

Insights into posterior cervical biportal endoscopic spine surgery outcomes in radiculopathy: a systematic review and meta-analysis

Bryan Gervais de Liyis¹, Stevanus Christian Surya², Sulaiman Liyis³, Tjokorda Istri Putri Mahadewi², Amal Rizky¹, Yunus Kuntawi Aji¹, Fadhil Panyalai¹, Tjokorda Gde Bagus Mahadewa⁴

¹Department of Neurosurgery, National Brain Center Hospital Mahar Mardjono, Jakarta, Indonesia

²Faculty of Medicine, Universitas Udayana, Denpasar, Indonesia

³Faculty of Medicine, Universitas Trisakti, Jakarta, Indonesia

⁴Department of Neurosurgery, Universitas Udayana, Prof. I.G.N.G Ngoerah General Hospital, Denpasar, Indonesia

Received Jul 4, 2025; Revised Sep 21, 2025; Accepted Oct 9, 2025

Corresponding author: Bryan Gervais de Liyis

Department of Neurosurgery, National Brain Center Hospital Mahar Mardjono, MT Haryono St No.Kav.11, Cawang, Kramat Jati, East Jakarta City, Jakarta 13630, Indonesia

Tel: +62-89666000898, **E-mail:** bgliyis@gmail.com

Background: Posterior cervical biportal endoscopic spine surgery (PCBESS), which enables selective decompression through two ipsilateral portals, has emerged as a minimally invasive option for treating cervical radiculopathy secondary to foraminal stenosis and/or disc herniation. This study aimed to assess the efficacy and safety of PCBESS in cervical radiculopathy.

Methods: A systematic search of the ScienceDirect, PubMed, Google Scholar, and Cochrane databases was conducted to identify longitudinal studies published up to September 2025. Data on patient demographics, perioperative clinical parameters, and complication rates were extracted. Meta-analyses were performed using random-effects models in STATA software.

Results: Fourteen studies comprising 712 patients (62.5% male; mean age, 54.78±1.7 years) were included. The mean operative time was 85.88±32.46 minutes, mean blood loss was 84.89±27.81 mL, and mean hospital stay was 4.45±1.33 days. The overall surgical success rate was 91%±7% (MacNab “excellent–good”), with a 3%±2% reoperation rate. Significant improvements were observed in Visual Analog Scale (VAS) pain scores (mean differences [MD], -4.77; 95% confidence intervals [CI], -6.07 to -3.47; $p<0.001$), Neck Disability Index scores (MD, -27.07; 95% CI, -32.83 to -21.30; $p<0.001$), and segmental range of motion (MD, 0.55; 95% CI, 0.27–0.84; $p<0.001$). The overall complication rate was 7%±3%, most commonly dural tears, epidural hematomas, and transient paralysis. Multi-level PCBESS exhibited a higher complication rate than single-level PCBESS (18%±10% vs. 4%±2%, $p<0.001$). Outcomes were comparable to those of uniportal endoscopic surgery.

Conclusions: PCBESS is a safe and effective treatment option for cervical radiculopathy, offering significant pain and functional improvement, low reoperation and complication rates, and outcomes comparable to uniportal endoscopic surgery.

Keywords: Biportal endoscopic spine surgery; Cervical vertebrae; Decompression; Minimally invasive surgery; Radiculopathy

Introduction

Cervical radiculopathy, often presenting as radiating arm pain, is typically caused by cervical foraminal stenosis or a herniated cervical disc [1]. Anterior cervical discectomy and fusion (ACDF) has long been regarded as the gold-standard surgical treatment for these conditions [2]. However, ACDF is associated with several drawbacks, including the risk of instrumentation failure, loss of motion at the fused level, adjacent-segment degeneration (ASD), and approach-related complications [3-5]. To circumvent fusion-related issues, posterior cervical foraminotomy (PCF) offers a motion-preserving alternative that directly decompresses the affected nerve root [6,7]. However, conventional PCF required extensive posterior muscle dissection, which may lead to acute blood loss, surgical site infection, C5 palsy, incidental durotomy, ASD, junctional kyphosis, and pseudoarthrosis [8]. To minimize such tissue trauma, percutaneous full-endoscopic PCF (FE-PCF) was developed as a minimally invasive alternative, though this uniportal technique presents a steep learning curve and necessitates specialized instruments [3,9]. More recently, a biportal endoscopic approach has been introduced in cervical spine surgery, offering an endoscopic view comparable to open surgery while allowing the use of standard spinal instruments [10]. This technique, referred to as the posterior cervical biportal endoscopic spine surgery (PCBESS), has its origins in lumbar procedures [11,12] and has now been adapted for posterior cervical foraminotomy to treat cervical radiculopathy. Early studies suggest that PCBESS effectively relieves cervical radicular pain and improves function, with low complication rates [13,14].

Despite these encouraging findings, the overall evidence supporting PCBESS for cervical radiculopathy remains limited. This systematic review and meta-analysis were therefore conducted to comprehensively evaluate its safety and efficacy for cervical radiculopathy. The insights from this study may contribute to the ongoing advancement of minimally invasive spinal techniques and improve surgical outcomes for patients with cervical radiculopathy.

Methods

Study design and inclusion criteria

This meta-analysis was conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The study pro-

tol was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO) before the systematic literature search. We focused on cohort studies reporting outcomes of PCBESS for radiculopathy. Eligible articles met all of the following criteria: (1) patients with radiologically diagnosed radiculopathy presenting with foraminal stenosis and/or disc herniation; (2) studies in which PCBESS was the primary intervention or was compared with other established approaches (e.g., traditional open surgery, posterior approaches, or conservative management); and (3) adult patients aged ≥ 18 years. Identified records were screened by titles and abstracts and subsequently assessed for eligibility. Exclusion criteria were studies of cervical spine conditions unrelated to radiculopathy, prior cervical spine surgery, individual case reports, reviews, conference abstracts, letters, and editorials. Studies reporting insufficient data for analysis were also excluded. A detailed list of inclusion and exclusion criteria and the full search strategy are provided in Tables 1 and 2.

Literature search and selection

A systematic literature search was conducted across four electronic databases (ScienceDirect, PubMed, Google Scholar, and Cochrane) from database inception to August 31, 2024, with no restrictions on publication year. The search approach involved the use of Medical Subject Headings terms and relevant synonyms. Duplicate and ineligible records were removed using Mendeley Desktop ver. 1.19.6 (<https://www.mendeley.com/>). Titles and abstracts were subsequently screened against predefined criteria according to the PRISMA flowchart using Microsoft Excel 2011 (Microsoft Corp., Redmond, WA, USA). The reference lists of included studies were manually screened to identify additional studies. The literature search and study selection were conducted collaboratively by four investigators. Any disagreements were resolved through consensus, with a fifth independent reviewer adjudicating unresolved conflicts.

Quality assessment of included studies

The risk of bias for each study was assessed using the Risk of Bias in Non-Randomized Studies of Interventions (ROBINS-I) tool (Cochrane, London, UK). This tool evaluates seven domains: confounding, participant selection, intervention classification, deviations from intended interventions, missing data, outcome mea-

Table 1. PICO framework and eligibility criteria

PICOS	Inclusion criteria	Exclusion criteria
Population (P)	Adult patients (≥18 years) with radiological-diagnosed radiculopathy due to foraminal stenosis and/or disc herniation	Pediatric population, other cervical spine pathologies unrelated to radiculopathy, patients with prior history of cervical spine surgery
Intervention (I)	Posterior cervical biportal endoscopic spine surgery	-
Comparison (C)	Uniportal endoscopic surgery/none	-
Outcome (O)	Perioperative outcomes: operative time, estimated intraoperative blood loss, hospitalization time, reoperation rate, and successful surgical rate Clinical outcomes: complications, reoccurrence rate, VAS, MacNab criteria, NDI Spinal-specific outcomes: CRP and CPK levels, segmental ROM, and Cobb's angle	-
Study design (S)	Longitudinal study	Unavailable full-text article Uncompleted article

VAS, Visual Analog Scale; NDI, Neck Disability Index; CRP, C-reactive protein; CPK, creatine phosphokinase; ROM, range of motion.

Table 2. Full search strategy

Search strategy	
Databases	Science Direct, PubMed, Google Scholar, and Cochrane
Keywords	("cervical radiculopathy" OR "stenosis" OR "herniation") AND ("laminectomy" OR "laminoplasty" OR "foraminotomy" OR "discectomy") AND ("biportal") AND ("endoscopy" OR "endoscopic") AND ("posterior")

surement, and selective reporting. A study was deemed to have a low risk of bias if none of these domains raised concerns. Assessments were performed independently by at least two reviewers. Discrepancies were resolved by discussion; if consensus was not reached, a third reviewer provided final adjudication.

Data extraction

We included study location, sample size, mean age, number of male participants, body mass index, type of surgical interventions, pathology included (disc herniation, spinal stenosis, or both), affected disc levels, operation time, estimated blood loss, follow-up duration, and number and type of complications.

The research endpoints were predicated on perioperative, clinical, and spinal-specific domains. Perioperative outcomes included operative time, estimated intraoperative blood loss, length of hospital stay, reoperation rate, and surgical success rate. Clinical outcomes included complication rate, recurrence rate, Visual Analog Scale (VAS) scores, MacNab criteria, and functional measures such as the Neck Disability Index (NDI). Spinal-specific outcomes included pre- and postoperative levels of C-reactive protein (CRP) and creatine phosphokinase (CPK), segmental range of motion, and Cobb angle. To compare PCBESS and uniportal endoscopic techniques, we extracted data on surgical success rate, operative time, VAS scores, NDI,

incidence of complications, and reintervention rate.

Data synthesis and analysis

Continuous variables were pooled as mean differences (MD) with corresponding 95% confidence intervals (CI); categorical variables were pooled as odds ratios (OR) or proportions with 95% CI. A random-effects model with restricted maximum likelihood estimation was used to account for between-study variability. Heterogeneity was quantified using the I^2 statistic and classified as low (<25%), moderate (25%–50%), or high (>50%). Forest plots were generated for each outcome to display pooled estimates and corresponding heterogeneity measures. For outcomes with high heterogeneity, subgroup analyses were performed (for example, by level of disc involvement, type of spinal disorder, or extent of decompression) to explore potential sources of heterogeneity. All statistical tests were two-tailed, and significance was set at $p < 0.05$.

Certainty of evidence assessment

Certainty of evidence was evaluated using the GRADE framework (Grading of Recommendations, Assessment, Development, and Evaluations) across five domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias, classifying overall certainty as high, moderate, low, or very low [15]. Unlike the conventional approach that assigns observational studies a low initial rating, we applied the ROBINS-I-adapted approach wherein observational evidence was considered from a high initial certainty level when randomized trials were not feasible, with downgrading applied as indicated by the GRADE domain [16].

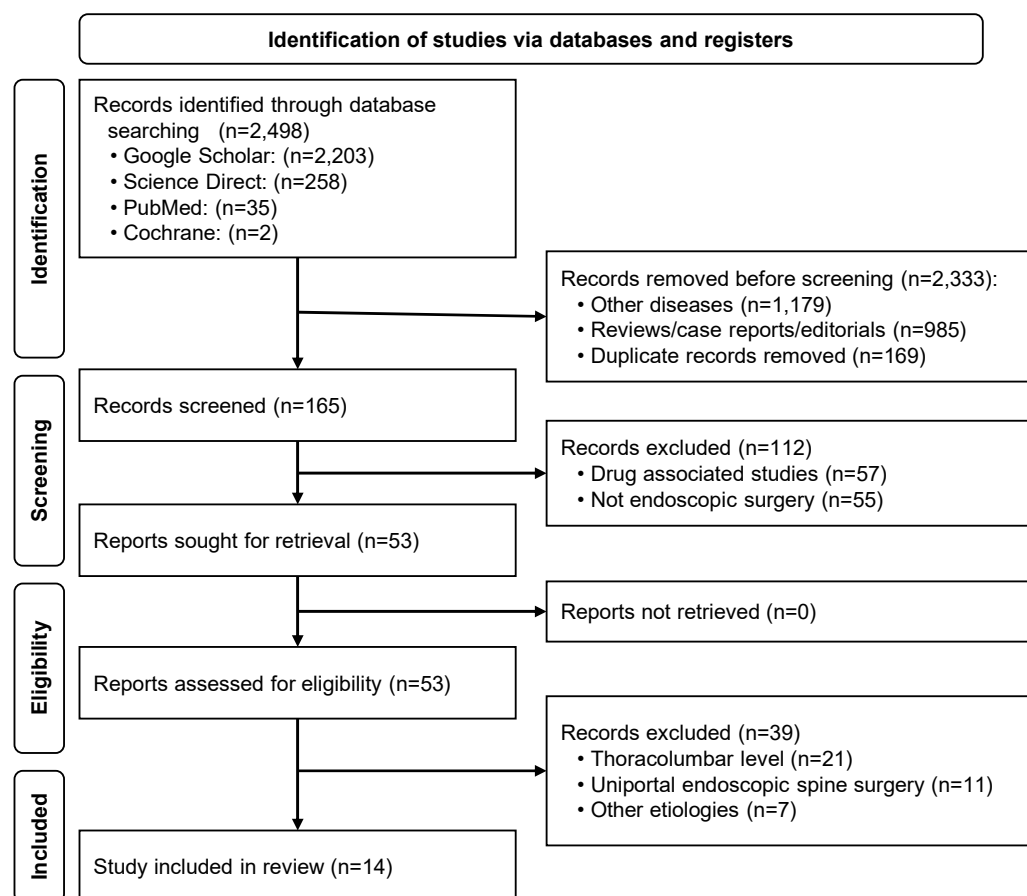


Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart.

Results

Study selection and identification

The initial database search yielded 2,498 records. Prior to the screening phase, 2,333 records were excluded. Title and abstract screening led to the exclusion of an additional 112 articles. A total of 53 full-text articles were retrieved for detailed evaluation. Following a full-text eligibility assessment, 14 studies met all inclusion criteria and were included in the final quantitative and qualitative synthesis. The study selection process is illustrated in the PRISMA flow diagram (Fig. 1).

Baseline characteristics and quality assessment of included studies

A total of 14 retrospective studies [10,13,14,17-27,] encompassing 712 patients with cervical radiculopathy were included in the meta-analysis. The underlying etiologies were predominantly foraminal stenosis and/or cervical disc herniation, treated with PCBESS (Table 3). Among the pooled cohort, 62.5 % of participants

were male, and the mean age was 54.78 ± 1.7 years. All included studies were conducted in Australia, China, or South Korea. Three studies evaluated multilevel disc involvement, whereas the remaining studies focused on single-level disease. Most studies described a combined foraminotomy and discectomy technique as the principal surgical procedure. The mean follow-up duration across studies was 15.6 months (range, 6–26.5 months).

All included studies were non-randomized and assessed for methodological quality using the ROBINS-I tool (Fig. 2). Moderate risk of bias was frequently identified in the domains of confounding, missing data, outcome measurement, and selective reporting. One study exhibited a high risk of bias in the participant selection domain, leading to an overall serious risk classification for that study.

Postoperative complications

Postoperative complications are summarized in Table 4. Seventeen patients experienced neurological complications, with temporary paralysis occurring in 47.1% of these cases. This notable proportion highlights the im-

Table 3. Characteristics of included studies

Author (year)	Location	Total patients	Male (%)	Age (yr)	Conditions	Level of disc involvement	Type of surgery	Follow-up (mo)
Akbari et al. [25] (2024)	Australia	20	15 (75)	56.7±10.2	Stenosis and disc herniation	Single	Foraminotomy with or without discectomy	8.4±1.8
Heo et al. [17] (2023)	Korea	12	10 (83.33)	57.8±6.7	Stenosis and disc herniation	Multiple	Foraminotomy with or without discectomy	13.6±1.9
Jung and Kim [10] (2022)	Korea	109	84 (77.06)	54.5±9.2	Disc herniation	Single	Foraminotomy and discectomy	6
Jung et al. [18] (2024)	Korea	162	113 (69.75)	54±10.39	Disc herniation	Single	Foraminotomy and discectomy	12
Kang et al. [19] (2022)	Korea	33	11 (33.33)	52.68±9.56	Stenosis and disc herniation	Single	Foraminotomy with or without discectomy	12
Kang et al. [20] (2023)	Korea	49	36 (73.47)	52.68±9.56	Stenosis and disc herniation	Single	Foraminotomy with or without discectomy	12
Kim et al. [24] (2022)	Korea	30	21 (70)	52.3±12	Stenosis	Single	Foraminotomy only	11.7±6.4
Lee et al. [26] (2025)	Korea	30	21 (70)	57.4±8.7	Stenosis and disc herniation	Multiple	Foraminotomy with or without discectomy	12
Park et al. [13] (2017)	Korea	13	5 (38.46)	47.10±6.66	Disc herniation	Single	Foraminotomy and discectomy	14.8±2.1
Park et al. [21] (2023)	Korea	45	31 (68.89)	57.7±10.5	Disc herniation	Multiple	Foraminotomy with or without discectomy	25.5±15.1
Song and Lee [14] (2020)	Korea	7	3 (42.86)	59±12.10	Stenosis and disc herniation	Multiple	Inclinary foraminotomy with or without discectomy	6.42±2.99
Song and Kim [27] (2025)	Korea	101	46 (45.55)	56.99±9.14	Stenosis	Multiple	Inclinary foraminotomy	17.3±4.1
Wang et al. [22] (2023)	China	89	42 (47.19)	58.28±11.94	Stenosis and disc herniation	Single	Foraminotomy and discectomy	26.48±2.22
Zhang et al. [23] (2023)	China	12	7 (58.33)	50.20±9.50	Disc herniation	Single	Foraminotomy and discectomy	16.8±1.8

Values are presented as number, number (%), or mean±standard deviation.

portance of meticulous surgical technique to minimize nerve irritation during decompression. Incomplete decompression was the next most frequent neurological event, reported in 35.3% of cases. Nineteen cases of mechanical, soft tissue, and miscellaneous complications were also identified. Among these, dural tears and epidural hematomas were the most common, occurring in 47.4% and 42.1% of cases, respectively. The overall pooled complication rate was 7% (95% CI, 4%–14%), indicating a relatively low incidence of adverse events (Fig. 3A). The certainty of evidence for this outcome was judged to be very low, primarily due to inclusion of studies with a high risk of bias, substantial heterogeneity, and wide CIs across the GRADE domains (Table 5).

Clinical outcomes

Clinical outcomes following PCBESS were favorable (Fig. 3). The pooled recurrence rate was low (effect size, 0.05; 95% CI, 0.02–0.09). Pain intensity, measured using the VAS, showed a significant reduction (MD, −4.77; 95% CI, −6.07 to −3.47) (Fig. 3C), and function-

Table 4. Reported postoperative complications (n=36)

Complications	Prevalence %
Neurological complications (n=17)	
Transient paralysis	47.06
Incomplete decompression	35.30
Nerve root palsy	5.88
Transient hypesthesia	5.88
Persistent dysesthesia	5.88
Mechanic, soft tissue, and other complications (n=19)	
Dural tear	47.37
Epidural hematoma	42.11
Muscle soreness	5.26
Bullae of chin	5.26

al improvement was reflected by a marked decrease in NDI score (MD, −27.07; 95% CI, −32.83 to −21.30) (Fig. 3D). According to MacNab criteria (Fig. 3E), 53% of patients (95% CI, 34%–83%) achieved “excellent” and 31% (95% CI, 15%–64%) achieved “good” outcomes. The heterogeneity of these measures ranged from moderate to high. The certainty of evidence varied across

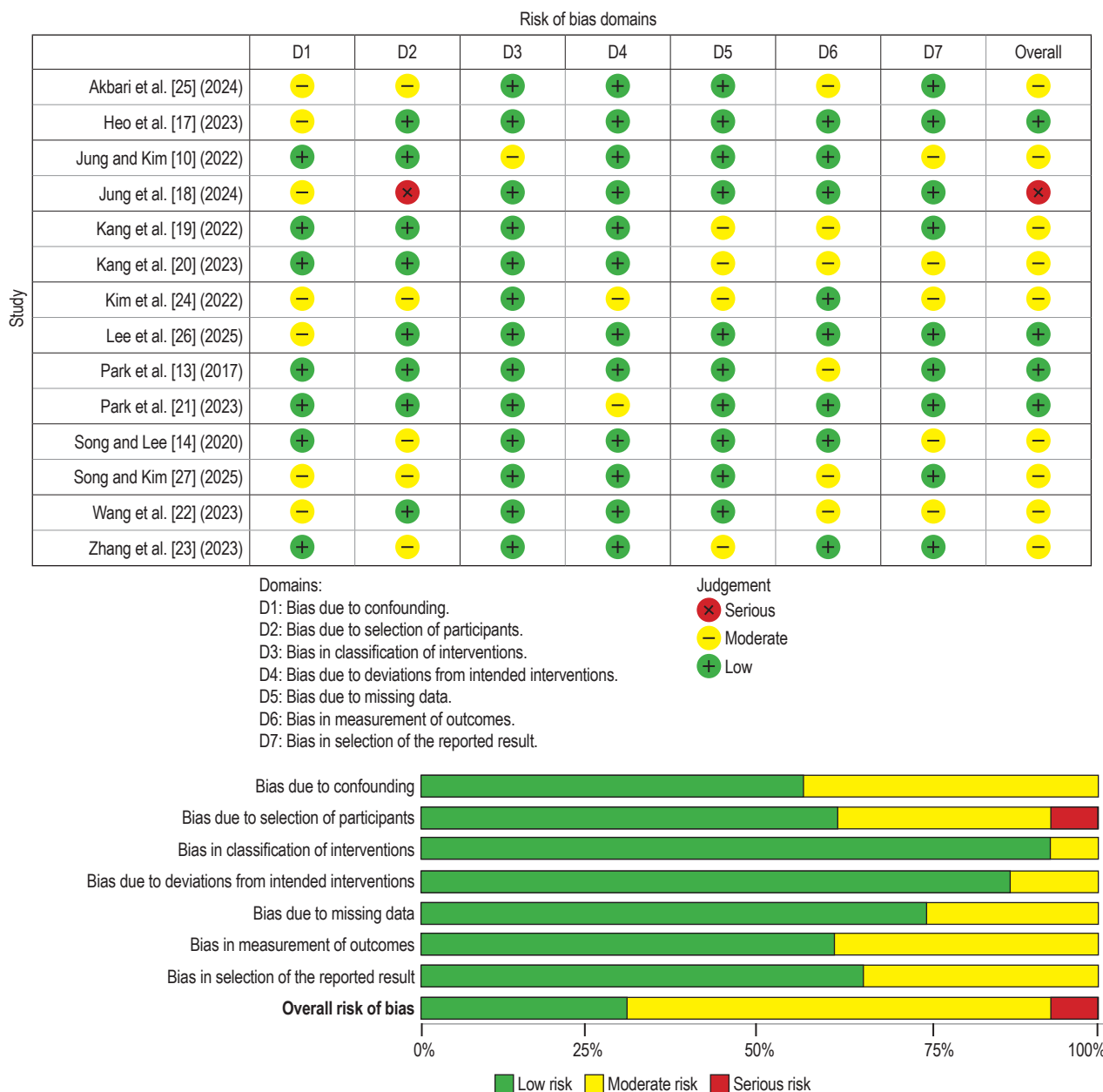


Fig. 2. ROBINS-I assessment of included studies.

outcomes (Table 5). Both VAS and NDI improvements were initially graded as very low due to the serious risk of bias, high heterogeneity, and wide CIs, but were upgraded to low certainty because of large effect sizes. The recurrence rate was supported by high-certainty evidence, as no serious limitations were identified. Certainty for the MacNab “fair” category was moderate owing to the wide CI.

Perioperative results

Perioperative outcomes of PCBESS, including operative efficiency and recovery parameters, are presented in

Fig. 4. The mean operative time was 84.89 minutes (95% CI, 57.08–112.70), and the mean intraoperative blood loss was 64.07 mL (95% CI, 47.69–80.45), consistent with minimally invasive surgical characteristics. The average hospital stay was 4.45 days (95% CI, 3.12–5.78). The pooled reoperation rate was low (3%; 95% CI, 1%–6%), while the surgical success rate was high (91%; 95% CI, 85%–98%; $p=0.00$). Considerable heterogeneity was observed across most perioperative parameters. The overall certainty of evidence for perioperative outcomes was predominantly low (Table 5). Operative time, estimated blood loss, and hospitalization duration were rated as very low certainty due to serious risk of bias,

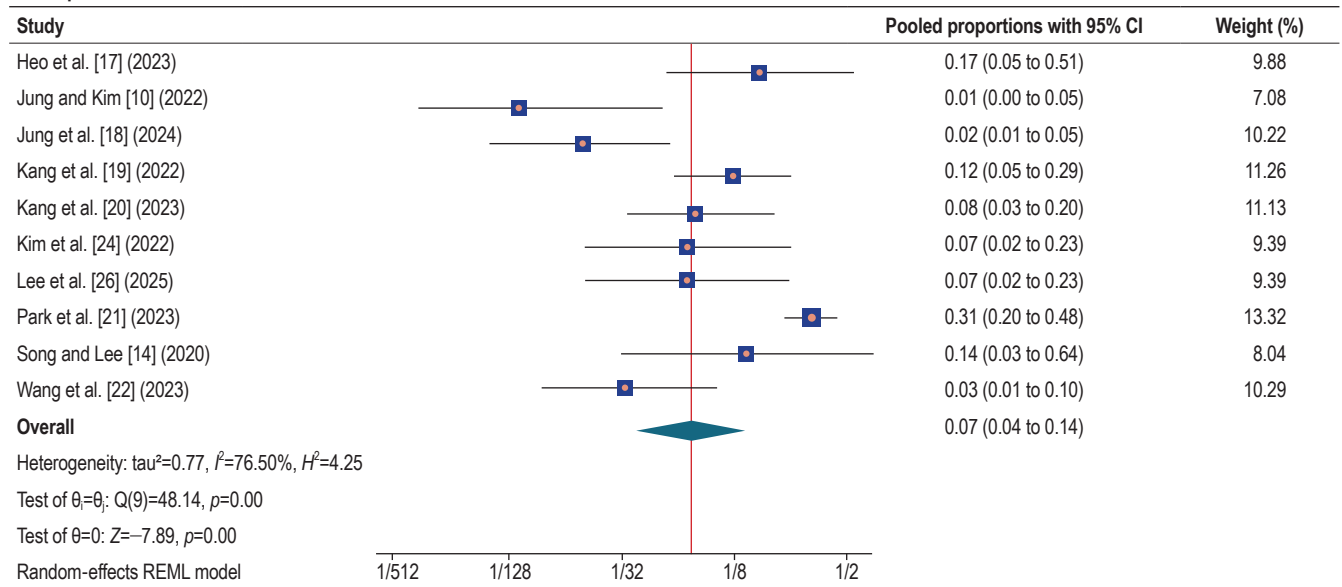
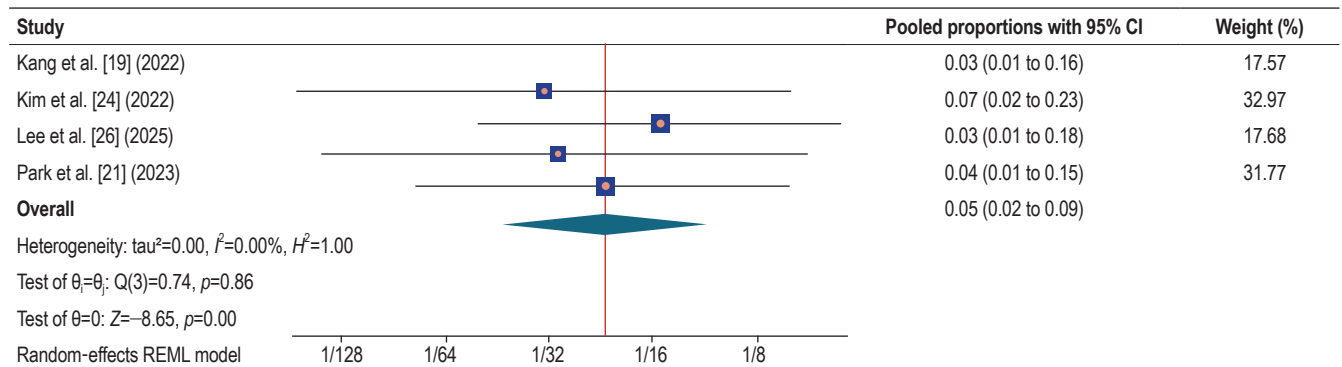
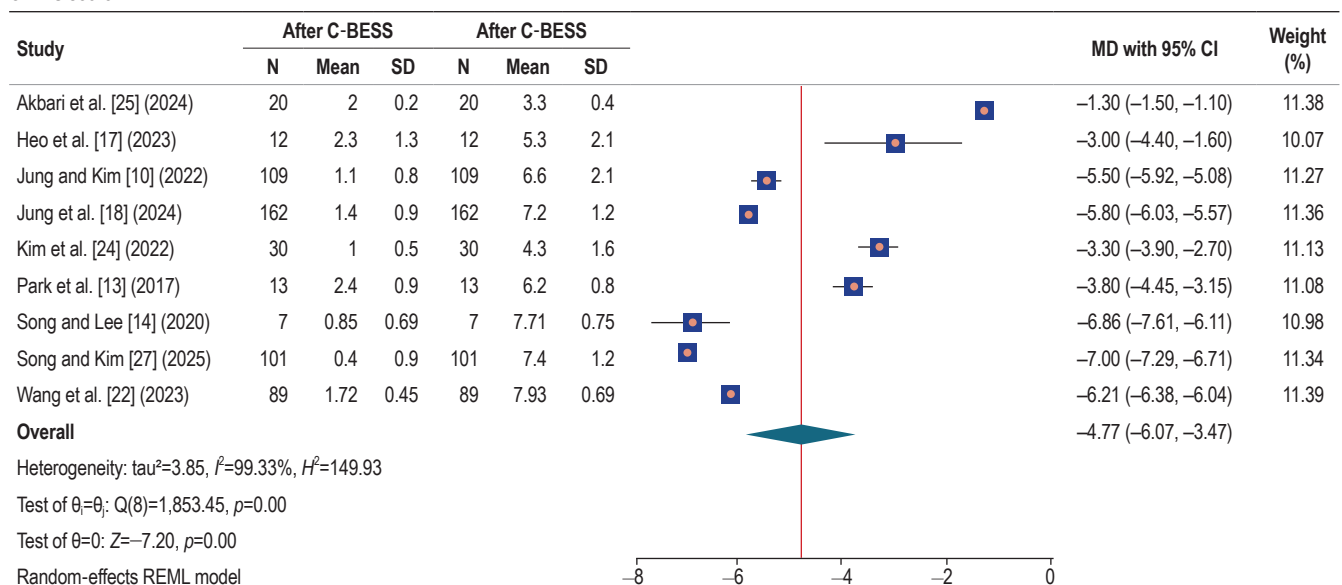
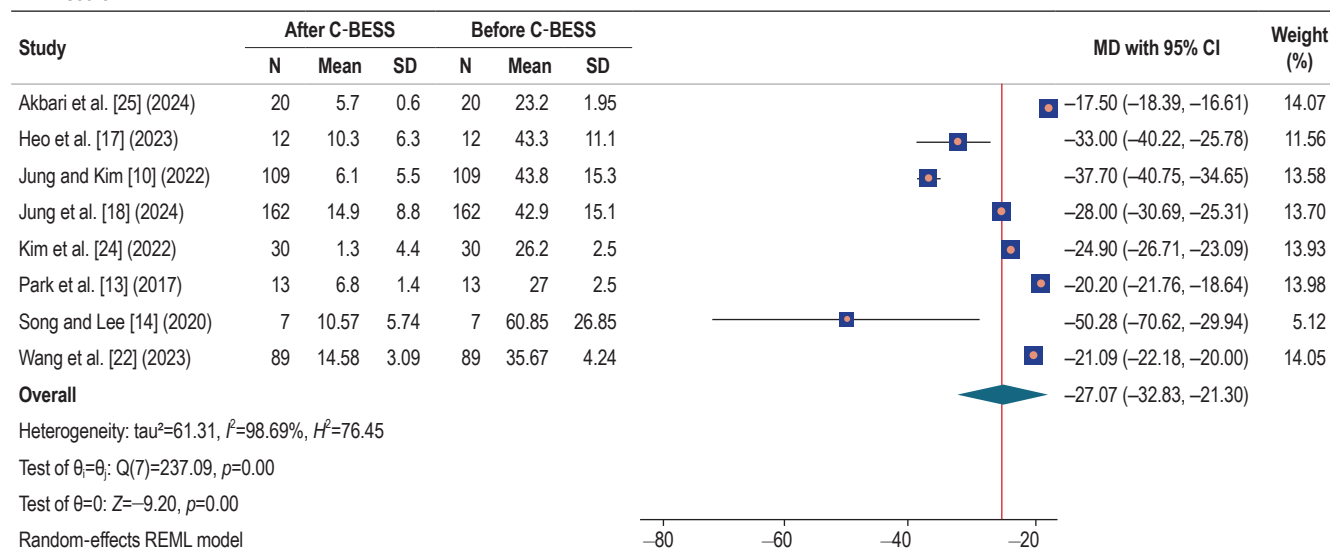
A. Complication**B. Reoccurrence rate****C. VAS score**

Fig. 3. Forest plot of clinical outcomes. (A) Complications, (B) reoccurrence rate, (C) Visual Analog Scale (VAS) score, (D) Neck Disability Index (NDI) score, and (E) MacNab criteria. CI, confidence interval; REML, restricted maximum likelihood; C-BESS, cervical biportal endoscopic spine surgery; SD, standard deviation; MD, mean difference. (Continued on the next page.)

D. NDI score



E. MacNab criteria

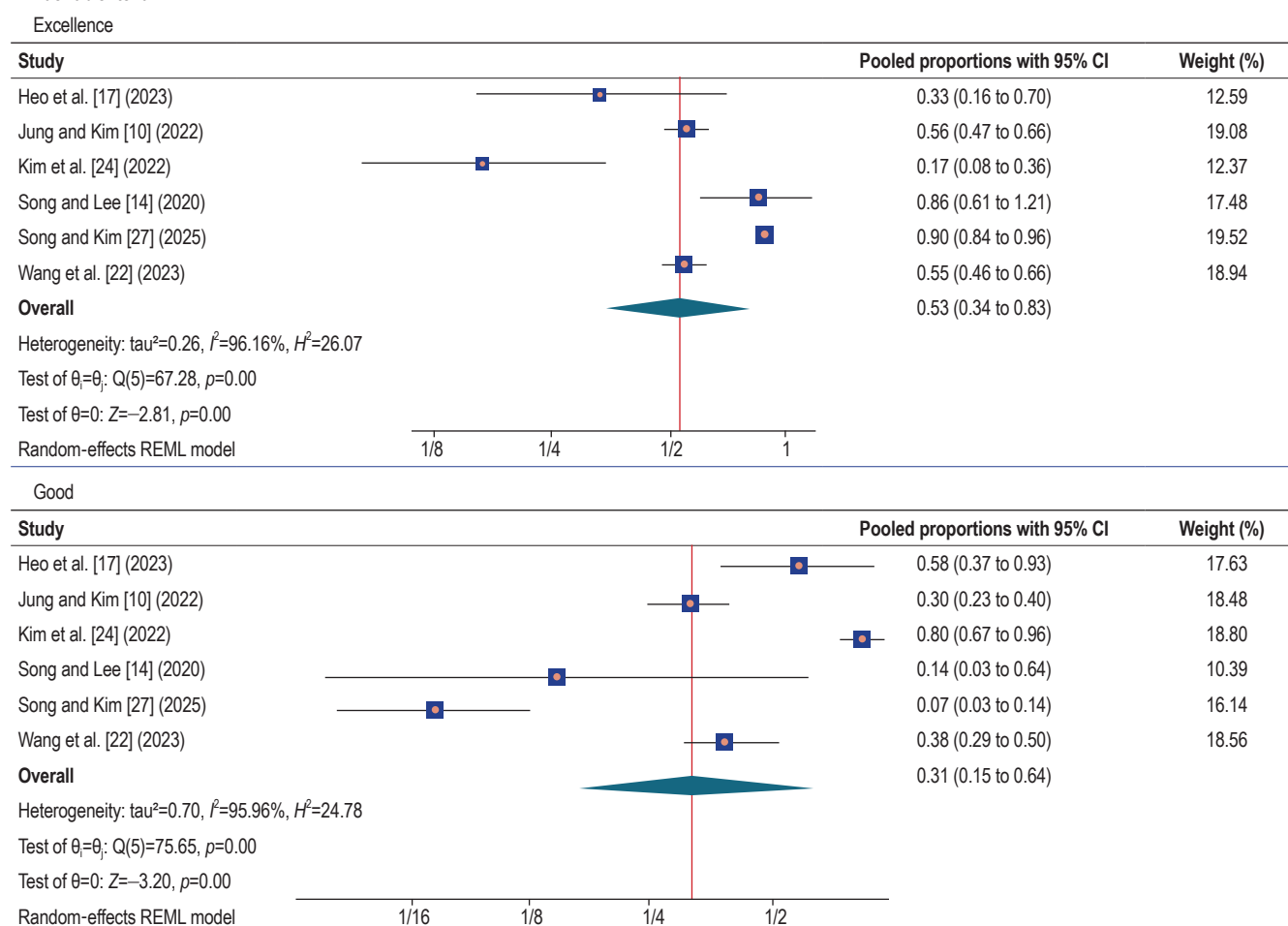


Fig. 3. (Continued; caption shown on previous page).

high heterogeneity, and wide CIs. The reoperation rate achieved moderate certainty after upgrading for a large effect size, while surgical success was upgraded from very low to low certainty for the same reason.

Spinal-specific outcomes

Spinal outcomes following PCBESS demonstrated favorable changes in inflammatory markers and spinal

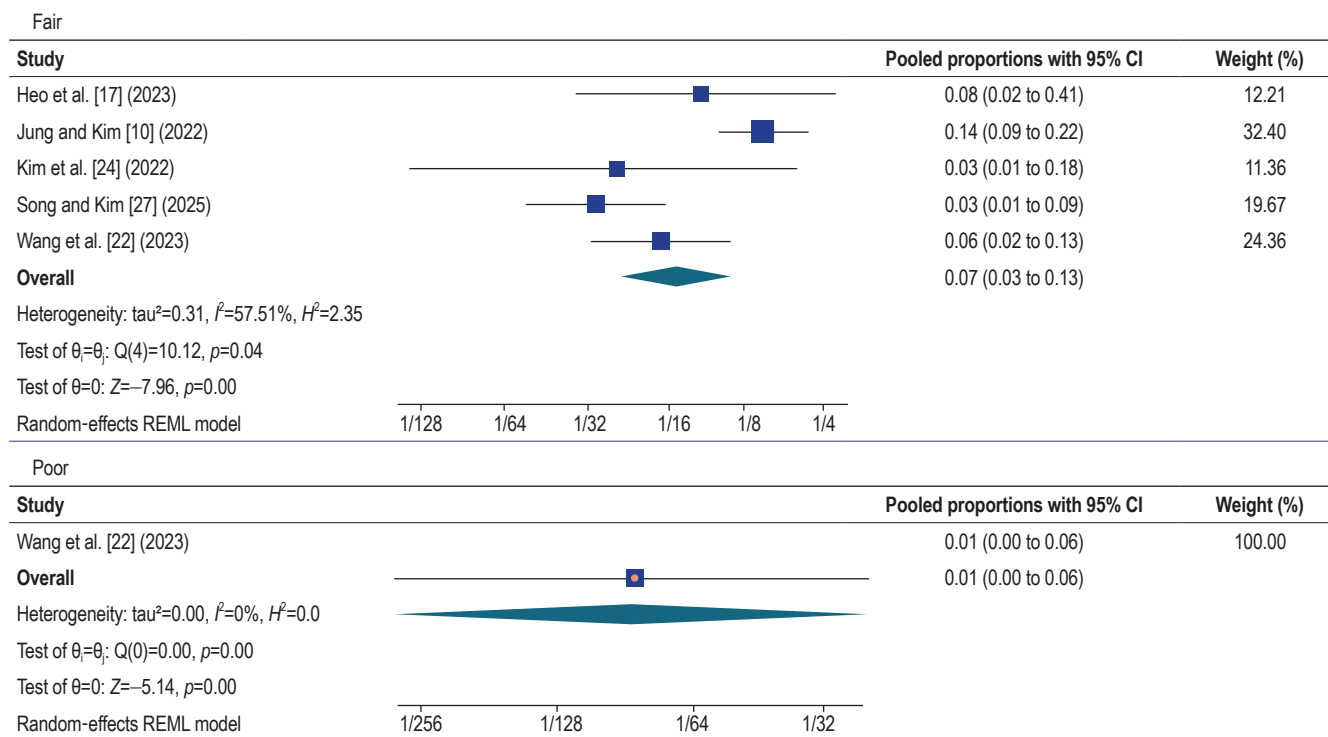


Fig. 3. (Continued; caption shown on previous page).

A. Operative time

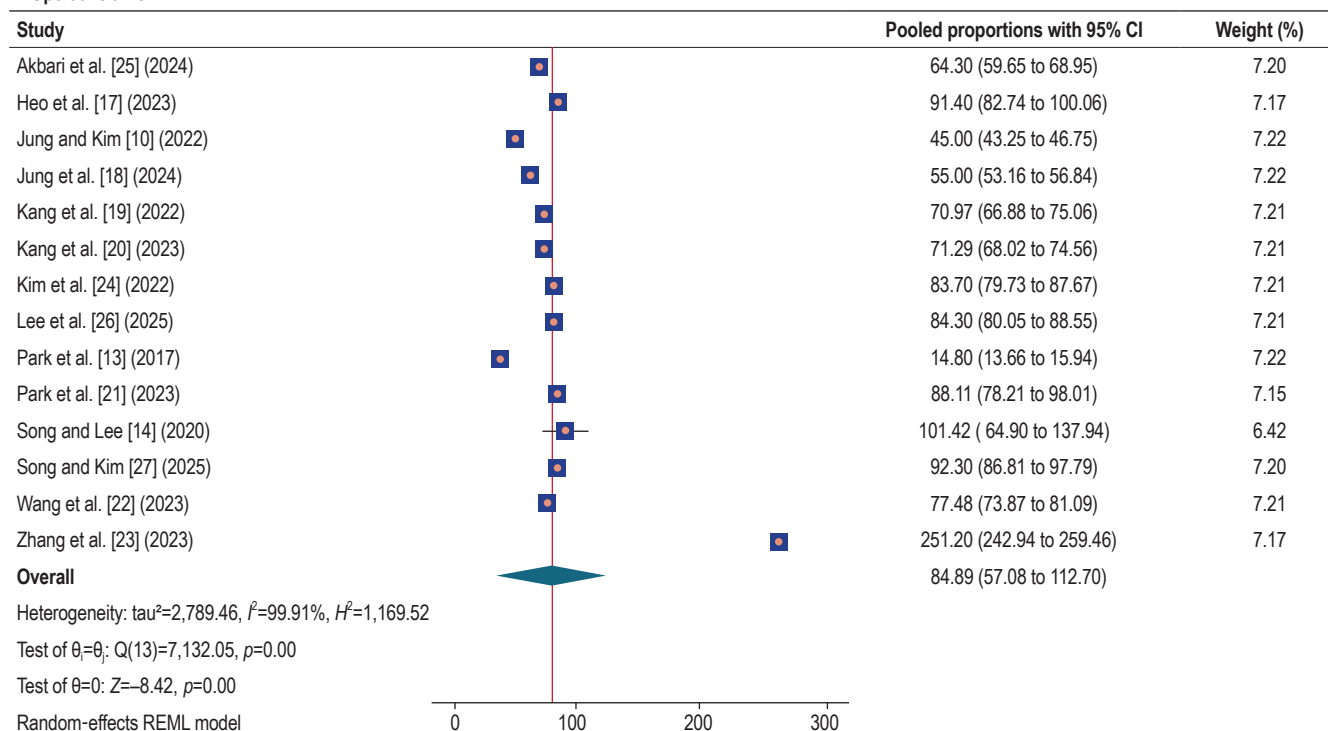


Fig. 4. Forest plot of perioperative outcomes. (A) Operative time, (B) estimated blood loss, (C) hospitalization time, (D) reoperation rate, and (E) success rate. CI, confidence interval; REML, restricted maximum likelihood. (Continued on the next page.)

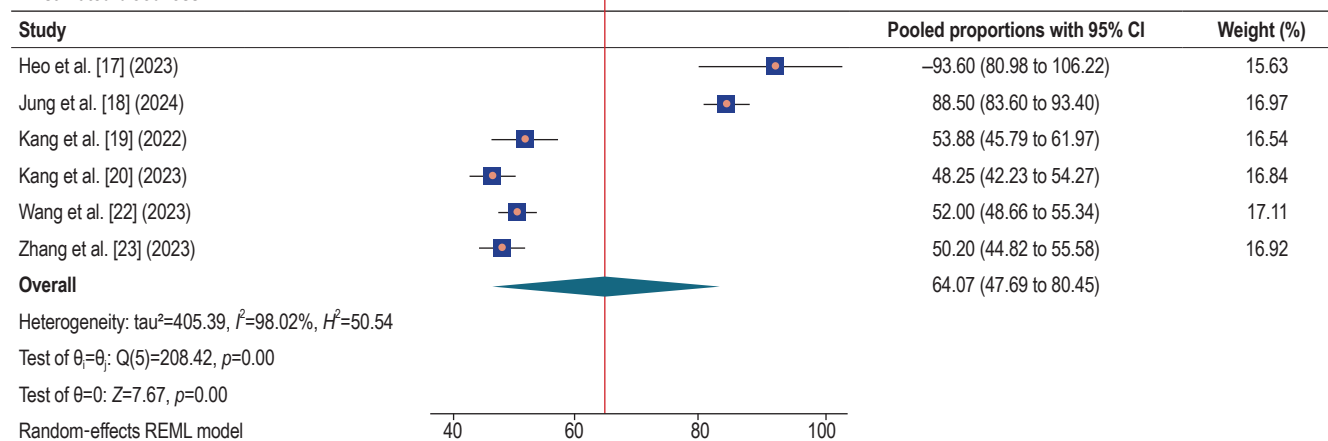
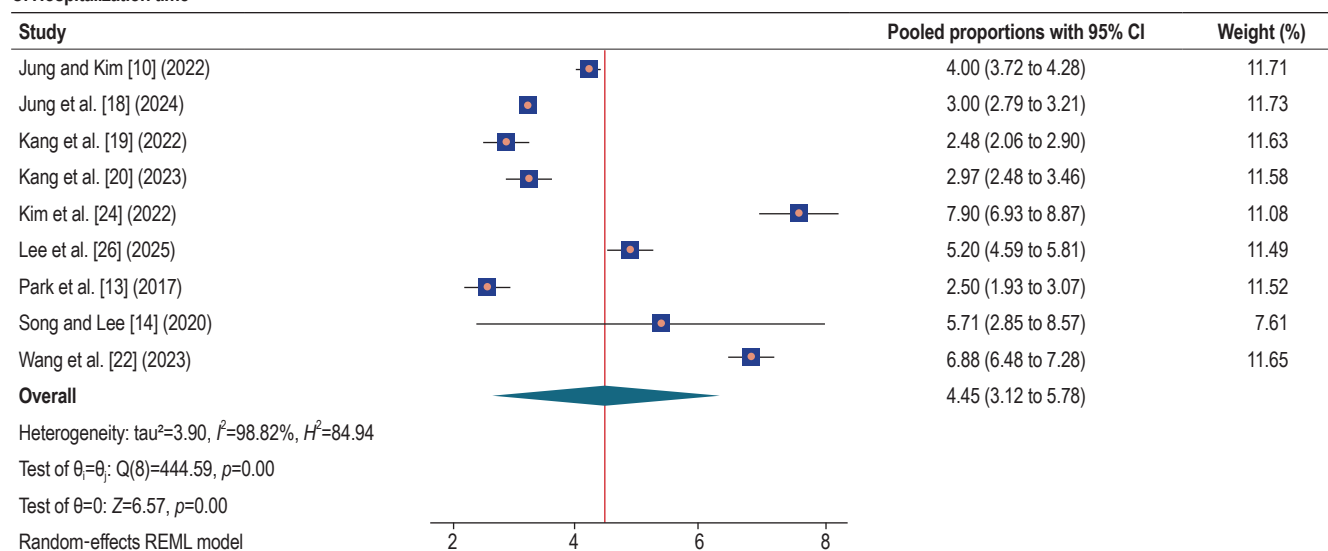
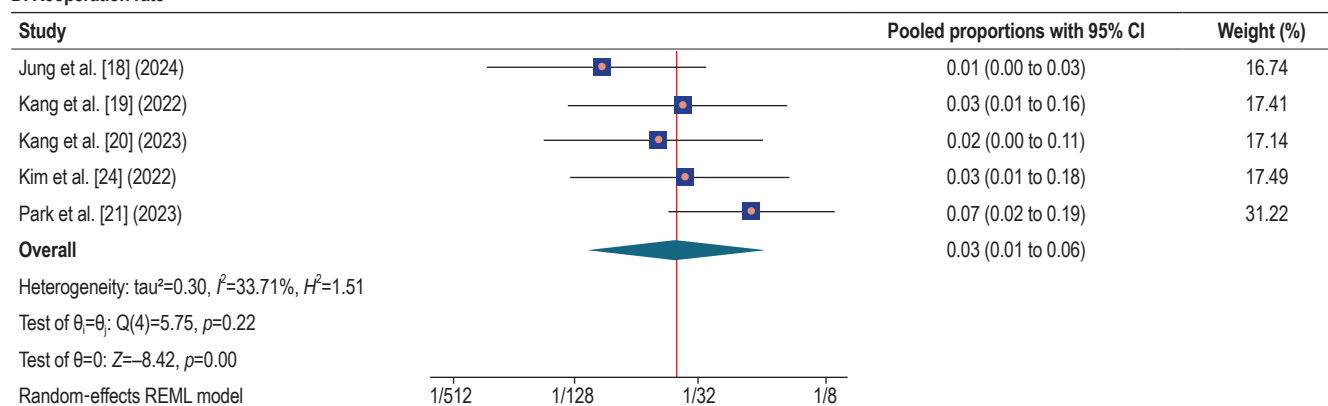
B. Estimated blood loss**C. Hospitalization time****D. Reoperation rate**

Fig. 4. (Continued; caption shown on previous page).

alignment parameters. Postoperative levels of CPK and CRP showed mild postoperative increases, consistent with a controlled inflammatory response. The pooled MD in CRP was 0.28 (95% CI, 0.21–0.34; $p=0.00$) (Fig. 5A), and the pooled MD in CPK was 47.81 (95% CI,

6.13–89.09; $p=0.02$) (Fig. 5B). Segmental range of motion improved significantly after surgery (MD, 0.55; 95% CI, 0.27–0.84; $p=0.00$), indicating restoration of mobility at the operated level. However, changes in Cobb angle were not statistically significant (MD, 4.25;

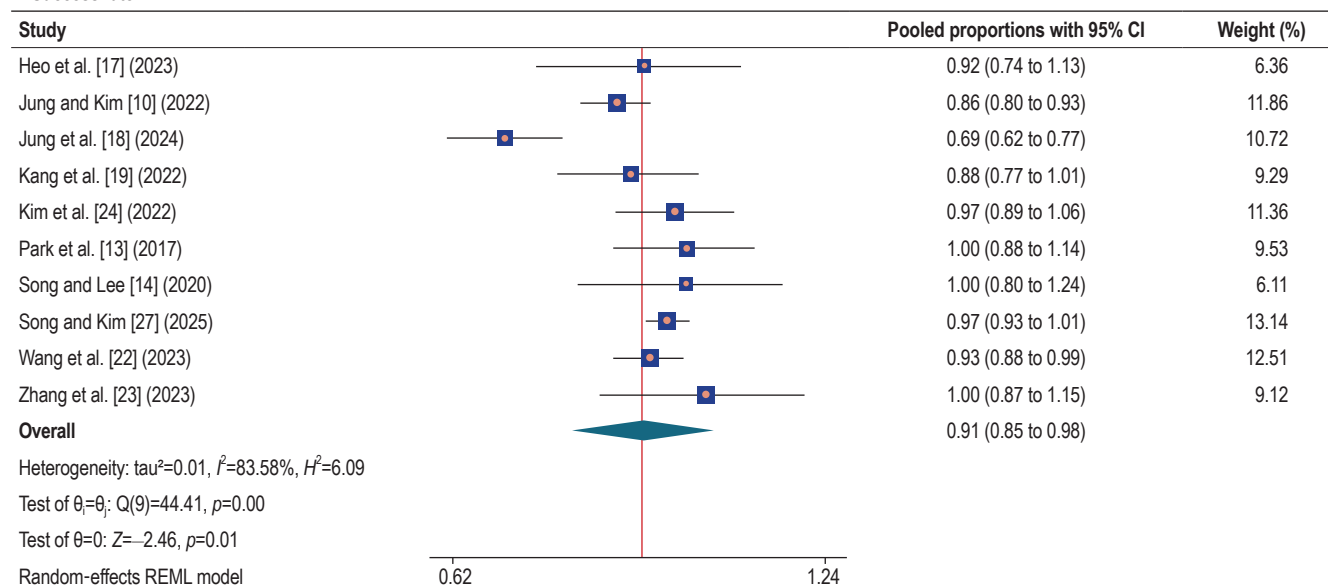
E. Success rate

Fig. 4. (Continued; caption shown on previous page).

95% CI, -2.69 to 11.18 ; $p=0.23$) (Fig. 5C). Heterogeneity among these parameters was minimal, suggesting consistent effects across studies. Based on GRADE assessment, the certainty of evidence for laboratory and radiological outcomes varied across measures (Table 5). CRP level and segmental range of motion were both rated as high-certainty evidence due to the absence of serious concerns in any domain. In contrast, CPK and Cobb angle outcomes were rated as low-certainty evidence because of inconsistency and imprecision.

Comparison with uniportal endoscopy

PCBESS demonstrated outcomes comparable to those of uniportal endoscopic spine surgery across most evaluated parameters (Fig. 6). The ORs for complications (OR, 0.83 ; 95% CI, 0.32 – 2.14 ; $p=0.7$), nerve root palsy (OR, 0.40 ; 95% CI, 0.08 – 2.13 ; $p=0.28$), dural tear (OR, 1.63 ; 95% CI, 0.33 – 8.06 ; $p=0.55$), and reoperation (OR, 1.11 ; 95% CI, 0.15 – 8.14 ; $p=0.92$) revealed no significant differences between the two techniques, indicating similar safety profiles. Likewise, clinical outcomes showed no statistically significant differences between the two methods. MDs in VAS scores (MD, 0.18 ; 95% CI, -0.21 to 0.56 ; $p=0.38$) and NDI (MD, 0.10 ; 95% CI, -0.71 to 0.91 ; $p=0.81$) were not significant. Operative time was also comparable (MD, 2.41 ; 95% CI, -10.72 to 15.53 ; $p>0.05$). Although not statistically significant, PCBESS was associated with a lower incidence of nerve-related complications such as transient palsy (OR, 0.40 ; $p=0.28$) and a marginally higher, albeit non-significant,

surgical success rate (OR, 1.45 ; 95% CI, 0.60 – 3.51 ; $p=0.41$). Heterogeneity across these parameters was predominantly low, suggesting consistent results among included studies. According to the GRADE assessment, most outcomes, including complication rate, nerve root palsy, dural tear, reoperation, success rate, and NDI score, were supported by moderate-certainty evidence (Table 5), reflecting wide CIs despite otherwise robust methodological consistency. Operative time and VAS score were rated as low-certainty evidence due to considerable heterogeneity and substantially wide CIs.

Subgroup analysis

As shown in Table 6, subgroup analysis revealed that postoperative complications following PCBESS were more frequent in multi-level procedures compared to single-level procedures (18% vs. 4% , $p=0.01$). Regarding the extent of decompression, combined foraminotomy and discectomy achieved a significantly greater reduction in VAS pain scores compared with foraminotomy alone ($p<0.001$). As summarized in Table 7, multi-level PCBESS was associated with higher intraoperative blood loss compared with single-level procedures (93.60 mL vs. 58.61 mL, $p<0.001$). Hospitalization duration was also longer among patients with spinal stenosis than those with disc herniation (7.90 days vs. 3.19 days, $p<0.001$). Performing discectomy in all patients and applying inclinatory foraminotomy, compared with foraminotomy with or without discectomy, resulted in prolonged operative time ($p=0.03$). Postopera-

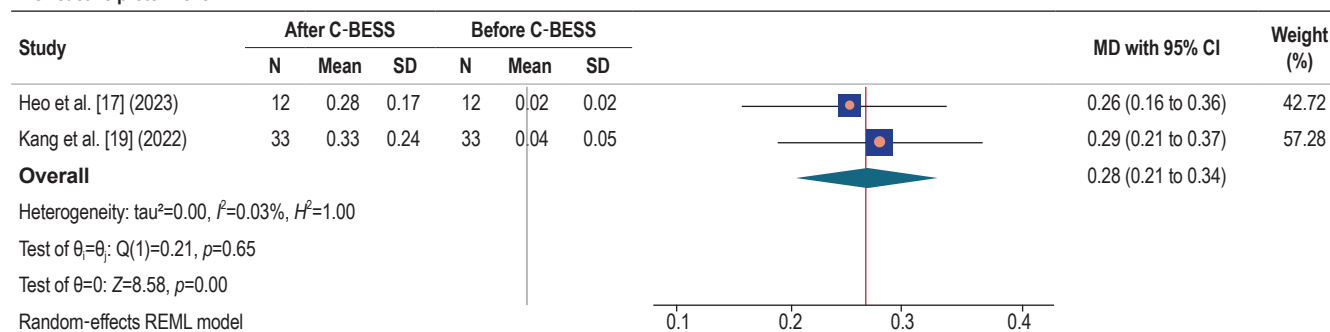
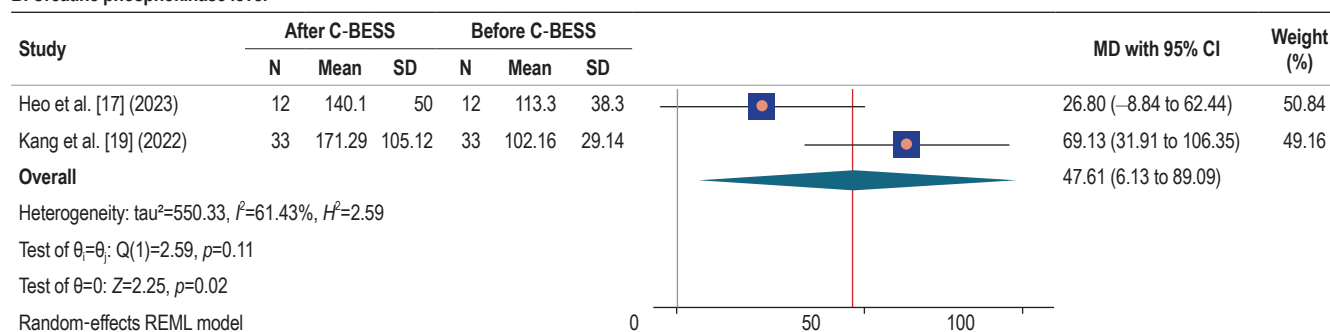
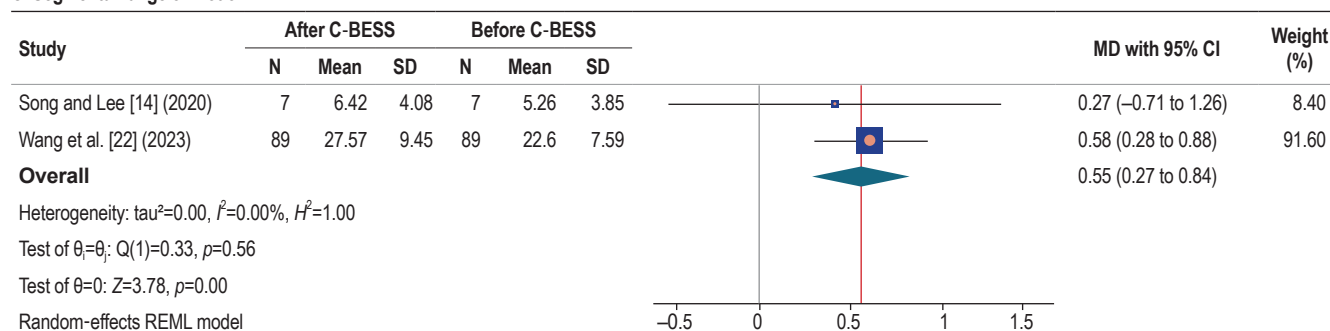
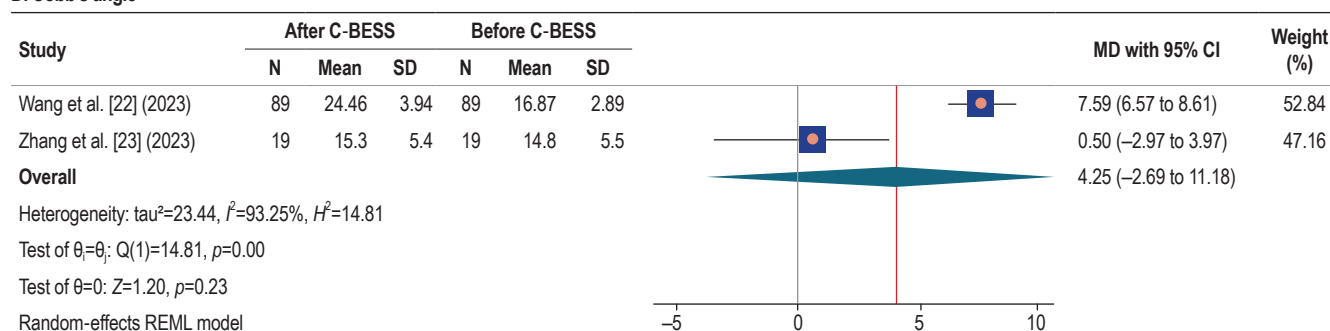
A. C-reactive protein level**B. Creatine phosphokinase level****C. Segmental range of motion****D. Cobb's angle**

Fig. 5. Forest plot of spinal variable outcomes. (A) C-reactive protein level, (B) creatine phosphokinase level, (C) segmental range of motion, and (D) Cobb's angle. C-BESS, cervical biportal endoscopic spine surgery; SD, standard deviation; MD, mean difference; CI, confidence interval; REML, restricted maximum likelihood.

tive biomarkers and spinal mobility parameters were not significantly affected by the number of disc levels treated (CPK: $p=0.11$; CRP: $p=0.65$; segmental range of motion: $p=0.56$) (Table 8). Collectively, these findings underscore the influence of surgical strategy on

postoperative outcomes, reinforcing the importance of individualized, anatomy-based planning to optimize efficacy, safety, and patient-centered outcomes in the management of cervical radiculopathy.

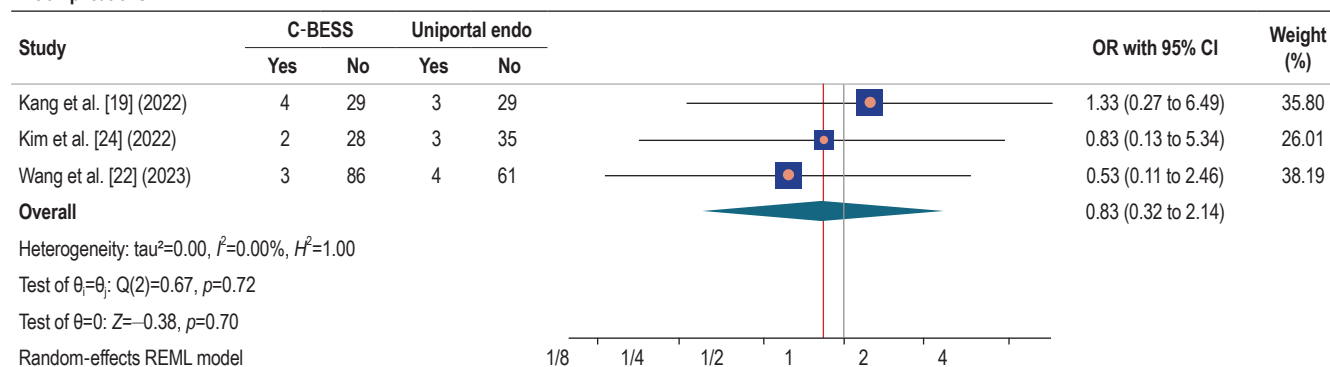
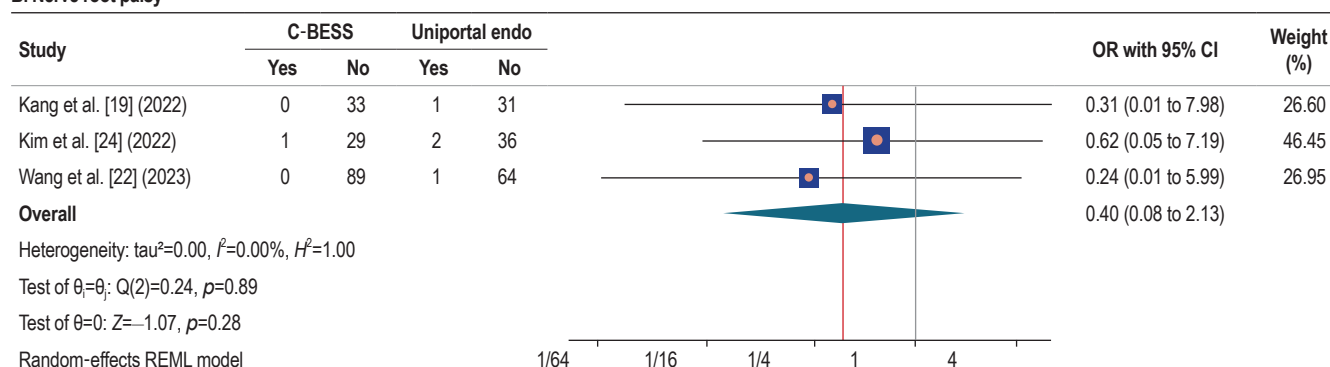
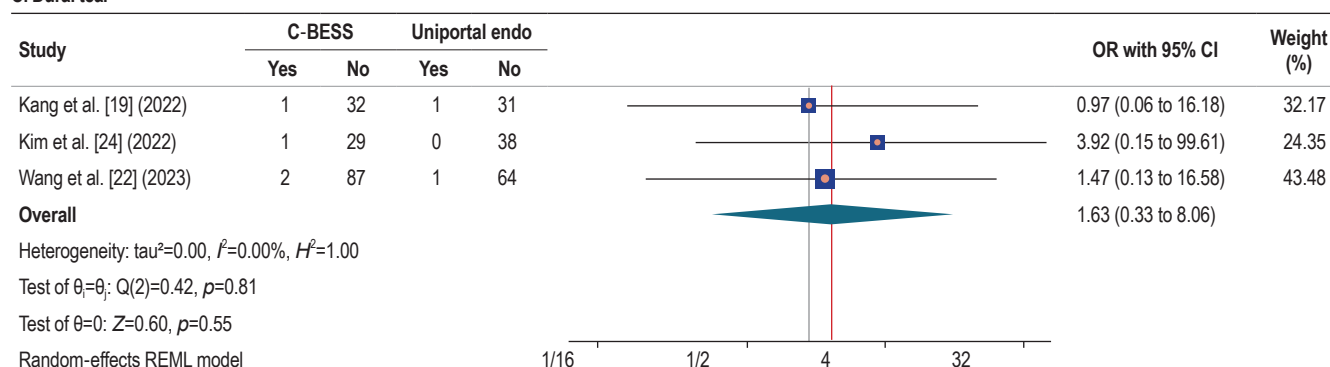
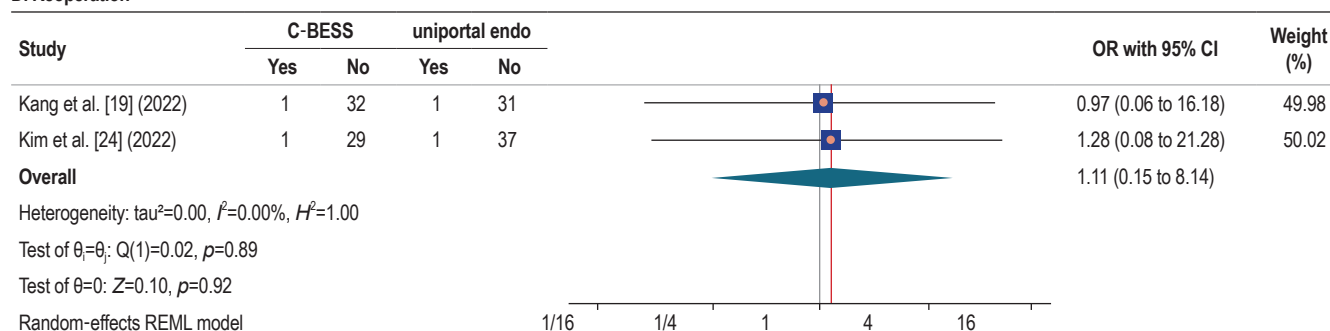
A. Complications**B. Nerve root palsy****C. Dural tear****D. Reoperation**

Fig. 6. Forest plot of posterior cervical biportal endoscopic spine surgery (C-BESS) vs. uniportal endoscopic. (A) Complications, (B) nerve root palsy, (C) dural tears, (D) reoperation, (E) operative time, (F) success rate, (G) Neck Disability Index (NDI) score, and (H) Visual Analog Scale (VAS) score. OR, odds ratio; CI, confidence interval; REML, restricted maximum likelihood; SD, standard deviation; MD, mean difference. (Continued on the next page.)

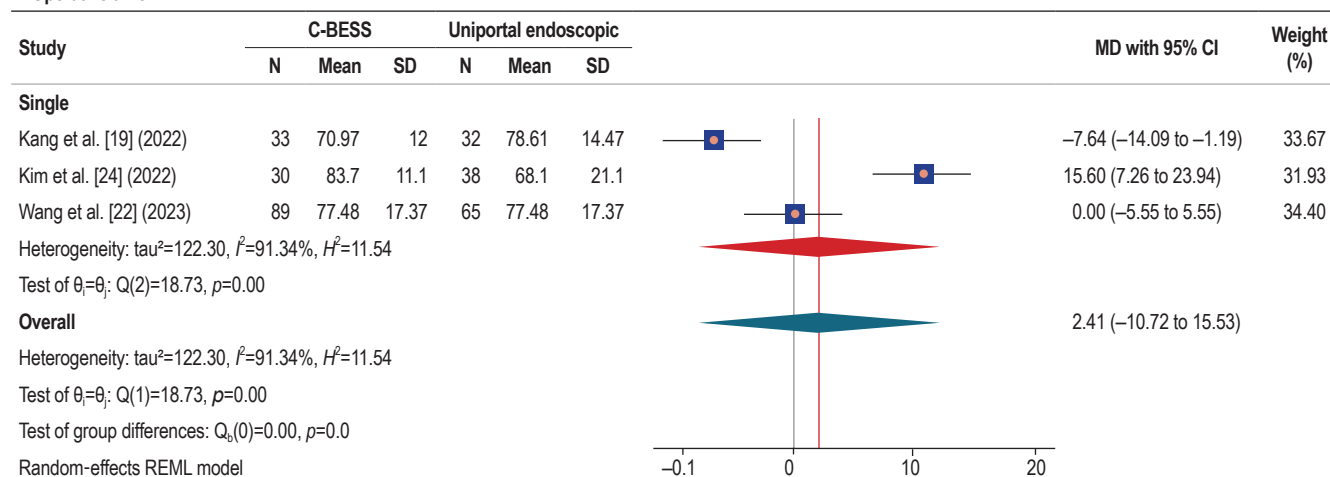
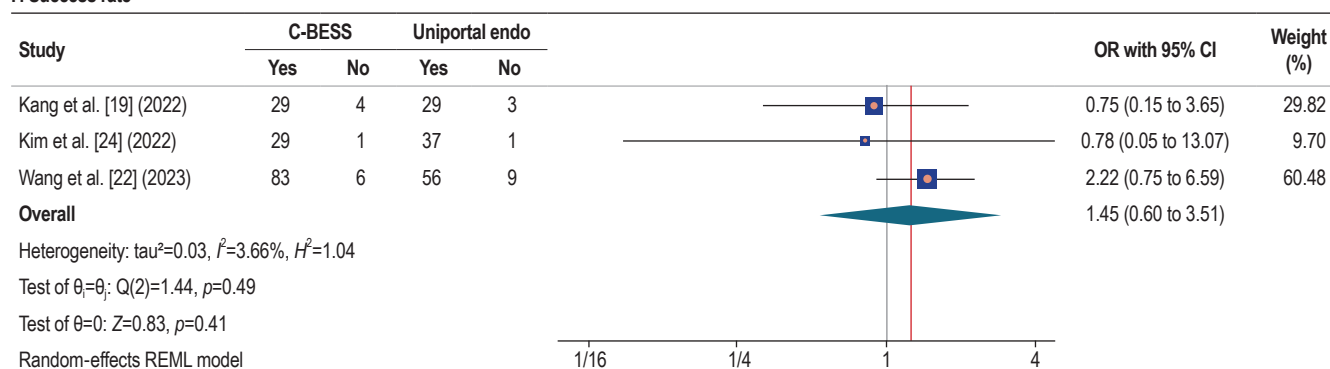
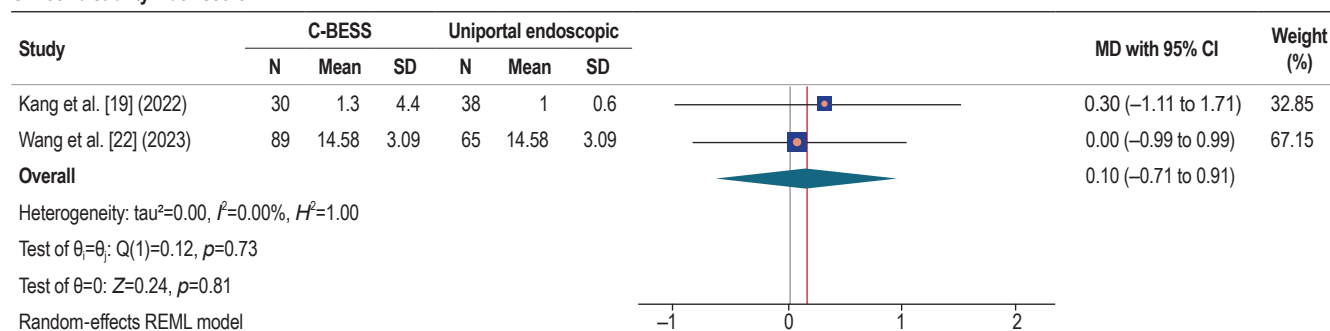
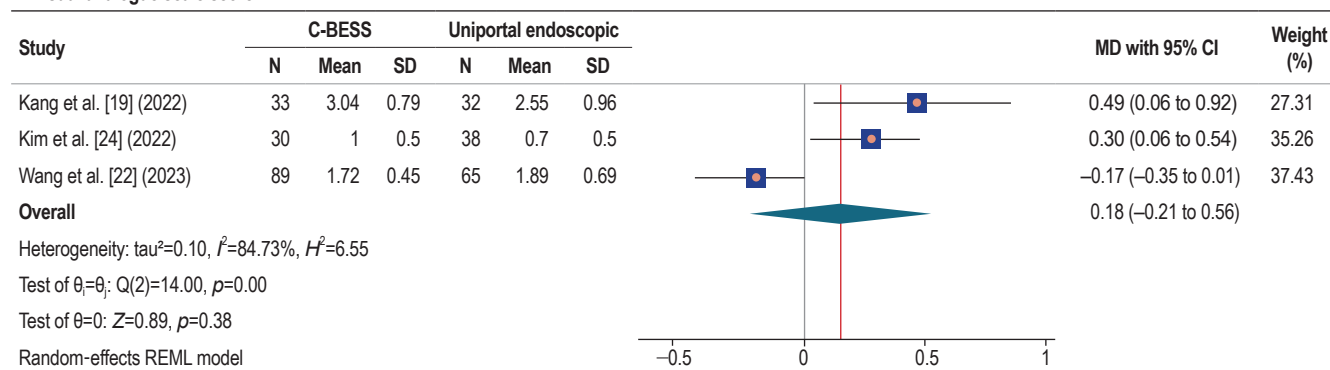
E. Operative time**F. Success rate****G. Neck disability index score****H. Visual analogue scale score**

Fig. 6. (Continued; caption shown on previous page).

Table 5. Certainty of evidence across outcomes based on grading of recommendations assessment, development, and evaluation (GRADE)

Outcomes	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Certainty
Clinical outcomes						
Complications	Serious	Serious	Not serious	Serious	NA	⊕○○○ Very low
Reoccurrence rate	Not serious	Not serious	Not serious	Not serious	NA	⊕⊕⊕⊕ High
VAS score	Serious	Serious	Not serious	Serious	NA	⊕⊕○○ Low ^{a)}
NDI score	Serious	Serious	Not serious	Serious	NA	⊕⊕○○ Low ^{a)}
MacNab criteria (excellence)	Not serious	Serious	Not serious	Serious	NA	⊕⊕○○ Low
MacNab criteria (good)	Not serious	Serious	Not serious	Serious	NA	⊕⊕○○ Low
MacNab criteria (fair)	Not serious	Not serious	Not serious	Serious	NA	⊕⊕⊕○ Moderate
MacNab criteria (poor)	Not serious	Serious	Not serious	Serious	NA	⊕⊕○○ Low
Perioperative outcomes						
Operative time	Serious	Serious	Not serious	Serious	NA	⊕○○○ Very low
Estimated blood loss	Serious	Serious	Not serious	Serious	NA	⊕○○○ Very low
Hospitalization time	Serious	Serious	Not serious	Serious	NA	⊕○○○ Very low
Reoperation rate	Serious	Not serious	Not serious	Not serious	NA	⊕⊕⊕⊕ High ^{a)}
Success rate	Serious	Serious	Not serious	Serious	NA	⊕⊕○○ Low ^{a)}
Spinal outcomes						
CRP level	Not serious	Not serious	Not serious	Not serious	NA	⊕⊕⊕⊕ High
CPK level	Not serious	Serious	Not serious	Serious	NA	⊕⊕○○ Low
Segmental ROM	Not serious	Not serious	Not serious	Not serious	NA	⊕⊕⊕⊕ High
Cobb's angle	Not serious	Serious	Not serious	Serious	NA	⊕⊕○○ Low
PCBESS vs. uniportal endoscopy						
Complications	Not serious	Not serious	Not serious	Serious	NA	⊕⊕⊕○ Moderate
Nerve root palsy	Not serious	Not serious	Not serious	Serious	NA	⊕⊕⊕○ Moderate
Dural tear	Not serious	Not serious	Not serious	Serious	NA	⊕⊕⊕○ Moderate
Reoperation	Not serious	Not serious	Not serious	Serious	NA	⊕⊕⊕○ Moderate
Operative time	Not serious	Serious	Not serious	Serious	NA	⊕⊕○○ Low
Success rate	Not serious	Not serious	Not serious	Serious	NA	⊕⊕⊕○ Moderate
NDI score	Not serious	Not serious	Not serious	Serious	NA	⊕⊕⊕○ Moderate
VAS score	Not serious	Serious	Not serious	Serious	NA	⊕⊕○○ Low

NA, not available; VAS, Visual Analog Scale; NDI, Neck Disability Index; CRP, C-reactive protein; CPK, creatine phosphokinase; ROM, range of motion; PCBESS, posterior cervical biportal endoscopic spine surgery.

^{a)}Upgraded one level due to large magnitude of effect.

Discussion

This study provides a comprehensive evaluation of PCBESS for cervical radiculopathy, including a meta-analysis and a thorough subgroup analysis. The findings offer valuable insights into the procedure's effectiveness, safety, and the influence of patient- and technique-related factors on surgical outcomes, thereby informing clinical decision-making and guiding future research.

The meta-analysis demonstrated that PCBESS is associated with a low overall complication rate, substantial improvements in pain and functional outcomes, and a high surgical success rate. These results suggest that

PCBESS is an effective treatment modality for cervical radiculopathy, combining strong clinical efficacy with favorable recovery profiles. Subgroup analyses further revealed that factors such as the degree of disc herniation, the number of operated levels, and surgical technique significantly influence perioperative and post-operative outcomes. This combined approach offered a nuanced understanding of how patient-specific and procedural variables influence the efficacy of PCBESS.

The present findings are particularly relevant in the context of an aging population, in which the prevalence of cervical radiculopathy continues to rise. Conventional open procedures, although effective, can entail

Table 6. Subgroup analyses results of clinical outcomes (single-arm intervention)

Outcome measure	Covariate/subgroup	No. of studies	Effect measure	95% CI	Subgroups difference
Complication	Type of conditions				0.75
	Disc herniation and stenosis	6	ES 0.09	0.06 to 0.14	
	Disc herniation	3	ES 0.04	0.00 to 0.36	
	Stenosis	1	ES 0.07	0.02 to 0.23	
	Level of disc involvement				0.01*
	Single	6	ES 0.04	0.02 to 0.09	
	Multiple	4	ES 0.18	0.08 to 0.36	
	Extend of decompression				<0.001*
	Foraminotomy only	1	ES 0.07	0.02 to 0.23	
	Foraminotomy w/ or w/o discectomy	5	ES 0.14	0.08 to 0.26	
	Foraminotomy and discectomy	3	ES 0.02	0.01 to 0.04	
	Inclinatory foraminotomy w/ or w/o discectomy	1	ES 0.14	0.03 to 0.64	
VAS	Type of conditions				0.88
	Disc herniation and stenosis	4	MD -4.35	-6.97 to -1.74	
	Disc herniation	3	MD -5.06	-6.26 to -3.87	
	Stenosis	2	MD -5.16	-8.79 to -1.53	
	Level of disc involvement				0.36
	Single	6	MD -4.32	-5.83 to -2.81	
	Multiple	3	MD -5.69	-8.19 to -3.20	
	Extend of decompression				<0.001*
	Foraminotomy only	1	MD -3.30	-3.90 to -2.70	
	Foraminotomy and discectomy	4	MD -5.36	-6.37 to -4.36	
NDI	Type of conditions				0.50
	Disc herniation and stenosis	3	MD -32.17	-47.01 to -17.33	
	Disc herniation	3	MD -28.57	-38.49 to -18.64	
	Stenosis	1	MD -24.90	-26.71 to -23.09	
	Level of disc involvement				0.15
	Single	5	MD -26.28	-32.40 to -20.17	
	Multiple	2	MD -38.92	-54.99 to -22.85	
	Extend of decompression				0.11
	Foraminotomy only	1	MD -24.90	-26.71 to -23.09	
	Foraminotomy w/ or w/o discectomy	2	MD -24.82	-39.99 to -9.65	
	Foraminotomy and discectomy	4	MD -26.66	-34.54 to -18.78	
	Inclinatory foraminotomy w/ or w/o discectomy	1	MD -50.28	-70.62 to -29.94	
MacNab criteria	Level of disc involvement				
	Excellent				0.20
	Single	3	ES 0.41	0.21 to 0.80	
	Multiple	3	ES 0.71	0.43 to 1.00	
	Good				0.24
	Single	3	ES 0.46	0.26 to 0.81	
	Multiple	3	ES 0.19	0.05 to 0.73	
	Fair				0.32
	Single	3	ES 0.08	0.04 to 0.18	

(Continued on the next page)

Table 6. Continued

Outcome measure	Covariate/subgroup	No. of studies	Effect measure	95% CI	Subgroups difference
Reoccurrence	Multiple	2	ES 0.04	0.02 to 0.11	-
	Poor				
	Single	1	ES 0.01	0.00 to 0.06	0.69
	Type of conditions				
	Disc herniation and stenosis	2	ES 0.03	0.01 to 0.10	
	Disc herniation	1	ES 0.04	0.01 to 0.15	
	Stenosis	1	ES 0.07	0.02 to 0.23	
	Level of disc involvement				
	Single	2	ES 0.05	0.02 to 0.14	0.74
	Multiple	2	ES 0.04	0.01 to 0.11	
	Extend of decompression				0.45
	Foraminotomy only	1	ES 0.07	0.02 to 0.23	
	Foraminotomy w/ or w/o discectomy	3	ES 0.04	0.02 to 0.09	

CI, confidence interval; ES, effect size; w/ or w/o, with or without; VAS, Visual Analog Scale; MD, mean difference; NDI, Neck Disability Index.

* $p < 0.05$ (statistical significance).

considerable morbidity, extended recovery periods, and elevated complication rates. The advent of minimally invasive approaches such as PCBESS represents a transformative change in spine surgery, offering comparable or superior outcomes with reduced surgical stress. Previous studies have similarly shown that minimally invasive techniques facilitate faster recovery, lower postoperative pain, and shorter hospital stays compared with traditional open approaches [28-31]. The results of this meta-analysis are consistent with these studies, supporting the clinical utility of PCBESS as a viable and effective minimally invasive alternative. This work contributes to the expanding evidence base for PCBESS, highlighting its capacity to enhance patient outcomes while reducing the disadvantages linked to more invasive interventions.

The analysis of PCBESS outcomes revealed nuanced insights underscoring the complex and multifactorial nature of surgical success in treating cervical radiculopathy [13,32,33]. Each evaluated parameter provides a distinct perspective on the procedure's effectiveness and highlights the key determinants that influence postoperative recovery and patient satisfaction.

Incidence of complications

The present subgroup analysis did not identify a significant association between the extent of disc involvement and complication rates, suggesting that disc pathology alone may not directly influence surgical risk. Instead, overall procedural complexity, particularly in multi-level decompressions, appears to be the predominant

determinant. Nevertheless, previous studies have reported that complex or extensive disc herniations can increase intraoperative difficulty and complication risk [19,34,35]. Patients with such lesions may therefore benefit from meticulous preoperative evaluation and individualized surgical planning [36]. High-resolution imaging modalities, such as magnetic resonance imaging, are essential for evaluating the severity and configuration of disc pathology and for guiding operative strategy [37]. A tailored approach enables surgeons to anticipate potential complications, refine their technique, and minimize the risk of adverse events, thus improving patient safety and outcomes.

The markedly higher complication rate observed in multi-level PCBESS procedures (18% vs. 4%) likely reflects the increased technical complexity of decompressing multiple spinal segments. Prior literature has similarly demonstrated that multi-level lumbar and cervical fusion surgeries are associated with longer operative times and greater blood loss, variables that correlate with higher complication rates [38-40]. Similarly, a comparative analysis of single- versus multi-level lateral lumbar interbody fusion reported significantly prolonged operative time (145.1 minutes vs. 98.9 minutes) and greater intraoperative blood loss in the multi-level cohort [39]. In the context of endoscopic multilevel decompression, a higher incidence of dural tears, epidural hematomas, and incomplete decompression has been documented, indicating that expanded surgical exposure and manipulation may predispose to neural irritation or suboptimal decompression [33,38,41,42]. These findings underline the importance of meticulous surgi-

Table 7. Subgroup analyses results of perioperative outcomes (single-arm intervention)

Outcome measure	Covariate/subgroup	No. of studies	Effect measure	95% CI	Subgroups difference
Blood loss	Type of conditions				0.71
	Disc herniation and stenosis	4	ES 61.35	41.28–81.41	
	Disc herniation	2	ES 69.37	31.83–106.90	
	Level of disc involvement				<0.001 [*]
	Single	5	ES 58.61	43.74–73.49	
	Multiple	1	ES 93.60	80.98–106.22	
	Extend of decompression				0.95
	Foraminotomy and discectomy	3	ES 63.55	39.12–87.98	
	Inclinary foraminotomy w/ or w/o discectomy	3	ES 64.79	37.23–92.35	
Hospitalization time	Type of conditions				<0.001 [*]
	Disc herniation and stenosis	5	ES 4.56	2.84–6.29	
	Disc herniation	3	ES 3.19	2.33–4.05	
	Stenosis	1	ES 7.90	6.93–8.87	
	Level of disc involvement				0.26
	Single	7	ES 4.23	2.60–5.86	
	Multiple	2	ES 5.22	4.63–5.86	
	Extend of decompression				<0.001 [*]
	Foraminotomy w/ or w/o discectomy	3	ES 3.54	1.91–5.17	
	Foraminotomy and discectomy	4	ES 4.10	2.18–6.01	
Operative time	Type of conditions				0.18
	Disc herniation and stenosis	7	ES 77.13	69.60–84.66	
	Disc herniation	5	ES 90.76	8.94–172.58	
	Stenosis	2	ES 87.78	79.37–96.20	
	Level of disc involvement				0.74
	Single	9	ES 81.46	37.84–126.07	
	Multiple	5	ES 88.78	84.23–93.33	
	Extend of decompression				0.03 [*]
	Foraminotomy w/ or w/o discectomy	6	ES 77.86	69.22–86.49	
	Foraminotomy and discectomy	5	ES 88.63	6.68–170.59	
Reoperation	Type of conditions				0.95
	Disc herniation and stenosis	2	ES 0.02	0.01–0.08	
	Disc herniation	2	ES 0.02	0.00–0.23	
	Stenosis	1	ES 0.02	0.01–0.18	
	Level of disc involvement				0.07
	Single	4	ES 0.02	0.01–0.04	
	Multiple	1	ES 0.07	0.02–0.19	
	Extend of decompression				0.13
	Foraminotomy only	1	ES 0.03	0.01–0.18	
	Foraminotomy and discectomy	1	ES 0.01	0.00–0.03	
	Foraminotomy w/ or w/o discectomy	3	ES 0.04	0.02–0.10	

(Continued on the next page)

Table 7. Continued

Outcome measure	Covariate/subgroup	No. of studies	Effect measure	95% CI	Subgroups difference
Successful surgery	Type of conditions				0.22
	Disc herniation and stenosis	4	ES 0.93	0.88–0.98	
	Disc herniation	4	ES 0.87	0.74–1.00	
	Stenosis	2	ES 0.97	0.94–1.00	
	Level of disc involvement				0.13
	Single	7	ES 0.90	0.82–0.99	
	Multiple	3	ES 0.97	0.93–1.00	
	Extend of decompression				0.47
	Foraminotomy only	1	ES 0.97	0.89–1.00	
	Foraminotomy w/ or w/o discectomy	2	ES 0.89	0.79–1.00	
	Foraminotomy and discectomy	5	ES 0.89	0.78–1.00	
	Inclinator foraminotomy w/ or w/o discectomy	1	ES 0.97	0.93–1.00	

CI, confidence interval; ES, effect size; w/ or w/o, with or without.
^{*} $p < 0.05$ (statistical significance).

Table 8. Subgroup analyses results of spinal-specified outcomes (single-arm intervention)

Outcome measure	Covariate/subgroup	No. of studies	Effect measure	95% CI	Subgroups difference
CPK	Level of disc involvement				0.11
	Single	1	MD 69.13	31.91 to 106.35	
	Multiple	1	MD 26.80	–8.84 to 62.44	
CRP	Level of disc involvement				0.65
	Single	1	MD 0.29	0.21 to 0.37	
	Multiple	1	MD 0.26	0.16 to 0.36	
Segmental ROM	Level of disc involvement				0.56
	Single	1	MD 0.58	0.27 to 0.84	
	Multiple	1	MD 0.27	–0.71 to 1.26	

CI, confidence interval; CPK, creatine phosphokinase; MD, mean difference; CRP, C-reactive protein; ROM, range of motion.
^{*} $p < 0.05$ (statistical significance).

cal planning and, when appropriate, the consideration of staged or alternative approaches to mitigate risk in complex multi-level cases.

Alleviation of pain and restoration of function

The present findings demonstrate that the surgical approach substantially influences pain relief, as measured by the VAS, and functional recovery, as reflected by the NDI score (both $p = 0.00$). These findings underscore the significance of surgical precision and proficiency in achieving optimal results. In minimally invasive surgery, where the goal is to minimize tissue damage while maintaining procedural effectiveness, the surgeon's proficiency in manipulating endoscopic instruments and performing accurate decompressions is paramount [38,43]. This highlights the need for extensive training

programs that foster endoscopic competence and familiarity with sophisticated surgical instruments.

Variations in postoperative discomfort and functional improvement across surgical approaches may stem from differences in the degree of decompression achieved, the management of neural structures, or the ability to address complex anatomical constraints. Surgeons should continually refine their techniques and integrate feedback from clinical outcomes to optimize performance and tailor interventions to each patient's unique anatomy and pathology [38].

PCBESS demonstrated substantial improvements in pain and function, corroborating its therapeutic efficacy for radiculopathy. When compared with uniportal endoscopic techniques, PCBESS yielded comparable outcomes, with no significant differences in mean VAS or NDI scores. These findings indicate that both methods

are effective for symptom relief. However, the biportal configuration of PCBESS offers improved visualization and a wider operative field, potentially facilitating more thorough decompression in complex anatomical regions. Although clinical outcome measures appear comparable, the biportal approach may confer technical advantages in terms of surgeon ergonomics and intraoperative flexibility.

Perioperative results

The influence of disease type on intraoperative blood loss highlights the interplay between patient-specific variables and surgical performance in determining perioperative outcomes. Conditions with greater soft-tissue or vascular involvement may predispose patients to increased blood loss, necessitating meticulous hemostatic control and surgical precision. Minimizing blood loss is a key advantage of minimally invasive spine surgeries such as PCBESS, as it contributes to reduced morbidity, faster recovery, and lower rates of postoperative complications, a finding consistently supported by prior literature on minimally invasive spine surgery [44]. Hospitalization duration was significantly longer in patients with spinal stenosis than in those with disc herniation, underscoring the effect of underlying pathology on recovery, whereas operative duration did not differ significantly across subgroups. The consistency of these parameters across varying patient profiles and surgical techniques underscores the procedural reliability of PCBESS and its adaptability across diverse clinical contexts.

In terms of perioperative parameters, PCBESS demonstrated mean operative time, blood loss, and hospital stay durations comparable to those reported for other minimally invasive spine procedures. When compared with the uniportal endoscopic approach, operative time and hospital stay did not significantly differ. However, the modular dual-port configuration of PCBESS may facilitate more efficient handling in multi-level or anatomically constrained cases, reducing surgeon fatigue and potentially shortening the learning curve. Although both techniques achieved favorable functional outcomes, PCBESS showed slightly superior segmental range of motion, likely reflecting its capacity for more complete decompression. These subtle advantages may justify PCBESS as a first-line option, particularly in technically demanding cases.

Spine-specific outcomes

Analysis of spinal-specific outcomes revealed that the degree of disc herniation did not significantly influence biochemical markers, including CPK and CRP levels, or segmental range of motion. These findings suggest that, although anatomical parameters are important for surgical planning, postoperative biochemical responses and spinal mobility are likely influenced by additional factors such as surgical technique, individual patient physiology, and rehabilitation protocols [31,45]. This emphasizes the multifactorial nature of spine surgery outcomes and highlights the importance of a holistic, multidisciplinary approach to patient management that accounts for both surgical and non-surgical elements.

Patient satisfaction and surgical revision frequencies

Patient satisfaction, as assessed by the MacNab criteria, was not significantly influenced by the extent of disc involvement. This finding suggests that patient-reported outcomes may depend more on subjective experiences, expectations, and the interaction between the patient and the healthcare team than on anatomical parameters alone [46–48]. Effective preoperative counseling and the establishment of realistic expectations are, therefore, essential for ensuring patient satisfaction and perceived surgical success [46].

Reoperation rates demonstrated borderline significance in relation to the level of disc herniation ($p=0.08$), indicating that certain disc pathologies may predispose patients to additional surgical interventions. This highlights the importance of thorough preoperative assessments and meticulous surgical planning to anticipate and mitigate potential complications. Ongoing postoperative monitoring and long-term follow-up are likewise crucial for the early detection and management of recurrence or residual symptoms, enhancing long-term outcomes and patient satisfaction [49,50].

Despite these insights, this study has several limitations. The retrospective nature of the included studies introduces the possibility of selection and reporting biases. Substantial heterogeneity among studies likely reflects variations in patient demographics, surgical approaches, and outcome assessment tools, limiting the generalizability of the findings. Moreover, the lack of large, randomized controlled trials restricts the ability to draw definitive conclusions. Future research should focus on prospective, multicenter designs with standardized outcome measures to enhance comparability and strengthen the evidence base. Overall, this study

reinforces the efficacy and safety of PCBESS for cervical radiculopathy, while emphasizing the influence of patient-specific factors and surgical methodology on outcomes.

Conclusions

This meta-analysis provides a comprehensive evaluation of PCBESS for cervical radiculopathy, demonstrating its efficacy in alleviating pain, improving functional outcomes, and achieving high surgical success rates with relatively low complication and reoperation rates. Subgroup analyses revealed that single-level procedures are associated with lower complication rates, reduced blood loss, and shorter hospitalization, whereas multi-level surgeries entail higher risks, reflecting their greater technical complexity and operative demands. Furthermore, combined foraminotomy and discectomy achieved greater pain reduction compared with foraminotomy alone, while cases involving stenosis pathology were associated with longer hospitalization than those with disc herniation. Collectively, these findings suggest that PCBESS is particularly suitable for single-level decompressions and cases requiring combined discectomy, whereas multi-level procedures should be undertaken with caution, emphasizing careful patient selection and meticulous surgical planning. Further prospective research is required to confirm these conclusions and refine technique selection.

Key Points

- Posterior cervical biportal endoscopic spine surgery (PCBESS) achieved 91% excellent–good outcomes, with a reoperation rate of only 3%.
- Pain reduced by 4.77 points (Visual Analog Scale) and disability improved by 27.07 points (Neck Disability Index) following surgery.
- Overall complication rate was 7%, but multi-level cases reached 18% vs. 4% in single-level cases.
- PCBESS showed comparable outcomes to uniportal approach.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgments

Additional data or further assessment is available upon reasonable request to the corresponding author. This study has not been published before. This meta-analysis was performed according to the Cochrane Collaboration and Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) and was registered prospectively in the PROSPERO database (CRD42024566055).

ORCID

Bryan Gervais de Liyis: <https://orcid.org/0000-0002-8272-754X>; Stevanus Christian Surya: <https://orcid.org/0000-0001-6845-9246>; Sulaiman Liyis: <https://orcid.org/0009-0001-2338-3759>; Tjokorda Istri Putri Mahadewi: <https://orcid.org/0009-0001-3131-9853>; Amal Rizky: <https://orcid.org/0009-0003-6133-4143>; Yunus Kuntawi Aji: <https://orcid.org/0000-0002-1877-6312>; Fadhil Panyalai: <https://orcid.org/0000-0002-2039-3652>; Tjokorda Gde Bagus Mahadewa: <https://orcid.org/0000-0003-1212-2219>

Author Contributions

Conceptualization: BGdL. Data curation: BGdL, TIPM. Formal analysis: BGdL. Investigation: SCS, AR. Methodology: SL, YKA. Project administration: SCS, AR. Resources: BGdL, FP. Software: BGdL, TGBM. Supervision: FP, TGBM. Validation: FP, TGBM. Visualization: MK. Writing–original draft: BGdL, SCS, TIPM, SL. Writing–review & editing: BGdL, AR, YKA, FP, TGBM. Final approval of the manuscript: all authors.

References

1. Kang KC, Lee HS, Lee JH. Cervical radiculopathy focus on characteristics and differential diagnosis. *Asian Spine J* 2020;14:921-30. <https://doi.org/10.31616/asj.2020.0647>
2. ElAbed K, Shawky A, Barakat M, Ainscow D. Anterior cervical discectomy and fusion with stand-alone trabecular metal cages as a surgical treatment for cervical radiculopathy: mid-term outcomes. *Asian Spine J* 2016;10:245-50. <https://doi.org/10.4184/asj.2016.10.2.245>
3. Lee SH, Seo J, Jeong D, et al. Clinical outcomes and complications of unilateral biportal endoscopic posterior

- cervical foraminotomy: a systematic review and meta-analysis with a comparison to full-endoscopic posterior cervical foraminotomy. *Neurospine* 2024;21:807-19. <https://doi.org/10.14245/ns.2448430.215>
4. Fountas KN, Kapsalaki EZ, Nikolakakos LG, et al. Anterior cervical discectomy and fusion associated complications. *Spine (Phila Pa 1976)* 2007;32:2310-7. <https://doi.org/10.1097/brs.0b013e318154c57e>
 5. Yee TJ, Swong K, Park P. Complications of anterior cervical spine surgery: a systematic review of the literature. *J Spine Surg* 2020;6:302-22. <https://doi.org/10.21037/jss.2020.01.14>
 6. Selvanathan SK, Beagrie C, Thomson S, et al. Anterior cervical discectomy and fusion versus posterior cervical foraminotomy in the treatment of brachialgia: the Leeds spinal unit experience (2008-2013). *Acta Neurochir (Wien)* 2015;157:1595-600. <https://doi.org/10.1007/s00701-015-2491-8>
 7. Wu PH, Kim HS, Lee YJ, et al. Posterior endoscopic cervical foraminotomy and discectomy: clinical and radiological computer tomography evaluation on the bony effect of decompression with 2 years follow-up. *Eur Spine J* 2021;30:534-46. <https://doi.org/10.1007/s00586-020-06637-8>
 8. Badiie RK, Mayer R, Pennicooke B, Chou D, Mummaneni PV, Tan LA. Complications following posterior cervical decompression and fusion: a review of incidence, risk factors, and prevention strategies. *J Spine Surg* 2020;6:323-33. <https://doi.org/10.21037/jss.2019.11.01>
 9. Kim HS, Wu PH, Tze-Chun Lau E, Jang IT. Narrative review of uniportal posterior endoscopic cervical foraminotomy. *World Neurosurg* 2024;181:148-53. <https://doi.org/10.1016/j.wneu.2023.10.021>
 10. Jung SB, Kim N. Biportal endoscopic spine surgery for cervical disk herniation: a technical notes and preliminary report. *Medicine (Baltimore)* 2022;101:e29751. <https://doi.org/10.1097/md.00000000000029751>
 11. Song KS, Lee CW, Moon JG. Biportal endoscopic spinal surgery for bilateral lumbar foraminal decompression by switching surgeon's position and primary 2 portals: a report of 2 cases with technical note. *Neurospine* 2019;16:138-47. <https://doi.org/10.14245/ns.1836330.165>
 12. Kim JE, Choi DJ, Park EJ, et al. Biportal endoscopic spinal surgery for lumbar spinal stenosis. *Asian Spine J* 2019;13:334-42. <https://doi.org/10.31616/asj.2018.0210>
 13. Park JH, Jun SG, Jung JT, Lee SJ. Posterior percutaneous endoscopic cervical foraminotomy and discectomy with unilateral biportal endoscopy. *Orthopedics* 2017;40:e779-83. <https://doi.org/10.3928/01477447-20170531-02>
 14. Song KS, Lee CW. The biportal endoscopic posterior cervical inclinatory foraminotomy for cervical radiculopathy: technical report and preliminary results. *Neurospine* 2020;17:S145-53. <https://doi.org/10.14245/ns.2040228.114>
 15. Atkins D, Best D, Briss PA, et al. Grading quality of evidence and strength of recommendations. *BMJ* 2004;328:1490. <https://doi.org/10.1136/bmj.328.7454.1490>
 16. Schunemann HJ, Cuello C, Akl EA, et al. GRADE guidelines: 18. How ROBINS-I and other tools to assess risk of bias in nonrandomized studies should be used to rate the certainty of a body of evidence. *J Clin Epidemiol* 2019;111:105-14. <https://doi.org/10.1016/j.jclinepi.2018.01.012>
 17. Heo DH, Ha JS, Jang JW. Biportal endoscopic posterior cervical foraminotomy for adjacent 2-level foraminal lesions using a single approach (sliding technique). *Neurospine* 2023;20:92-8. <https://doi.org/10.14245/ns.2346144.072>
 18. Jung SB, Gunadala I, Kim N. Comparison of cervical biportal endoscopic spine surgery and anterior cervical discectomy and fusion in patients with symptomatic cervical disc herniation. *J Clin Med* 2024;13:1823. <https://doi.org/10.3390/jcm13061823>
 19. Kang MS, You KH, Han SY, Park SM, Choi JY, Park HJ. Percutaneous full-endoscopic versus biportal endoscopic posterior cervical foraminotomy for unilateral cervical foraminal disc disease. *Clin Orthop Surg* 2022;14:539-47. <https://doi.org/10.4055/cios22050>
 20. Kang MS, Park HJ, Park SM, You KH, Ju WJ. Learning curve for biportal endoscopic posterior cervical foraminotomy determined using the cumulative summation test. *J Orthop Surg Res* 2023;18:146. <https://doi.org/10.1186/s13018-023-03611-0>
 21. Park S, Lee JH, Chough C. Overview and prevention of complications during biportal endoscopic cervical spine surgery. *J Minim Invasive Spine Surg Tech* 2023;8(Suppl 1):S51-5. <https://doi.org/10.21182/jmisst.2023.00808>
 22. Wang D, Xu J, Zhu C, Zhang W, Pan H. Comparison of outcomes between unilateral biportal endoscopic and percutaneous posterior endoscopic cervical keyhole surgeries. *Medicina (Kaunas)* 2023;59:437. <https://doi.org/10.3390/medicina59030437>
 23. Zhang P, Jin Y, Zhu B, Zheng M, Ying X, Zheng Q. Unilateral biportal endoscopic foraminotomy and discectomy combined with piezosurgery for treating cervical spondylotic radiculopathy with neuropathic radicular pain. *Front Neurol* 2023;14:1100641. <https://doi.org/10.3389/fneur.2023.1100641>
 24. Kim JY, Hong HJ, Lee DC, Kim TH, Hwang JS, Park CK. Comparative analysis of 3 types of minimally invasive posterior cervical foraminotomy for foraminal stenosis, uniportal-, biportal endoscopy, and microsurgery: radiologic and midterm clinical outcomes. *Neurospine* 2022;19:212-23. <https://doi.org/10.14245/ns.2142942.471>
 25. Akbari KK, Terry TH, Kanade U, Choi J. Clinical outcomes following treatment of cervical spondylotic radiculopathy with cervical posterior decompression using unilateral biportal endoscopic technique: a single center retrospective series of 20 patients. *Int J Spine Surg* 2025;19:19-26. <https://doi.org/10.14444/8690>
 26. Lee HR, Park JM, Kim IH, Kim JH, Yang JH. Comparison of open microscopic and biportal endoscopic approaches in multi-level posterior cervical foraminotomy: radiological and clinical outcomes. *J Clin Med* 2024;14:164. <https://doi.org/10.3390/jcm14010164>
 27. Song KS, Kim P. Assessment of clinical and radiologic outcomes of biportal endoscopic posterior cervical inclinatory foraminotomy : a retrospective cohort study. *J Korean Neurosurg Soc* 2025;68:446-55. <https://doi.org/10.3340/jkns.2024.0197>
 28. Lv J, Mei J, Feng X, Tian X, Sun L. Clinical efficacy and safe-

- ty of posterior minimally invasive surgery in cervical spondylosis: a systematic review. *J Orthop Surg Res* 2022;17:389. <https://doi.org/10.1186/s13018-022-03274-3>
29. Ross MN, Ross DA. Minimally invasive cervical laminectomy for cervical spondylotic myelopathy. *Clin Spine Surg* 2018;31:331-8. <https://doi.org/10.1097/bsd.0000000000000683>
 30. Thompson K, Travers H, Ngan A, Reed T, Shahsavarani S, Verma RB. Updates in current concepts in degenerative cervical myelopathy: a systematic review. *J Spine Surg* 2024;10:313-26. <https://doi.org/10.21037/jss-23-123>
 31. Johansen TO, Holmberg ST, Danielsen E, et al. Long-term results after surgery for degenerative cervical myelopathy. *Neurosurgery* 2024;94:454-60. <https://doi.org/10.1227/neu.0000000000002712>
 32. Heo DH, Lee N, Park CW, Kim HS, Chung HJ. Endoscopic unilateral laminotomy with bilateral discectomy using biportal endoscopic approach: technical report and preliminary clinical results. *World Neurosurg* 2020;137:31-7. <https://doi.org/10.1016/j.wneu.2020.01.190>
 33. Ju CI, Lee SM. Complications and management of endoscopic spinal surgery. *Neurospine* 2023;20:56-77. <https://doi.org/10.14245/ns.2346226.113>
 34. Boadi BI, Ikwuegbuenyi CA, Inzerillo S, et al. Complications in minimally invasive spine surgery in the last 10 years: a narrative review. *Neurospine* 2024;21:770-803. <https://doi.org/10.14245/ns.2448652.326>
 35. Park DK, Weng C, Zakko P, Choi DJ. Unilateral biportal endoscopy for lumbar spinal stenosis and lumbar disc herniation. *JBJS Essent Surg Tech* 2023;13:e22.00020. <https://doi.org/10.2106/jbjs.st.22.00020>
 36. Choi JH, Birring PS, Lee J, Hashmi SZ, Bhatia NN, Lee YP. A comparison of short-term outcomes after surgical treatment of multilevel degenerative cervical myelopathy in the geriatric patient population: an analysis of the national surgical quality improvement program database 2010-2020. *Asian Spine J* 2024;18:190-9. <https://doi.org/10.31616/asj.2023.0276>
 37. He B, Sheldrick K, Das A, Diwan A. Clinical and research MRI techniques for assessing spinal cord integrity in degenerative cervical myelopathy: a scoping review. *Biomedicines* 2022;10:2621. <https://doi.org/10.3390/biomedicines10102621>
 38. Kotheeranurak V, Lokhande PV, Tangdamrongtham T, et al. Complications in full-endoscopic posterior cervical surgery: a review of the literature and preventive strategies. *Global Spine J* 2025;15:3379-94. <https://doi.org/10.1177/21925682251328615>
 39. Hiyama A, Sakai D, Katoh H, Sato M, Watanabe M. Evaluating single-level vs. multi-level lateral lumbar interbody fusion: clinical outcomes and complications. *J Clin Neurosci* 2025;134:111082. <https://doi.org/10.1016/j.jocn.2025.111082>
 40. Mahesh B, Upendra B, Vijay S, Kumar GA, Reddy S. Complication rate during multilevel lumbar fusion in patients above 60 years. *Indian J Orthop* 2017;51:139-46. <https://doi.org/10.4103/0019-5413.201704>
 41. Park DY, Upfill-Brown A, Curtin N, et al. Clinical outcomes and complications after biportal endoscopic spine surgery: a comprehensive systematic review and meta-analysis of 3673 cases. *Eur Spine J* 2023;32:2637-46. <https://doi.org/10.1007/s00586-023-07701-9>
 42. Gonzalez-Murillo M, Castro-Toral J, Bonome-Gonzalez C, de Mon-Montoliu JA. Endoscopic surgery for multilevel spinal stenosis: a comprehensive meta-analysis and subgroup analysis of uniportal and biportal approaches. *Asian Spine J* 2025;19:133-47. <https://doi.org/10.31616/asj.2024.0171>
 43. Heo DH. Biportal endoscopic posterior cervical foraminotomy with discectomy for unilateral radicular arm pain due to cervical herniated disc. *Neurosurg Focus Video* 2024;10:V12. <https://doi.org/10.3171/2024.1.focvid23225>
 44. Huang YH, Lin CS, Pao JL. Contralateral inside-out biportal endoscopic posterior cervical foraminotomy: surgical techniques and preliminary clinical outcomes. *J Minim Invasive Spine Surg Tech* 2023;8:44-54. <https://doi.org/10.21182/jmisst.2023.00689>
 45. Fehlings MG, Tetreault LA, Riew KD, et al. A clinical practice guideline for the management of patients with degenerative cervical myelopathy: recommendations for patients with mild, moderate, and severe disease and nonmyelopathic patients with evidence of cord compression. *Global Spine J* 2017;7:70S-83S. <https://doi.org/10.1177/2192568217701914>
 46. Godil SS, Parker SL, Zuckerman SL, Mendenhall SK, McGirt MJ. Accurately measuring the quality and effectiveness of cervical spine surgery in registry efforts: determining the most valid and responsive instruments. *Spine J* 2015;15:1203-9. <https://doi.org/10.1016/j.spinee.2013.07.444>
 47. Zhang Y, Dai J, Dai G, Zhan W, Wang Y, Hu P. Comparison of clinical efficacy of posterior percutaneous endoscopic cervical discectomy versus unilateral biportal endoscopy key-hole techniques for cervical spondylotic radiculopathy: a retrospective study with 2 years. *J Orthop Surg Res* 2025;20:200. <https://doi.org/10.25236/ijfm.2021.030110>
 48. Mjaset C, Zwart JA, Kolstad F, Solberg T, Grotle M. Clinical improvement after surgery for degenerative cervical myelopathy; a comparison of patient-reported outcome measures during 12-month follow-up. *PLoS One* 2022;17:e0264954. <https://doi.org/10.1371/journal.pone.0264954>
 49. Lonne VV, Hara S, Gulati S, et al. Return to work after surgery for degenerative cervical myelopathy: a nationwide registry-based observational study. *Acta Neurochir (Wien)* 2023;165:779-87. <https://doi.org/10.1007/s00701-023-05521-w>
 50. Baumann AN, Chen M, Ahorukomeye P, Furey CG, Cheng CW. Factors associated with the rate of recovery after cervical decompression surgery for degenerative cervical myelopathy: a retrospective analysis. *Cureus* 2023;15:e39654. <https://doi.org/10.7759/cureus.39654>