
Moon 2019 [60]	South Korea	RS	ACCF	70	50/20	57.2 ± 9.7	47.9 ± 16.9	JOA recovery rate;
			LP	63	48/15	55.3 ± 9.1	40.4 ± 12.3	
Morishita 2019 [61]	Japan	RS	ADF	1192	847/385	60.9 ± 11.3	/	overall complications;
			LP	1192	859/333	60.8 ± 11.7	/	
Nakano 1988 [59]	Japan	RS	LP	75	/	55.0(32–75)	54	JOA recovery rate; JOA scores; surgical duration; blood loss;
			LC	14	/	59.2(46–74)	128	
Nakashima 2022 [22]	Japan	RS	LP	137	96/41	64.2 ± 11.6	24	JOA recovery rate; JOA scores; cervical lordosis; VAS; overall complications;
			LF	52	38/14	63.9 ± 10.6	24	
Noh 2020 [62]	Korea	RS	ACDF	41	30/11	55.24 ± 9.12	42.7 ± 10.5	JOA scores; VAS; NDI; cervical lordosis; surgical duration; blood loss; overall complications;
			LP	45	25/20	55.6 ± 7.75	42.7 ± 10.5	
Ota 2016 [66]	Japan	RS	LP	23	20/3	59.8 ± 10.2	47.2 ± 29.3	JOA recovery rate; JOA scores; surgical duration; blood loss; overall complications;
			PDIF	27	23/4	63.7 ± 11	45.4 ± 32.6	
Park 2021 [68]	USA	RS	ACCF	18	10/8	55.5(39–72)	≥ 12	JOA scores; VAS; surgical duration; blood loss; overall complications;
			LP	16	9/7	60(41–74)	≥ 12	
			LF	10	8/2	54.5(45–69)	≥ 12	
Sakai 2012 [65]	Japan	PS	ADF	20	/	59.5 ± 9.3	60	JOA recovery rate; JOA scores; surgical duration; blood loss; overall complications;
			LP	22	/	58.4 ± 9.6	60	
Sun 2019 [83]	China	RS	ACAF	38	27/11	58.18 ± 1.82	≥ 12	JOA recovery rate; JOA scores; cervical lordosis; overall complications;
			LC	33	22/11	58.06 ± 2.33	≥ 12	
Sun 2019 [84]	China	RS	ACAF	42	23/19	57.2 ± 12.2	18.2 ± 2.9	JOA recovery rate; JOA scores; overall complications;
			LP	38	19/19	58.1 ± 13.4	17.7 ± 4.0	
Tani 2022 [64]	Japan	RS	ADF	14	11/3	62 ± 11	49 ± 34	JOA recovery rate; JOA scores; excellent and good recovery rate; overall complications;
			LP	12	9/3	66 ± 6	50 ± 43	
Wang 2024 [71]	China	RS	ACAF	27	16/11	62.96 ± 9.34	≥ 12	JOA recovery rate; JOA scores; VAS; NDI; cervical lordosis; surgical duration; blood loss; overall complications;
			LP	43	24/19	59.47 ± 10.60	≥ 12	
Xu 2019 [85]	China	RS	ADF	17	12/5	55.2 ± 12.1	42 ± 16.8	JOA recovery rate; JOA scores; cervical lordosis; surgical duration; blood loss; overall complications;
			LP	33	25/8	54.8 ± 10.7	54 ± 34.8	
Yang 2018 [69]	China	RS	ACCF	36	19/17	58.4 ± 8.3	12.4 ± 4.7	JOA recovery rate; JOA scores; surgical duration; blood loss; overall complications;
			ACAF	34	21/13	58.6 ± 10.8	10.1 ± 2.8	
Yoo 2017 [73]	Korea	RS	LP	38	30/8	60.93 ± 8.45	35.17 ± 15.91	JOA recovery rate; JOA scores; VAS; NDI; cervical lordosis; overall complications;
			LC	35	25/10	64.57 ± 10.55	40.93 ± .94	
Yoshii 2016 [72]	Japan	RS	ADF	39	31/8	61.1 ± 8.5	44.5 ± 18.8	JOA recovery rate; JOA scores; VAS; cervical lordosis; surgical duration; blood loss;
			PDF	22	18/4	60.6 ± 12.8	37.2 ± 16.3	

Table 2 (continued)

Author	Country	Study design	Interventions	Sample size	Sex (M/F)	Age (years)	FU (months)	Outcome
Yoshii 2020 [74]	Japan	RS	ADF	854	602/252	62.6 ± 11.2	/	overall complications;
			PDF	854	602/252	62.4 ± 10.8	/	
Yoshii 2021 [75]	Japan	PS	LP	270	201/69	66.0 ± 11.4	≥ 24	overall complications;
			PDIF	110	86/24	65.3 ± 11.0	≥ 24	
Yoshii 2022 [76]	Japan	PS	ADF	89	61/28	60.1 ± 10.9	≥ 24	JOA recovery rate; JOA scores; VAS; overall complications;
			LP	211	158/53	65.1 ± 11.7	≥ 24	
Yuan 2015 [77]	China	PS	LP	20	14/6	59 ± 11.6	≥ 12	JOA recovery rate; JOA scores; VAS; overall complications;
			LF	18	11/7	62 ± 13.1	≥ 12	
Zhang B 2019 [78]	China	RS	ACCF	30	14/16	53.3 ± 7.0	18.6 ± 4.7	JOA recovery rate; JOA scores; excellent and good recovery rate; NDI; cervical lordosis;surgical duration; blood loss; overall complications;
			ACAF	32	15/17	49.8 ± 10.2	19.8 ± 3.4	
Zhang Q 2023 [79]	China	RS	LP	46	24/22	58.77 ± 6.45	≥ 24	JOA scores;VAS; surgical duration; blood loss; overall complications;
			LF	56	31/25	57.75 ± 4.72	≥ 24	

M/F male/female, *FU* follow-up time, *RCT* randomized controlled trial, *RS* retrospective study, *PS* Prospective cohort study, *ADF* anterior decompression and fusion, *ACCF* anterior cervical corpectomy and fusion, *ACAF* anterior controllable antedisplacement fusion, *PDIF* posterior decompression with instrumented fusion, *PDF* posterior decompression and fusion, *LC* laminectomy, *LP* laminoplasty, *LF* laminectomy with fusion, *VBSO* vertebral body sliding osteotomy

Table 3 Risk of bias of the included randomized controlled trials

study	Sequence_ generation	Allocation_ concealment	Blinding			Selective_ reporting-bias	Attrition_bias
			participant	therapist	assessor		
Cao 2023 [33]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Chen Y 2020 [32]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk

Secondary outcomes

Total complications

Forty-one studies involving 7,930 patients reported total complication rates across ten surgical interventions: ACDF, ADF, ACCF, ACAF, PDIF, PDF, LC, LP, LF, and VBSO. Network meta-analysis demonstrated statistically significant differences in total complication rate: ACDF showed significantly fewer complications than ADF, ACCF, PDIF, PDF, LP, and LF; ADF had significantly more complications than ACCF, ACAF, LP, and VBSO; ACCF demonstrated fewer complications than LF. ACAF exhibited lower complication rates than PDIF, LP, and LF; PDIF was associated with higher complication rates than LP and VBSO. LP showed fewer complications than LF; VBSO had significantly lower complication rates than LF. All results are presented in Table 4 and Fig. 4C.

Figure 5C presents the ranking probabilities for total postoperative complications across surgical interventions. SUCRA analysis yielded the following safety profile hierarchy (lower percentages indicate better outcomes): ACDF (6.4%), VBSO (11.9%), ACAF (19.2%), LP (42.2%), LC (51.3%), ACCF (51.8%), PDF (65.4%), LF (82.6%), PDIF (83.2%), ADF (86.0%). These results indicate ACDF had the lowest likelihood of postoperative complications, while ADF carried the highest risk. The interventions were thus ranked in ascending order of complication probability (from most to least favorable): ACDF, VBSO, ACAF, LP, LC, ACCF, PDF, LF, PDIF, and ADF.

Excellent/good recovery rates

Eleven studies involving 826 patients evaluated excellent/good recovery rates across eight surgical interventions: ACDF, ADF, ACCF, ACAF, PDIF, LP, LF, and VBSO. Network meta-analysis revealed no statistically significant differences in excellent/good recovery rates between these interventions (Table 4 and Fig. 4D).

Figure 5D displays the probability distributions for excellent/good postoperative recovery rates across surgical interventions. SUCRA analysis demonstrated the following efficacy hierarchy (higher percentages indicate

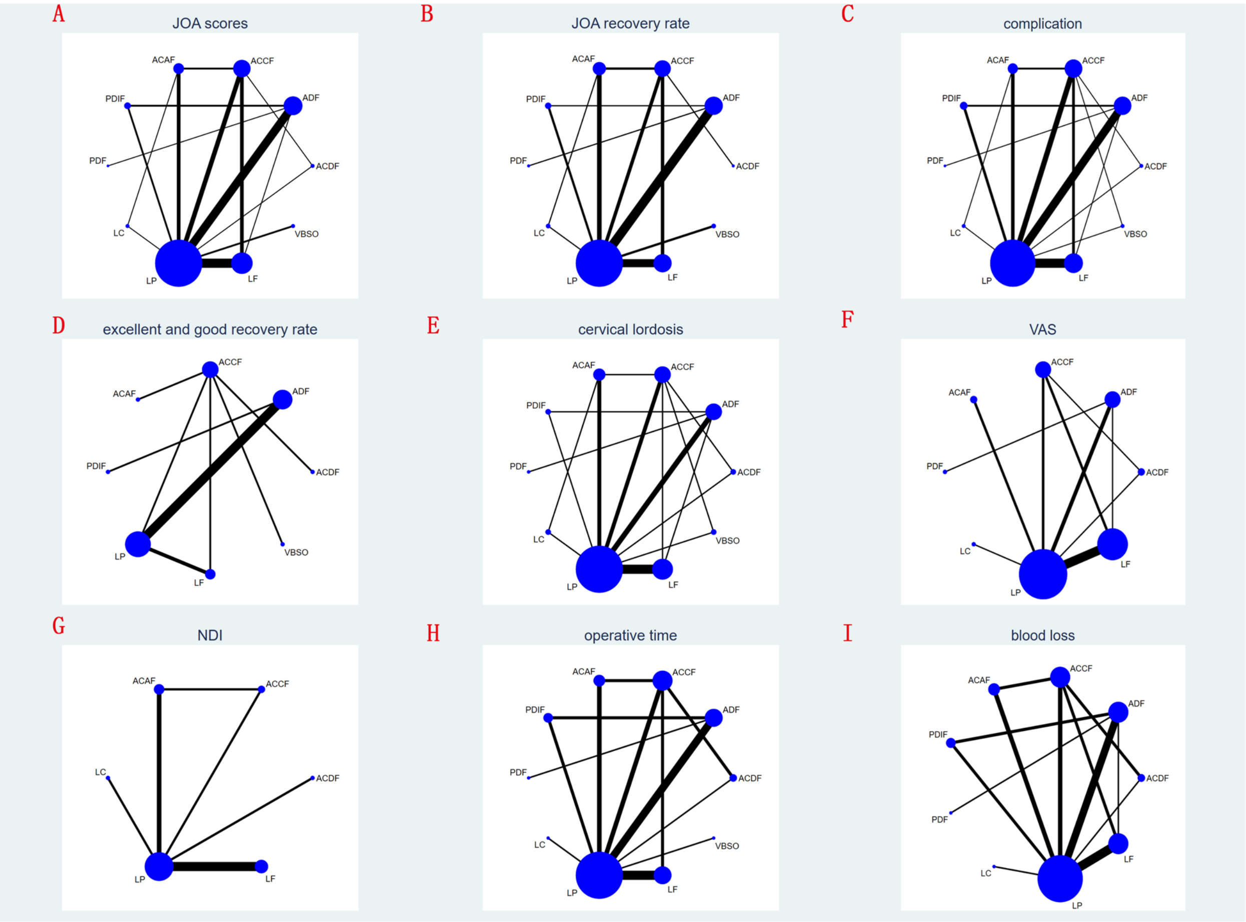


Fig. 2 Network analysis was performed for eligible comparison for (**A**) the JOA scores, **B** the JOA improvement rates, **C** total complications, **D** excellent/good recovery rates, **E** cervical lordosis, **F** VAS, **G** NDI scores, **H** surgical duration and (**I**) intraoperative blood loss. The node size corresponds to the number of participants, while the line thickness indicates the number of studies with direct comparisons between two interventions

better outcomes): VBSO (75.6%), ACCF (69.4%), ACDF (66.1%), ACAF (56.1%), ADF (40.1%), PDIF (37.1%), LF (27.8%), LP (27.7%). These results suggest VBSO had the highest probability of achieving excellent/good recovery outcomes, while LP showed the lowest probability. The interventions were accordingly ranked in descending order of recovery efficacy: VBSO > ACCF > ACDF > ACAF > ADF > PDIF > LF > LP.

Cervical lordosis

Twenty-five studies involving 2,360 patients evaluated cervical lordosis across ten surgical interventions: ACDF, ADF, ACCF, ACAF, PDIF, PDF, LC, LP, LF, and VBSO. Network meta-analysis demonstrated statistically significant differences in cervical lordosis restoration: ACAF achieved significantly greater lordosis compared to ACCF, PDIF, LC, LP, and LF; LP showed significantly less lordosis than both ACDF and ADF. All results are presented in Table 4 and Fig. 4E.

Figure 5E presents the probability distributions for postoperative cervical lordosis restoration across surgical interventions. SUCRA analysis revealed the following efficacy hierarchy for lordosis improvement (higher percentages indicate better outcomes): ACAF (92.6%), ACDF (74.1%), VBSO (69.4%), PDF (62.4%), ADF (62.0%), ACCF (45.6%), LF (27.2%), LC (25.4%), PDIF (25.1%), LP (16.3%). These results indicate ACAF had the highest probability of achieving optimal cervical lordosis restoration, while LP demonstrated the lowest probability. The interventions were accordingly ranked in descending order of efficacy for lordosis improvement: ACAF > ACDF > VBSO > PDF > ADF > ACCF > LF > LC > PDIF > LP.

VAS

Twenty-one studies comprising 1,920 patients evaluated the VAS scores across eight surgical interventions: ACDF, ADF, ACCF, ACAF, PDF, LC, LP, and

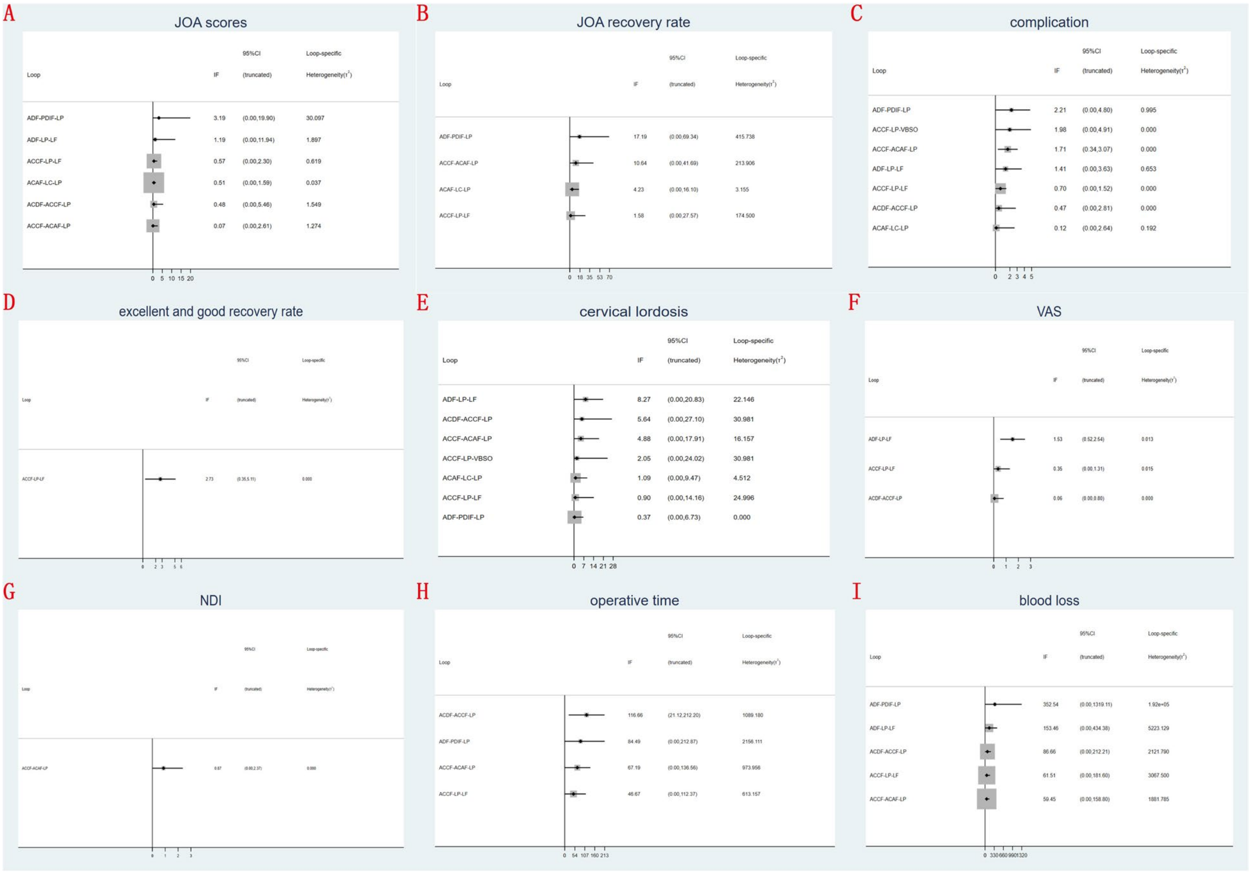


Fig. 3 Inconsistency plots were generated for eligible comparison of (**A**) the JOA scores, **B** the JOA improvement rates, **C** total complications, **D** excellent/good recovery rates, **E** cervical lordosis, **F** VAS, **G** NDI scores, **H** surgical duration and (**I**) intraoperative blood loss

LF. Network meta-analysis demonstrated statistically significant differences in VAS scores: ACAF showed significantly lower VAS scores (indicating better outcomes) compared to ACDF, ADF, ACCF, PDF, LC, LP, and LF; PDF was associated with significantly higher VAS scores than ACDF, ADF, ACCF, and LP; ADF demonstrated significantly lower VAS scores than LF. All results are presented in Table 4 and Fig. 4F.

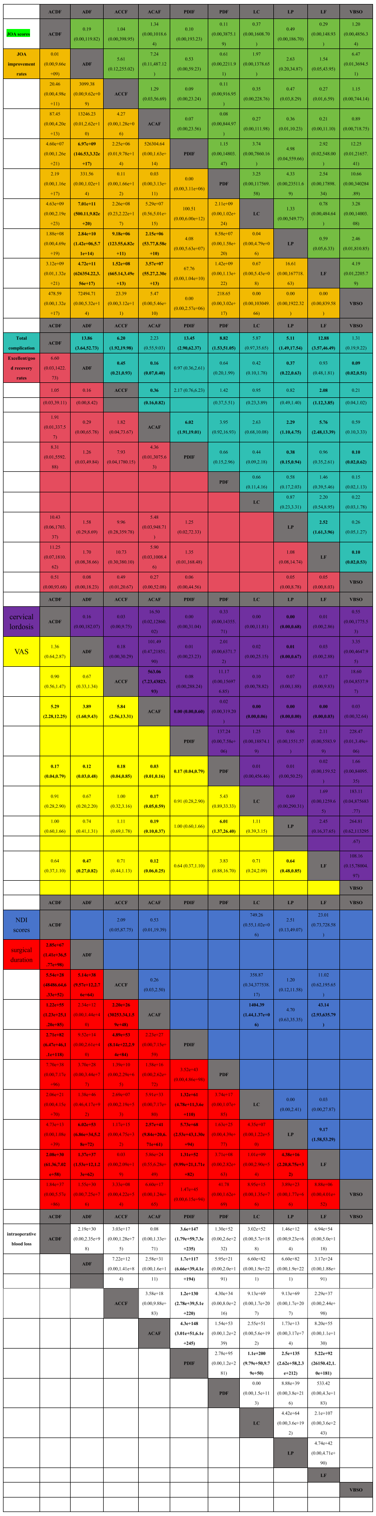
Figure 5F displays the probability distributions for postoperative VAS scores across surgical interventions. SUCRA analysis revealed the following pain reduction efficacy hierarchy (lower percentages indicate better outcomes): ACAF (0.1%), ADF (24.8%), ACDF (44.7%), LP (44.8%), LC (52.5%), ACCF (54.1%), LF (80.6%), PDF (98.4%). These results indicate ACAF had the highest probability of achieving optimal VAS reduction (representing superior pain relief), while PDF showed the lowest probability. The interventions were accordingly ranked in ascending order of pain reduction efficacy: ACAF, ADF, ACDF, LP, LC, ACCF, LF, and PDF.

NDI scores

Ten studies involving 747 patients evaluated NDI scores across six surgical interventions: ACDF, ACCF, ACAF, LC, LP, and LF. Network meta-analysis demonstrated statistically significant differences in NDI outcomes: ACAF showed significantly lower NDI scores (indicating better functional outcomes) compared to both LC and LF; LP demonstrated significantly lower NDI scores than LF (Table 4 and Fig. 4G).

Figure 5G presents the probability distributions for postoperative NDI scores across surgical interventions. SUCRA analysis revealed the following functional improvement hierarchy (lower percentages indicate better outcomes): ACAF (11.3%), ACDF (26.8%), ACCF (41.3%), LP (45.6%), LF (81.2%), LC (93.8%). These results indicate ACAF had the highest probability of achieving optimal NDI reduction (representing superior functional improvement), while LC showed the lowest probability. The interventions were accordingly

Table 4 Comparative outcomes for the JOA scores, the JOA improvement rates, total complications, excellent/good recovery rates, cervical lordosis, VAS, NDI scores, surgical duration and intraoperative blood loss. Significant results are in bold text



	ACDF	ADF	ACCF	ACAF	PDIF	PDF	LC	LP	LF	VBSO
JOA scores	ACDF	0.19 (0.00,119.82)	1.04 (0.00,398.95)	1.34 (0.00,1018.64)	0.10 (0.00,193.23)	0.11 (0.00,3875.19)	0.37 (0.00,1608.70)	0.49 (0.00,186.70)	0.29 (0.00,148.93)	1.20 (0.00,4856.34)
JOA improvement rates	0.01 (0.00,9.66e+09)	ADF	5.61 (0.12,255.02)	7.24 (0.11,487.12)	0.53 (0.00,59.23)	0.61 (0.00,2211.91)	1.97 (0.00,1378.65)	2.63 (0.20,34.87)	1.54 (0.05,43.95)	6.47 (0.01,3694.51)
	20.46 (0.00,4.98e+11)	3099.38 (0.00,9.62e+09)	ACCF	1.29 (0.03,56.69)	0.09 (0.00,23.24)	0.11 (0.00,916.95)	0.35 (0.00,228.76)	0.47 (0.03,8.29)	0.27 (0.01,6.59)	1.15 (0.00,744.14)
	87.45 (0.00,4.20e+13)	13246.23 (0.01,2.62e+10)	4.27 (0.00,1.28e+06)	ACAF	0.07 (0.00,23.56)	0.08 (0.00,844.97)	0.27 (0.00,111.98)	0.36 (0.01,10.23)	0.21 (0.00,11.10)	0.89 (0.00,718.75)
	4.60e+07 (0.00,1.26e+21)	**6.97e+09 (146.53,3.32e+17)**	2.25e+06 (0.01,9.78e+14)	526304.64 (0.00,1.63e+14)	PDIF	1.15 (0.00,14803.47)	3.74 (0.00,7860.16)	4.98 (0.04,559.66)	2.92 (0.02,548.00)	12.25 (0.01,21657.41)
	2.19 (0.00,1.16e+17)	331.56 (0.00,1.02e+14)	0.11 (0.00,1.66e+12)	0.03 (0.00,3.13e+11)	0.00 (0.00,3.11e+06)	PDF	3.25 (0.00,117569.58)	4.33 (0.00,23511.69)	2.54 (0.00,17898.34)	10.66 (0.00,340284.89)
	4.63e+09 (0.00,2.19e+23)	**7.01e+11 (500.11,9.82e+20)**	2.26e+08 (0.23,2.22e+17)	5.29e+07 (0.56,5.01e+15)	100.51 (0.00,6.00e+12)	2.11e+09 (0.00,1.02e+24)	LC	1.33 (0.00,549.77)	0.78 (0.00,484.64)	3.28 (0.00,14003.08)
	1.88e+08 (0.00,4.69e+19)	**2.84e+10 (1.42e+06,5.71e+14)**	**9.18e+06 (123.55,6.82e+11)**	**2.15e+06 (53.77,8.58e+10)**	4.08 (0.00,5.63e+07)	8.58e+07 (0.00,1.58e+20)	0.04 (0.00,4.79e+06)	LP	0.59 (0.05,6.33)	2.46 (0.01,810.85)
	3.12e+09 (0.01,1.32e+21)	**4.72e+11 (626354.22,3.56e+17)**	**1.52e+08 (665.14,3.49e+13)**	**3.57e+07 (55.27,2.30e+13)**	67.76 (0.00,1.04e+10)	1.42e+09 (0.00,1.13e+22)	0.67 (0.00,5.43e+08)	16.61 (0.00,167718.63)	LF	4.19 (0.01,2205.79)
	478.59 (0.00,1.32e+17)	72494.71 (0.00,5.32e+14)	23.39 (0.00,3.12e+11)	5.47 (0.00,5.46e+10)	0.00 (0.00,2.57e+06)	218.65 (0.00,3.02e+17)	0.00 (0.00,103049.66)	0.00 (0.00,1922.32)	0.00 (0.00,839.58)	VBSO
	ACDF	ADF	ACCF	ACAF	PDIF	PDF	LC	LP	LF	VBSO
Total complication	ACDF	**13.86 (3.64,52.73)**	**6.20 (1.92,19.98)**	2.23 (0.55,9.03)	**13.45 (2.90,62.37)**	**8.82 (1.53,51.05)**	5.87 (0.97,35.65)	**5.11 (1.49,17.54)**	**12.88 (3.57,46.49)**	1.31 (0.19,9.22)
Excellent/good recovery rates	6.60 (0.03,1422.73)	ADF	**0.45 (0.21,0.93)**	**0.16 (0.07,0.40)**	0.97 (0.36,2.61)	0.64 (0.20,1.99)	0.42 (0.10,1.78)	**0.37 (0.22,0.63)**	0.93 (0.48,1.81)	**0.09 (0.02,0.51)**
	1.05	0.16	ACCF	**0.36**	2.17 (0.76,6.23)	1.42	0.95	0.82	**2.08**	0.21
	(0.03,39.11)	(0.00,8.42)		**(0.16,0.82)**		(0.37,5.51)	(0.23,3.89)	(0.49,1.40)	**(1.12,3.85)**	(0.04,1.02)
	1.91 (0.01,337.57)	0.29 (0.00,65.78)	1.82 (0.04,73.67)	ACAF	**6.02 (1.91,19.01)**	3.95 (0.92,16.93)	2.63 (0.68,10.08)	**2.29 (1.10,4.75)**	**5.76 (2.48,13.39)**	0.59 (0.10,3.33)
	8.31 (0.01,5592.88)	1.26 (0.03,49.84)	7.93 (0.04,1780.15)	4.36 (0.01,3075.63)	PDIF	0.66 (0.15,2.96)	0.44 (0.09,2.18)	**0.38 (0.15,0.94)**	0.96 (0.35,2.61)	**0.10 (0.02,0.62)**
						PDF	0.66 (0.11,4.16)	0.58 (0.17,2.03)	1.46 (0.39,5.46)	0.15 (0.02,1.13)
							LC	0.87 (0.23,3.31)	2.20 (0.54,8.95)	0.22 (0.03,1.78)
	10.43 (0.06,1703.37)	1.58 (0.29,8.69)	9.96 (0.28,359.78)	5.48 (0.03,948.71)	1.25 (0.02,72.33)			LP	**2.52 (1.61,3.96)**	0.26 (0.05,1.27)
	11.25 (0.07,1810.62)	1.70 (0.08,38.66)	10.73 (0.30,380.10)	5.90 (0.03,1008.46)	1.35 (0.01,168.48)			1.08 (0.08,14.74)	LF	**0.10 (0.02,0.53)**
	0.51 (0.00,93.68)	0.08 (0.00,18.23)	0.49 (0.01,20.67)	0.27 (0.00,52.08)	0.06 (0.00,44.56)			0.05 (0.00,8.78)	0.05 (0.00,8.03)	VBSO
	ACDF	ADF	ACCF	ACAF	PDIF	PDF	LC	LP	LF	VBSO
cervical lordosis	ACDF	0.16 (0.00,182.07)	0.03 (0.00,9.75)	16.50 (0.02,12860.02)	0.00 (0.00,31.04)	0.33 (0.00,14355.71)	0.00 (0.00,11.81)	**0.00 (0.00,0.68)**	0.01 (0.00,2.86)	0.55 (0.00,1775.53)
VAS	1.36 (0.64,2.87)	ADF	0.18 (0.00,30.29)	101.49 (0.47,21851.90)	0.01 (0.00,23.23)	2.01 (0.00,6371.72)	0.02 (0.00,25.15)	**0.01 (0.00,0.67)**	0.03 (0.00,2.88)	3.35 (0.00,4647.95)
	0.90 (0.56,1.47)	0.67 (0.33,1.34)	ACCF	**563.06 (7.23,43823.93)**	0.08 (0.00,288.24)	11.17 (0.00,156976.85)	0.10 (0.00,78.82)	0.07 (0.00,1.88)	0.17 (0.00,9.83)	18.60 (0.04,8537.97)
	5.29 (2.28,12.25)	**3.89 (1.60,9.43)**	**5.84 (2.56,13.31)**	ACAF	**0.00 (0.00,0.60)**	0.02 (0.00,319.20)	**0.00 (0.00,0.06)**	**0.00 (0.00,0.00)**	**0.00 (0.00,0.03)**	0.03 (0.00,32.64)
					PDIF	137.24 (0.00,7.58e+06)	1.25 (0.00,18874.19)	0.86 (0.00,1551.57)	2.11 (0.00,5583.99)	228.47 (0.01,3.49e+06)
	0.17 (0.04,0.79)	**0.12 (0.03,0.48)**	**0.18 (0.04,0.85)**	**0.03 (0.01,0.16)**	**0.17 (0.04,0.79)**	PDF	0.01 (0.00,456.46)	0.01 (0.00,50.25)	0.02 (0.00,159.52)	1.66 (0.00,84095.35)
	0.91 (0.28,2.90)	0.67 (0.20,2.20)	1.00 (0.32,3.16)	**0.17 (0.05,0.59)**	0.91 (0.28,2.90)	5.43 (0.89,33.33)	LC	0.69 (0.00,290.31)	1.69 (0.00,1259.65)	183.11 (0.04,875683.77)
	1.00 (0.60,1.66)	0.74 (0.41,1.31)	1.11 (0.69,1.78)	**0.19 (0.10,0.37)**	1.00 (0.60,1.66)	**6.01 (1.37,26.40)**	1.11 (0.39,3.15)	LP	2.45 (0.16,37.65)	264.81 (0.62,113295.67)
	0.64 (0.37,1.10)	**0.47 (0.27,0.82)**	0.71 (0.44,1.13)	**0.12 (0.06,0.25)**	0.64 (0.37,1.10)	3.83 (0.88,16.70)	0.71 (0.24,2.09)	**0.64 (0.48,0.85)**	LF	108.16 (0.15,78004.97)
										VBSO
	ACDF	ADF	ACCF	ACAF	PDIF	PDF	LC	LP	LF	VBSO
NDI scores	ACDF		2.09 (0.05,87.75)	0.53 (0.01,19.39)			749.26 (0.55,1.02e+06)	2.51 (0.13,49.07)	23.01 (0.73,728.58)	
surgical duration	**2.85e+67 (1.41e+36,5.77e+98)**	ADF								
	5.54e+28 (48486.64,6.33e+52)	**5.14e+38 (9.57e+12,2.76e+64)**	ACCF	0.26 (0.03,2.50)			358.87 (0.34,377538.17)	1.20 (0.12,11.58)	11.02 (0.62,195.65)	
	1.22e+55 (1.23e+25,1.20e+85)	2.34e+12 (0.00,1.44e+40)	**2.20e+26 (30253.34,1.59e+48)**	ACAF			**1404.39 (1.44,1.37e+06)**	4.70 (0.63,35.35)	**43.14 (2.93,635.79)**	
	2.71e+82 (6.47e+46,1.1e+118)	9.52e+14 (0.00,2.61e+40)	**4.89e+53 (8.14e+22,2.94e+84)**	2.23e+27 (0.00,7.15e+59)	PDIF					
	7.70e+38 (0.00,7.17e+96)	3.70e+28 (0.00,3.44e+77)	1.39e+10 (0.00,2.29e+65)	1.58e+16 (0.00,2.62e+72)	3.52e+43 (0.00,4.86e+98)	PDF				
	2.06e+21 (0.00,4.15e+70)	1.38e+46 (0.46,4.17e+92)	2.69e+07 (0.00,2.19e+53)	5.91e+33 (0.00,7.17e+80)	**1.32e+61 (4.78e+11,3.6e+110)**	3.74e+17 (0.00,1.07e+85)	LC	0.00 (0.00,2.41)	0.03 (0.00,27.87)	
	4.73e+13 (0.00,1.08e+39)	**6.02e+53 (6.86e+34,5.28e+72)**	1.17e+15 (0.00,4.75e+32)	**2.57e+41 (9.84e+20,6.71e+61)**	**5.73e+68 (2.53e+43,1.30e+94)**	1.63e+25 (0.00,4.39e+77)	4.35e+07 (0.00,1.22e+50)	LP	**9.17 (1.58,53.29)**	
	2.08e+30 (61.36,7.02e+58)	**1.37e+37 (1.53e+12,1.23e+62)**	0.03 (0.00,2.09e+19)	5.86e+24 (0.55,6.28e+49)	**1.31e+52 (9.99e+21,1.71e+82)**	3.71e+08 (0.00,2.82e+63)	1.01e+09 (0.00,2.90e+54)	**4.38e+16 (2.20,8.75e+32)**	LF	
	1.84e+37 (0.00,5.57e+86)	1.55e+30 (0.00,7.25e+76)	3.33e+08 (0.00,4.22e+54)	6.60e+17 (0.00,1.24e+65)	1.47e+45 (0.00,6.15e+94)	41.78 (0.00,1.62e+69)	8.95e+15 (0.00,1.35e+76)	3.89e+23 (0.00,1.77e+66)	8.88e+06 (0.00,4.01e+52)	VBSO
	ACDF	ADF	ACCF	ACAF	PDIF	PDF	LC	LP	LF	VBSO
intraoperative blood loss	ACDF	2.19e+30 (0.00,2.35e+98)	3.03e+17 (0.00,1.28e+75)	0.08 (0.00,1.33e+71)	**3.6e+147 (1.79e+59,7.3e+235)**	1.30e+52 (0.00,2.6e+232)	3.02e+52 (0.00,5.7e+188)	1.46e+12 (0.00,9.23e+64)	6.94e+54 (0.00,5.0e+118)	
		ADF	7.22e+12 (0.00,1.41e+84)	2.58e+31 (0.00,1.6e+111)	**1.7e+117 (6.66e+39,4.1e+194)**	5.95e+21 (0.00,2.0e+191)	6.60e+82 (0.00,1.9e+221)	6.60e+82 (0.00,1.9e+221)	3.17e+24 (0.00,1.88e+91)	
			ACCF	3.58e+18 (0.00,9.88e+83)	**1.2e+130 (2.78e+39,5.1e+220)**	4.30e+34 (0.00,8.0e+216)	9.13e+69 (0.00,1.7e+207)	9.13e+69 (0.00,1.7e+207)	2.29e+37 (0.00,2.44e+98)	
				ACAF	**4.3e+148 (3.01e+51,6.1e+245)**	1.54e+53 (0.00,1.2e+239)	2.55e+51 (0.00,5.6e+192)	1.73e+13 (0.00,3.17e+74)	8.20e+55 (0.00,1.1e+130)	
					PDIF	2.78e+95 (0.00,1.2e+281)	**1.1e+200 (9.79e+50,9.79e+50)**	**2.5e+135 (2.62e+58,2.3e+212)**	**5.22e+92 (26150.42,1.0e+181)**	
						PDF	0.00 (0.00,1.5e+113)	8.88e+39 (0.00,3.8e+216)	533.42 (0.00,4.3e+183)	
							LC	4.42e+64 (0.00,3.6e+192)	2.1e+107 (0.00,3.6e+243)	
								LP	4.74e+42 (0.00,4.71e+90)	
									LF	
										VBSO

ranked in ascending order of functional improvement efficacy: ACAF, ACDF, ACCF, LP, LF, and LC.

Surgical duration

Twenty-seven studies involving 2,215 patients evaluated surgical duration across ten interventions: ACDF, ADF, ACCF, ACAF, PDIF, PDF, LC, LP, LF, and VBSO. Network meta-analysis demonstrated statistically significant differences in operative time: ACDF required significantly less time than ADF, ACCF, ACAF, PDIF, and LF; LP was significantly faster than ADF, ACAF, LF, and PDIF; LC required less time than PDIF; ACCF was faster than ADF, ACAF and PDIF; LF required less time than ADF and PDIF. All results are presented in Table 4 and Fig. 4H.

Figure 5H displays the probability distributions for operative time across surgical interventions. SUCRA analysis revealed the following efficiency hierarchy (lower percentages indicate shorter operative times): ACDF (6.1%), LP (17.8%), LC (32.1%), ACCF (41.5%), LF (44.0%), VBSO (50.8%), PDF (52.0%), ACAF (73.5%), ADF (85.3%), PDIF (96.9%). These results indicate ACDF had the highest probability of being the most time-efficient procedure, while PDIF was least likely to be time-efficient. The interventions were accordingly ranked in ascending order of operative time efficiency: ACDF, LP, LC, ACCF, LF, VBSO, PDF, ACAF, ADF, and PDIF.

Intraoperative blood loss

Twenty-seven studies involving 2,173 patients evaluated intraoperative blood loss across nine surgical interventions: ACDF, ADF, ACCF, ACAF, PDIF, PDF, LC, LP, and LF. Network meta-analysis demonstrated statistically significant differences in blood loss: PDIF was associated with significantly greater intraoperative blood loss compared to ACDF, ADF, ACCF, ACAF, LC, LP, and LF. No other comparisons reached statistical significance (Table 4 and Fig. 4I).

Figure 5I presents the probability distributions for intraoperative blood loss across surgical interventions. SUCRA analysis revealed the following haemostatic efficacy hierarchy (lower percentages indicate less blood loss): LC (14.3%), ACDF (30.0%), ACAF (30.7%), LP (40.6%), ACCF (45.9%), ADF (56.2%), PDF (60.3%), LF (74.4%), PDIF (97.6%). These results indicate LC had the highest probability of achieving optimal haemostasis, while PDIF was associated with the greatest blood loss. The interventions were accordingly ranked in ascending order of haemostatic efficacy: LC, ACDF, ACAF, LP, ACCF, ADF, PDF, LF, and PDIF.

Publication bias

To evaluate publication bias and small-study effects across all analyzed outcomes (JOA scores, JOA

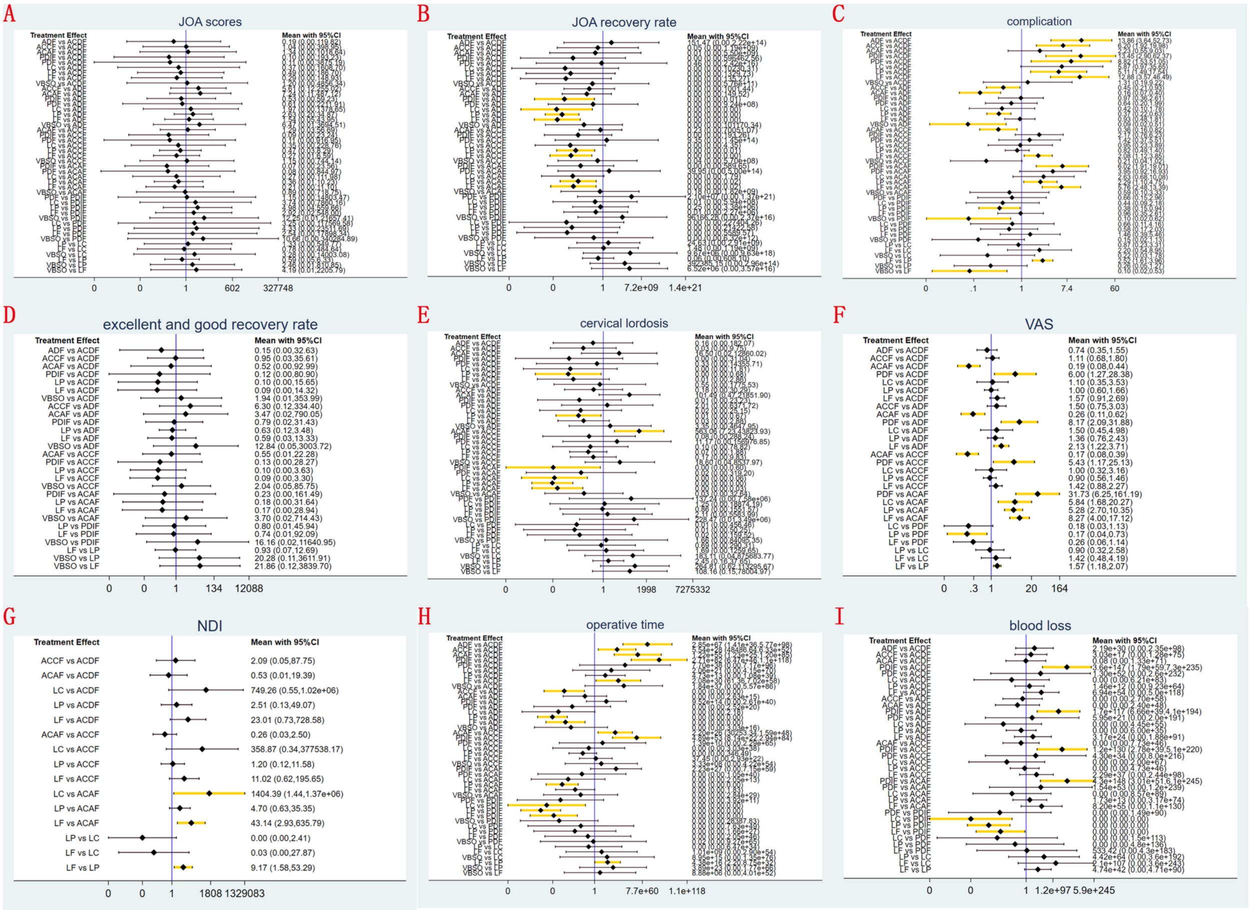


Fig. 4 Forest plots were generated for (**A**) the JOA scores, **B** the JOA improvement rates, **C** total complications, **D** excellent/good recovery rates, **E** cervical lordosis, **F** VAS, **G** NDI scores, **H** surgical duration and (**I**) intraoperative blood loss

improvement rates, total complications, excellent/good recovery rates, cervical lordosis, VAS, NDI scores, surgical duration and intraoperative blood loss), we generated adjusted funnel plots for the network meta-analysis. The symmetrical distribution of data points within the funnel plots and balanced dispersion on both sides indicate minimal publication bias. Furthermore, the near-horizontal orientation of the regression line relative to the x-axis suggests negligible small-study effects (Fig. 6).

Discussion

The optimal surgical approach for cervical OPLL remains controversial. While multiple studies have compared ACCF versus LP [13, 24, 25, 86] and LP versus LF [23, 37, 53], no consensus has been established. Previous network meta-analyses by Wang H et al. [87] and Li et al. [12] evaluating surgical interventions for cervical OPLL demonstrated that anterior approaches (particularly ACCF and anterior controllable antedisplacement and fusion [ACAF]) provide better Japanese Orthopaedic Association (JOA) scores and neurological improvement rates, though with higher complication rates compared to posterior procedures. Their evaluations included only 4 or 5 of the surgical procedures examined in this study and excluded newer alternatives such as VBSO, thereby limiting their clinical applicability. The current network meta-analysis advances beyond prior research by incorporating a broader range of surgical techniques, more detailed evaluation of surgical outcomes, and a larger sample size. To our knowledge, this represents the largest and most comprehensive systematic review comparing surgical interventions for cervical OPLL, encompassing ten distinct surgical techniques. We anticipate that our findings will enhance evidence-based clinical decision-making for optimal treatment strategies.

ACAF, a novel surgical technique for cervical OPLL, was first developed by the Shi Jiangang team at Shanghai Changzheng Hospital in 2017 [88] and has demonstrated particular efficacy in severe of cervical OPLL cases. The ACAF procedure involves the following

Fig. 5 The surface under the cumulative ranking curve (SUCRA) values were calculated for (**A**) the JOA scores, **B** the JOA improvement rates, **C** total complications, **D** excellent/good recovery rates, **E** cervical lordosis, **F** VAS, **G** NDI scores, **H** surgical duration and (**I**) intraoperative blood loss

steps: (1) exposing the superior and inferior target segments of the cervical spine, (2) partially resecting the anterior vertebral body edge, (3) performing a slotting osteotomy at one uncinated process, (4) inserting a screw bridge, (5) performing an osteotomy at the contralateral uncinated process, (6) circumferentially mobilizing the target vertebral body, and (7) tightening the screws to anteriorly translate and fix the ossified mass. This achieves both spinal cord decompression and restoration of the cervical spine's physiological curvature [32, 67, 78, 89, 90]. This study demonstrates that ACAF yields optimal postoperative outcomes, including the highest JOA scores, greatest cervical lordosis improvement, and most favourable VAS scores, along with the lowest NDI scores. Furthermore, ACAF shows superior JOA improvement rates, higher excellent/good recovery rates, fewer total complications, and reduced intraoperative blood loss compared to alternative techniques, though it requires longer operative times. These findings contrast with prior studies in several key aspects. For instance, Li et al.'s network meta-analysis identified ACCF as having the best postoperative JOA scores, highest excellent/good recovery rates, and shortest surgical duration—outcomes that were significantly better than those achieved with ACAF and other procedures, though ACAF demonstrated the greatest JOA improvement rates. Similar conclusions were reported by Wang H et al. However, Wang M et al. [26], in a direct comparative study of ACAF versus ACCF clinical outcomes, demonstrated that ACAF showed significant advantages in improving both JOA and NDI scores while also reducing complication rates findings consistent with our results. These discrepancies among studies may stem from inadequate sample sizes in previous investigations. This study proposes that ACAF represents the optimal surgical intervention for cervical OPLL, demonstrating comprehensive therapeutic benefits including: (1) significant improving in clinical functional scores, (2) restoration of cervical lordosis, (3) stabilization of cervical segments, (4) reconstruction of spinal canal volume, (5) effective decompression of spinal cord compression, (6) marked symptom relief,

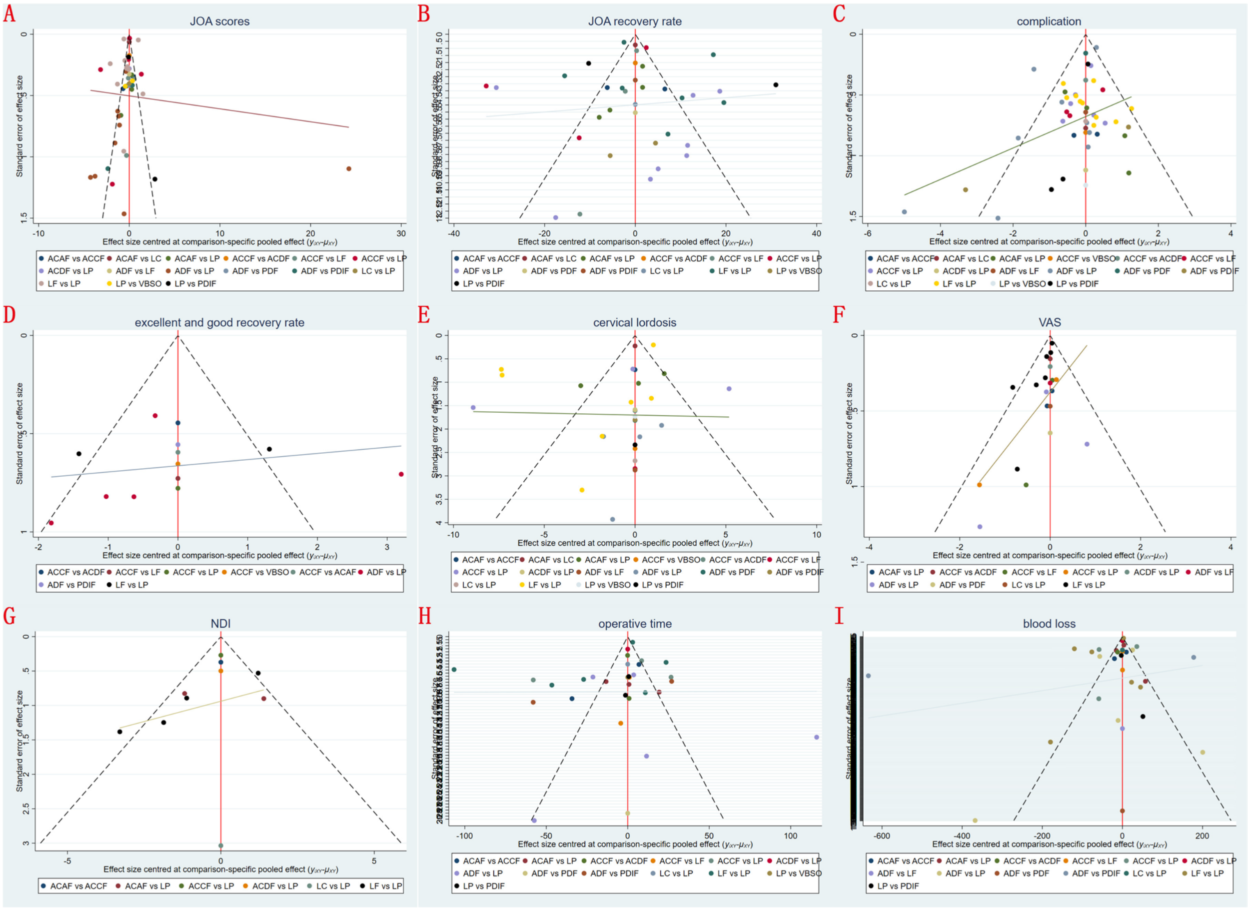


Fig. 6 Funnel plots were generated to assess potential publication bias for: **A** the JOA scores, **B** the JOA improvement rates, **C** total complications, **D** excellent/good recovery rates, **E** cervical lordosis, **F** VAS, **G** NDI scores, **H** surgical duration and **I** intraoperative blood loss

and (7) enhanced quality of life. From both technical and conceptual perspectives, ACAF provides superior outcomes compared to alternative approaches. The theoretical advantages of ACAF include: (1) Enhanced Safety Profile: The bilateral slotting osteotomies are performed near the uncinated processes, lateral to the spinal cord, which anatomically minimizes spinal cord injury risk. This approach avoids manipulation of dura-OPLL adhesions, significantly reducing both technical difficulty and complication rates. (2) Effective Decompression: Through anterior translation of the vertebral body with the ossified mass, ACAF simultaneously increases spinal canal volume and improves cervical lordosis (as measured by Cobb angle), achieving direct decompression of both the spinal cord and nerve roots [26]. (3) Broad Clinical Applicability: The technique is suitable for both continuous and mixed-type cervical OPLL, with minimal risk of postoperative cervical kyphosis or segmental instability. (4) Economic Advantage: Compared to combined surgical approaches, ACAF demonstrates superior cost-effectiveness for OPLL patients [32].

This study demonstrates that ACAF is associated with the lowest overall postoperative complication rate among surgical approaches, showing statistically significant differences compared to alternative techniques. The most frequent complications include: (1) postoperative dysphagia (most prevalent), (2) C5 nerve root palsy, and (3) cerebrospinal fluid leakage [26]. These findings align with existing literature, as Kong et al. reported a 9.5% complication rate following ACAF [20]. Furthermore, Chen et al. observed that ACAF carries an increased risk of postoperative dysphagia and hoarseness, primarily attributed to prevertebral soft tissue edema and potential superior laryngeal nerve injury—complications that may be reduced through meticulous surgical technique [32]. Sun et al. reported a C5 nerve root palsy incidence of merely 2.4% following ACAF [63], which represents a statistically significant reduction compared to the 8.3% range (3.2%—28.6%) observed with conventional cervical procedures

[1, 91–93]. Regarding cerebrospinal fluid leakage—a well-documented complication of anterior approaches [88] – ACAF demonstrates an occurrence rate of 3.6% to 5.9%, with no associated cases of spinal cord injuries reported in the literature [69, 89]. The ACAF technique conceptualizes the vertebral body and ossified mass as a integrated unit [88]. The procedure involves: (1) circumferential mobilization of the target vertebral segment, followed by (2) anterior elevation using a titanium plate-screw construct to achieve controlled anterior displacement of the ossified mass. This mechanical translation, combined with the adherent dura mater, generates a protective 'tent effect' that substantially decreases the risks of both intraspinal haemorrhage and dural tear [94]. The study by Wang H et al. [87] demonstrated significantly lower complication rates with ACAF compared to ACCF. The ACAF technique employs an 'in situ decompression' principle [95] that simultaneously: (1) relieves spinal cord compression and (2) achieves anterior translation of the vertebral body-ossified mass complex, thereby improving cervical lordosis. In contrast to posterior approaches such as LP and LC, ACAF prevents posterior the spinal cord drift, consequently reducing both C5 nerve root traction and the incidence of postoperative nerve root palsy. ACAF represents a safe and effective surgical intervention for cervical OPLL, demonstrating three key therapeutic benefits: (1) significant reduction of spinal canal stenosis, (2) restoration of cervical lordosis, and (3) marked improvement in neurological symptoms, collectively yielding favorable clinical outcomes. This technique establishes itself as a viable surgical option for OPLL management. As reported by Yan et al. [96], surgeons typically require approximately 29 ACAF procedures to achieve technical proficiency; following this learning curve, the standardized technique can be successfully applied to various cervical OPLL presentations. Therefore, during the initial ACAF learning phase, surgeons must: (1) rigorously adhere to established indications and contraindications, and (2) maintain heightened vigilance for potential complications.

Consistent with previous studies, our findings demonstrate that anterior surgical approaches—including ACAF, ACCF, ADF, and ACDF—generally yield superior postoperative functional outcomes compared to posterior procedures. While ACCF involves direct resection of both the vertebral body and ossified mass, ACAF achieves decompression through anterior translation of these structures, providing immediate relief for OPLL-induced cervical spinal stenosis [35, 69, 97]. Posterior surgeries approaches – encompassing LP, LC, LF, PDF, and PDIF—achieve indirect decompression through posterior spinal canal expansion. However, these techniques carry two significant limitations: (1) potential development of axial neck pain secondary to iatrogenic damage to posterior cervical musculature [98], and (2) risk of incomplete decompression due to anterior spinal cord tethering against residual OPLL masses [34]. Posterior surgical approaches carry inherent risks of destabilizing the cervical posterior column, potentially leading to complications such as cervical kyphosis. PDF, a posterior stabilization procedure based on LC, prioritizes spinal stability at the expense of motion (ROM) [40]. Long-term outcome studies consistently demonstrate superior clinical results with anterior approaches [52], making them the preferred choice for many surgeons [97]. Nevertheless, posterior techniques remain clinically relevant, offering distinct advantages including: (1) shorter operative duration for LP, (2) reduced intraoperative blood loss with [LC], and (3) lower overall complication rates. Additionally, LP preserves cervical ROM, maintaining functional mobility [99, 100].

This study has several key strengths. First, it incorporates a substantial dataset comprising 8,705 patients from 50 studies, spanning 10 surgical methods for cervical ossification of the OPLL, with extended follow-up durations. To our knowledge, this is the first large-scale network meta-analysis to comprehensively evaluate and compare multiple surgical treatments for OPLL. Second, we conducted a rigorous analysis of the clinical efficacy and complication rates across these surgical approaches, yielding clinically relevant conclusions. Third, strict adherence to PRISMA guidelines and the use of the ROBINS-I tool for quality assessment ensured satisfactory methodological quality among the included studies (Table 5). This approach enhanced the transparency and robustness of our network meta-analysis, strengthening the validity and reliability of the results. Fourth, inconsistency test analysis demonstrated that most outcomes were consistent with exceptions for: Total complications (e.g., ACCF ~ ACAF ~ LP); excellent/good recovery rates (e.g., ACCF ~ LP ~ LF_); VAS scores (e.g., ADF ~ LP ~ LF); and surgical duration (e.g., ACDF ~ ACCF ~ LP) (Fig. 3). Given the close relationship between heterogeneity and inconsistency in network meta-analysis, we consider the evidence from this study to be reliable.

This study has several limitations. First, most included studies were conducted in East Asian countries (e.g., Japan, China, and South Korea), which may restrict the generalizability of our findings due to unaccounted variations in ethnicity, genetics, environmental factors, and lifestyle. Second, cervical OPLL cases exhibit heterogeneity in morphology, lesion positioning, segmental length, spinal canal encroachment, and degree of dural ossification. Future studies should perform detailed subgroup analyses to address these variables. Third, while the overall study quality was satisfactory, the lack of RCTs

Table 5 Risk of bias of the included non-randomized controlled trials with the ROBINS-I checklist

Study	①	②	③	④	⑤	⑥	⑦
Chen T 2023 [36]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Chen Y 2011 [34]	Moderate risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Chen Y 2012 [35]	Low risk	Low risk	Low risk	Low risk	Low risk	Moderate risk	Low risk
Fujimori 2014 [38]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Ha 2019 [80]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Hou 2017 [39]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Inoue 2022 [45]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Kang 2019 [42]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Kim 2015 [41]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Koda 2016 [40]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Kong 2021 [21]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Lee DH 2019 [81]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Lee DH 2021 [44]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Lee DH 2022 [46]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Lee JJ 2021 [49]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Lee SH 2008 [47]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Li JH 2024 [51]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Li YC 2022 [50]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Lin 2012 [48]	Moderate risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Liu HC 2013 [52]	Low risk	Low risk	Low risk	Low risk	Serious risk	Moderate risk	Moderate risk
Liu JW 2023 [56]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Liu T 2024 [57]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Liu XW 2017 [53]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Iwasaki 2007 [82]	Moderate risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Ma 2024 [58]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Masaki 2007 [55]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Moon 2019 [60]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Morishita 2019 [61]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Nakano 1988 [59]	Moderate risk	Low risk	Low risk	Low risk	Moderate risk	Low risk	Low risk
Nakashima 2022 [22]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Noh 2020 [62]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Ota 2016 [66]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Park 2021 [68]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Sakai 2012 [65]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Sun 2019 [83]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Sun 2019 [84]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Tani 2022 [64]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Wang 2024 [71]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Xu 2019 [85]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Yang 2018 [69]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Yoo 2017 [73]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Yoshii 2016 [72]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Yoshii 2020 [74]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Yoshii 2021 [75]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Yoshii 2022 [76]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Yuan 2015 [77]	Low risk	Low risk	Low risk	Low risk	Serious risk	Moderate risk	Moderate risk
Zhang B 2019 [78]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Zhang Q 2023 [79]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk

①Confounding bias; ②Selection bias; ③Bias in measurement classification of interventions; ④Bias due to deviationsfrom intended interventions; ⑤Bias due to missing data; ⑥Bias in measurement of outcomes; ⑦Bias in selection of the reported result may reduce the reliability of our evidence. We strongly recommend future high-quality RCTs to validate these findings. Fourth, the included studies did not evaluate the positional relationship between the K-line and OPLL. The extent of ossification relative to the K-line (whether reaching or surpassing it) is a critical determinant in surgical decision-making and should be incorporated in future analyses. Although some surgical procedures have technical overlap, separate analysis can reveal subtle differences. Future studies could further validate their commonalities through subclass grouping (e.g., anterior 'vertebral translation techniques').

Conclusions

This studies demonstrate that ACAF significantly improves JOA scores and cervical lordosis while reducing VAS and NDI scores. Additionally, it achieves higher postoperative JOA improvement rates and excellent/good recovery rates, with fewer total complications and reduced intraoperative blood loss. Based on these findings, ACAF can be one of the preferred options for clinicians treating cervical OPLL, but it requires high surgical experience and strict indication selection. Additionally, the surgical team need to develop the best surgical plan based on imaging features and patient functional needs. However, Future large-scale, multicentre randomized controlled trials with diverse demographic representation are necessary to validate the efficacy and safety outcomes of this study and ensure broader applicability of these results.

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Authors' contributions

Conceptualization: XC, YH-F. Data curation: XC, YH-F. Formal analysis: XC, YH-F. Funding acquisition: XC, YH-F. Investigation: XC, YH-F, JC, HL-T. Methodology: XC. Project administration: XC, YH-F, JC, HL-T. Resources: XC, YH-F, JC, HL-T. Software: XC. Supervision: XC, YH-F, JC, HL-T. Validation: XC, YH-F, JC, HL-T. Visualization: XC, YH-F, JC, HL-T. Writing – original draft: XC. Writing – review & editing: XC.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Competing interests

The authors declare no competing interests.

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of the Campbell Collaboration which produces systematic reviews and co-convenor of the Campbell and Cochrane equity methods group. DM is chair of the EQUATOR Network, IB is adjunct director of the French EQUATOR Centre and TCH is co-director of the Australasian EQUATOR Centre, which advocate for the use of reporting guidelines to improve the quality of reporting in research articles. JMT received salary from Evidence Partners Inc, creators of DistillerSR software for systematic reviews; Evidence Partners Inc was not involved in the design or outcomes of the statement and the views expressed solely represent those of the author.

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