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Original Article

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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

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Objective: The unilateral biportal endoscopic posterior cervical foraminotomy (UBE-PCF) has been recently adopted for unilateral radiating arm pain due to cervical herniated intervertebral disc or foraminal stenosis. We systematically meta-analyzed clinical outcomes and complications of the UBE-PCF and compared them with those of full-endoscopic PCF (FE-PCF).
Methods: We systematically searched the PubMed, Embase, and Web of Science until February 29, 2024. Clinical outcomes and complications of the UBE-PCF and FE-PCF were collected and analyzed using the fixed-effect or random-effects model. Clinical outcomes of the UBE-PCF were compared with minimal clinically important difference (MCID) following PCF to evaluate the efficacy of UBE-PCF.
Results: Ten studies were included in the meta-analysis. In the random-effects meta-analysis, the Neck Disability Index (NDI), visual analogue scale (VAS) neck, and VAS arm were significantly decreased after the UBE-PCF ($p < 0.001$). The improvement of NDI, VAS neck, and VAS arm were significantly higher than MCID ($p < 0.05$). The improvement of NDI, VAS neck, and VAS arm were not significantly different between the UBE-PCF and FE-PCF ($p > 0.05$). Overall incidence of complications of the UBE-PCF was 6.2% (24 of 390). The most common complication was dura tear (2.1%, 8 of 390). The incidence in overall complications was not significantly different between the UBE-PCF and FE-PCF ($p = 0.813$).
Conclusion: We found that the UBE-PCF significantly improved clinical outcomes. Regarding clinical outcomes and complications, the UBE-PCF and FE-PCF were not significantly different. Therefore, the UBE-PCF would be an advantageous surgical option comparable to FE-PCF for unilateral radiating arm pain.

Keywords: Cervical foraminotomy, Biportal endoscopic surgery, Endoscopic spine surgery, Full-endoscopic surgery, Herniated Intervertebral disc, Spinal stenosis

INTRODUCTION

Unilateral radiating arm pain often results from cervical herniated intervertebral disc (HIVD) or foraminal stenosis. Anterior cervical discectomy and fusion (ACDF) has been a gold standard for these pathologies.[1-4] However, ACDF has several disadvantages, including risks of instrument failure of a plate with screw and interbody cage, motion limitation and adjacent segment disease due to fusion, and approach-related complications, such as tracheo-esophageal complex injury.[5,6] To avoid these disadvantages of ACDF, posterior cervical foraminotomy (PCF) would be another surgical option for unilateral radiating arm pain.[7-9] Nevertheless, conventional microscopic PCF also has a limitation: posterior neck musculature injury. The microscopic PCF requires posterior neck muscle dissection, which could cause postoperative kyphosis and persistent neck pain. The full-endoscopic PCF (FE-PCF) has been adopted for minimally invasive surgery in response to this limitation.[10-13] However, the FE-PCF has a steep learning curve and requires specialized instruments for uniportal spine surgery.[10]

The unilateral biportal endoscopic (UBE) spine surgery has recently emerged as a novel technique.[14,15] The UBE spine surgery offers a familiar endoscopic view comparable to that of conventional open microscopic spine surgery. Furthermore, unlike the FE spine surgery, the UBE spine surgery does not require specialized instruments. Most of the instruments used in open microscopic spine surgery, such as Kerrison rongeur, nerve freer, and ball tip probe, can also be used in the UBE spine surgery, potentially making it more accessible for most spine surgeons. The UBE spine surgery, initially developed for and applied to the lumbar region, has recently expanded to include treatments for the cervical region.[14,15] The UBE-PCF has been adopted as another surgical option for unilateral radiating arm pain. Subsequently, literatures that evaluated the efficacy and complication of the UBE-PCF have been published.[16-25] However, despite the advantages of the UBE-PCF, the level of evidence of the UBE-PCF remains limited, contrary to open microscopic and FE-PCF for which meta-analysis has been reported.[26-32] Although the FE-PCF and UBE-PCF are both endoscopic surgery, the FE-PCF has high-level evidence for clinical efficacy and outcomes, while the UBE-PCF did not.[10,12,13,28,29,32] The absence of high-level evidence of the UBE-PCF warrants a comprehensive review of the UBE-PCF in terms of efficacy for radiating pain relief and safety. Furthermore, because the UBE-PCF is a relatively novel technique, it is imperative that complications of the UBE-PCF have to be analyzed to evaluate the safety of the UBE-PCF and to prevent and manage the complications adequately. Therefore, this meta-analysis aims to evaluate the clinical efficacy and complications of the UBE-PCF and to compare them with those of FE-PCF.

MATERIALS AND METHODS

This study was registered in the PROSPERO (ID: CRD42024510721) and reported in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guideline.[33] We conducted a systematic review and meta-analysis of clinical studies on the UBE-PCF for unilateral radiating pain due to cervical foraminal stenosis or HIVD. Furthermore, we compared UBE-PCF with FE-PCF regarding clinical outcomes and complications.

1. Search Strategy

We searched records in the PubMed, Embase, and Web of Science from their inception to February 29, 2024. The following queries were used to search the records: ('cervical spine' OR 'cervical radiculopathy' OR 'cervical herniated intervertebral disc' OR 'cervical herniated intervertebral disk' OR 'cervical disc herniation' OR 'cervical disk herniation' OR 'cervical foraminal stenosis') AND ('foraminotomy' OR 'laminoforaminotomy' OR 'keyhole' OR 'discectomy' OR 'diskectomy') AND ('uniportal endoscopic' OR 'uniportal endoscope' OR 'full endoscopic' OR 'full endoscope' OR 'unilateral biportal endoscope' OR 'unilateral biportal endoscopic' OR 'unilateral-biportal endoscope' OR 'unilateral-biportal endoscopic' OR 'percutaneous endoscope' OR 'percutaneous endoscopic' OR 'percutaneous' OR 'uniportal' OR 'biportal' OR 'endoscopic' OR 'endoscope'). In addition, we manually searched the additional relevant studies. Two reviewers (SHL and JS) independently searched and selected the literature. In instances of disagreements, disagreements were resolved through a discussion.

2. Study Selection

We used patients, interventions, outcomes, and study design (PICOS) criteria to choose inclusion for the studies. PICOS criteria in this study were as follows: (1) "patients" with unilateral radiating arm pain due to cervical foraminal stenosis or HIVD, (2) UBE-PCF as the "intervention," (3) FE-PCF as the "comparator," (4) clinical outcome (neck disability index [NDI], visual analogue scale [VAS] neck, and VAS arm), and complications as the "outcome," and (5) original articles for "study design". The exclusion criteria were as follows: (1) nonoriginal articles, (2) animal, experimental, or cadaveric studies, (3) irrelevant articles, (4) reporting only FE-PCF without comparison to UBE-PCF, (5) not written in English.

3. Extraction of Data

Demographics, clinical outcomes, and complications were collected for the UBE-PCF and FE-PCF. Demographics of the studies were extracted, including author, publication year,

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country, study design, number of patients, age, sex, number of operation segments, segment range, and follow-up periods. Clinical outcomes were extracted, including NDI, VAS neck, and VAS arm at the preoperative, postoperative, and final follow-up. Clinical outcomes of the UBE-PCF were compared with minimal clinically important difference (MCID) following PCF. MCIDs were defined as NDI improvement 8 or more, and VAS neck and arm improvement 3 or more.[34,35] Occurrences of surgical complications were analyzed and categorized as follows: dural tear, postoperative transient root palsy, epidural hematoma, infection, and others.

4. Quality Assessment

The quality of studies included in the meta-analysis was assessed by the ROBINS-I (Risk Of Bias In Nonrandomized Studies of Interventions).[36] Risk of biases in 7 domains were evaluated in terms of confounding, selection of participants, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes, and selection of the reported result. The judgment of risk of bias was classified as low, moderate, severe, and critical risks.

5. Statistical Analysis

Statistical analyses were conducted using R ver. 4.1.1 (R Foundation for Statistical Computing, Vienna, Austria). All statistical analyses were two-sided. A p-value of < 0.05 was considered statistically significant. The Cochran Q and Higgins I^2 were used to assess heterogeneity between studies. The Higgins $I^2 > 50\%$ was used as a threshold to indicate significant heterogeneity. The fixed-effect model or random-effects model was chosen according to Higgins I^2. To estimate the overall effect size of UBE-PCF, we calculated the mean difference (MD) with a 95% confidence interval (CI) between clinical outcomes at preoperative and final follow-up. A 1-sample t-test was conducted to compare clinical outcomes between the pooled effect of UBE-PCF and MCID. We compared the MDs in clinical outcomes and the incidence of complications between the UBE-PCF and FE-PCF. Publication bias was assessed using a funnel plot and quantified by the Egger test.

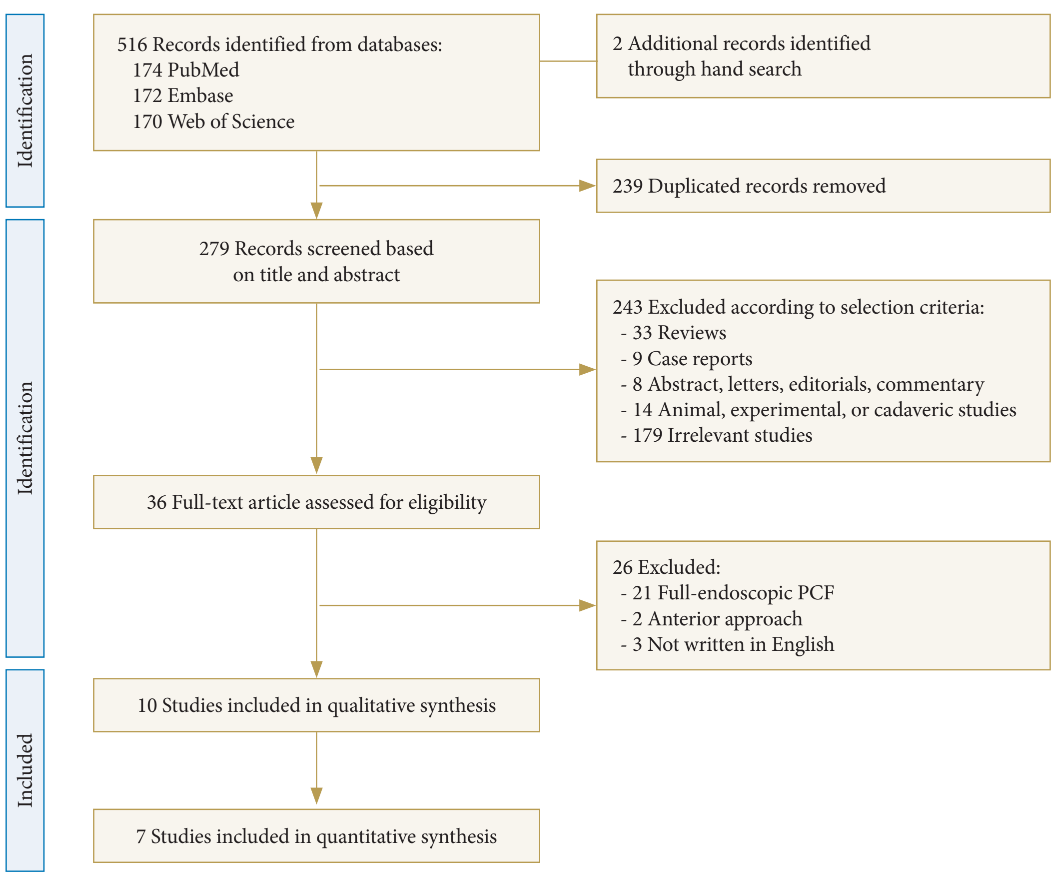

Fig. 1. Flowchart of the study inclusion. PCF, posterior cervical foraminotomy.

RESULTS

1. Literature Search

A total of 516 articles were searched using subject heading, 174 from PubMed, 172 from Embase, and 170 from Web of Science. Two additional articles were identified through hand search. Among these 518 articles, 239 duplicated articles were removed. Among 279 articles were screened based on title and abstract, and 243 were excluded: 33 reviews, 9 case reports, 8 nonoriginal articles, 14 animal, experimental, or cadaveric studies, and 179 irrelevant studies. Full-text articles were assessed for eligibility in 36 articles, and 26 articles were excluded: 21 full-endoscopic PCF without comparison to UBE-PCF, 2 anterior approaches, 3 not written in English. Finally, 10 studies were included in qualitative synthesis.[16-25] Of the 10 studies, 7 were included in quantitative synthesis of clinical outcomes because 1 did not report clinical outcome and 2 suggested clinical outcomes as line graphs without numerical values (Fig. 1).

2. Characteristics of Studies

Table 1 summarizes the characteristic of the studies included in the meta-analysis. The 10 studies comprised a total of 558 patients, 390 in the UBE-PCF and 168 in FE-PCF. All studies were retrospective single-center studies. Among them, 7 studies were published from Korea and 3 from China. In a total of 10 studies, 6 were case series of the UBE-PCF and 4 were retrospective comparative studies between the UBE-PCF and FE-PCF. Number of segments for which PCF were performed were 1–2 segments.

Supplementary Fig. 1 shows the risk of bias for quality assessment using the ROBINS-I tool.

3. Clinical Outcomes of the UBE-PCF

Clinical outcomes of the UBE-PCF are presented in Table 2. In the study of Song et al.,[22] NDI was multiplied by 2; therefore, NDI in study of Song et al.,[22] was divided by 2 in this meta-analysis. In the random-effects meta-analysis, the NDI, VAS neck, and VAS arm were significantly decreased after the UBE-PCF (Fig. 2). The NDI was significantly decreased with MD of 24.83, 95% CI (20.35–29.32), and $p < 0.001$. The improvement of NDI was significantly higher than MCID with a p-value < 0.001. The VAS neck was significantly decreased with MD of 4.61, 95% CI (3.56–5.66), and $p < 0.001$. The improvement of VAS neck was significantly higher than MCID with a p-value of

Table 1. Characteristic of the studies included in the meta-analysis

Study	Country	Study design	Operation	Sample size (n)	Age (yr), (mean ± SD)	Sex, M:F	No. of segments	Segments range	Mean follow-up (mo)
Park et al.[21] 2017	Korea	CS	UBE-PCF	13	47.1 ± NA	5/8	1	C4–7	14.8
Song et al.[22] 2020	Korea	CS	UBE-PCF	7	59.0 ± 12.1	3/4	1–2	C4–7	6.4
Kim et al.[20] 2022	Korea	RCS	UBE-PCF	30	52.3 ± 12.0	21/9	1	C4–T1	11.7
			FE-PCF	38	55.3 ± 9.1	27/11	1	C4–T1	10.0
Jung and Kim[17] 2022	Korea	CS	UBE-PCF	109	54.5 ± 9.2	84/25	1	C3–T1	6.0
Kang et al.[19] 2022	Korea	RCS	UBE-PCF	33	52.7 ± 9.6	11/22	1	C4–T1	Minimum 12
			FE-PCF	32	53.7 ± 8.5	10/22		C4–T1	Minimum 12
Heo et al.[16] 2023	Korea	CS	UBE-PCF	12	57.8 ± 6.7	10/2	2	C4–T1	13.6
Kang et al.[18] 2023	Korea	CS	UBE-PCF (group 1)	19	50.6 ± 10.8	15/4	1	C4–T1	Minimum 12
			UBE-PCF (group 2)	30	54.6 ± 7.8	21/9	1	C5–T1	Minimum 12
Wang et al.[23] 2023	China	RCS	UBE-PCF	89	58.3 ± 12.0	42/47	1	C4–7	26.5
			FE-PCF	65	60.1 ± 9.7	28/37	1	C4–7	26.6
Zhang et al.[24] 2023	China	CS	UBE-PCF	12	50.2 ± 9.5	7/5	1	C4–7	16.8
Zhong et al.[25] 2024	China	RCS	UBE-PCF	36	53.5 ± NA	20/16	1–2	C4–T1	Minimum 3
			FE-PCF	33		18/15	1–2	C3–T1	Minimum 3

SD, standard deviation; CS, case series; UBE, unilateral biportal endoscopic; PCF, posterior cervical foraminotomy; FE, full-endoscopic; RCS, retrospective cohort study; NA, not available.

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0.030. The VAS arm was significantly decreased with MD of 5.96, 95% CI (5.21–6.72), and $p < 0.001$. The improvement of VAS arm was significantly higher than MCID with a p-value < 0.001.

4. Comparison of Clinical Outcomes Between the UBE-PCF and FE-PCF

Clinical outcomes of the UBE-PCF and FE-PCF are presented in Table 2. In this meta-analysis, the improvement of NDI, VAS neck, and VAS arm between preoperatively and final follow-up were not significantly different between the UBE-PCF and FE-PCF. In the random effect meta-analysis, the change of NDI was not significantly different (MD, -1.24; 95% CI, -3.38 to 0.90; $p = 0.257$) between the 2 groups. In the random-effects meta-analysis, the change of VAS neck was not significantly different (MD, 0.98; 95% CI, -0.50 to 2.46; $p = 0.195$) between the 2 groups. In both the fixed and random-effects meta-analysis, the change of the VAS arm was not significantly different (MD,

Table 2. Clinical outcomes of the studies included in the meta-analysis

Study	Modality	State	NDI	VAS neck	VAS arm
Park et al.[21] 2017	UBE	Baseline	27.0 ± 2.5	6.2 ± 0.8	7.0 ± 1.1
		POD 1	NA	NA	NA
		Final	6.8 ± 1.3	2.4 ± 0.9	2.2 ± 0.6
Song et al.[22] 2020	UBE	Baseline	30.5 ± 13.5	NA	7.7 ± 0.8
		POD 1	NA	NA	NA
		Final	5.3 ± 2.9	NA	0.9 ± 0.7
Kim et al.[20] 2022	UBE	Baseline	26.2 ± 2.5	4.3 ± 1.6	7.6 ± 0.7
		POD 1	NA	1.8 ± 0.8	2.5 ± 1.0
		Final	1.3 ± 4.4	1.0 ± 0.5	0.8 ± 1.0
	FE	Baseline	22.3 ± 3.9	6.5 ± 1.1	7.4 ± 0.8
		POD 1	NA	2.4 ± 0.7	2.5 ± 0.9
		Final	1.0 ± 0.6	0.7 ± 0.5	0.6 ± 0.7
Jung and Kim[17] 2022	UBE	Baseline	21.9 ± 7.7	6.6 ± 2.1	7.2 ± 2.4
		POD 1	NA	NA	NA
		Final	3.1 ± 2.8	1.1 ± 0.8	1.0 ± 0.7
Heo et al.[16] 2023	UBE	Baseline	43.3 ± 11.1	5.3 ± 2.1	8.1 ± 1.1
		POD 1	NA	NA	NA
		Final	10.3 ± 6.3	2.3 ± 1.3	1.2 ± 0.9
Wang et al.[23] 2023	UBE	Baseline	35.7 ± 4.2	7.9 ± 0.7	6.3 ± 0.9
		POD 1	NA	NA	NA
		Final	14.6 ± 3.1	1.7 ± 0.5	1.9 ± 0.8
	FE	Baseline	36.3 ± 3.4	8.1 ± 0.8	6.4 ± 1.1
		POD 1	NA	NA	NA
		Final	15.2 ± 3.2	1.9 ± 0.7	1.9 ± 0.7
Zhong et al.[25] 2024	UBE	Baseline	34.6 ± 3.4	5.9 ± 0.8	6.8 ± 0.9
		POD 1	NA	2.6 ± 0.6	3.4 ± 1.8
		Final	1.5 ± 0.5	0.5 ± 0.5	0.8 ± 0.6
	FE	Baseline	34.2 ± 2.3	6.4 ± 0.7	6.6 ± 1.0
		POD 1	NA	2.9 ± 0.6	3.0 ± 0.8
		Final	1.5 ± 0.5	0.5 ± 0.6	0.6 ± 0.6

Values are presented as mean ± standard deviation.
NDI, neck disability index; VAS, visual analogue scale; UBE, unilateral biportal endoscopic; POD, postoperative day; FE, full-endoscopic; NA, not available.

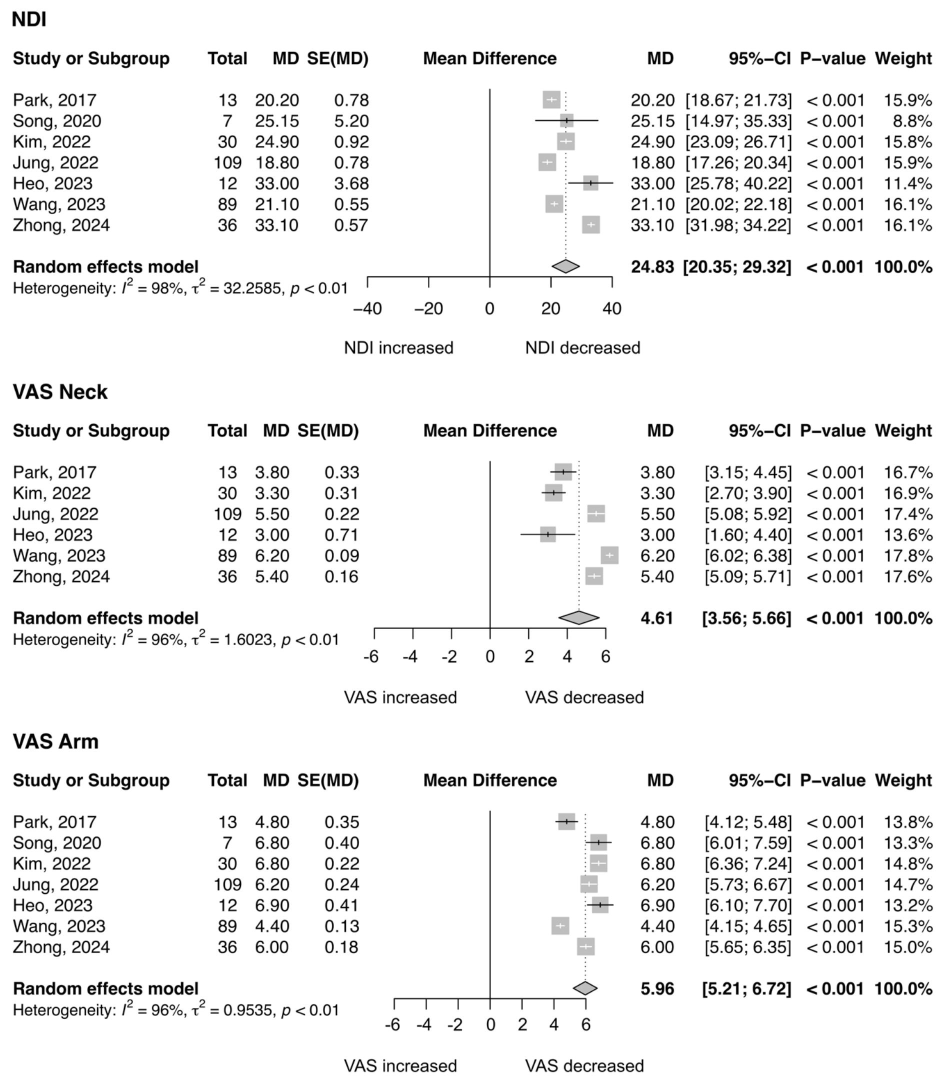

Fig. 2. Forest plots for the clinical outcomes of the UBE-PCF in the random-effects meta-analysis. NDI, VAS neck, and VAS arm were significantly decreased following the UBE-PCF ($p < 0.001$). UBE, unilateral biportal endoscopic; PCF, posterior cervical foraminotomy; MD, mean difference; SE, standard error; CI, confidence interval; NDI, neck disability index; VAS, visual analogue scale.

0.05; 95% CI, -0.16 to 0.25; p = 0.646) between the 2 groups.

The improvements of the VAS neck and VAS arm between preoperative and postoperative one day were also analyzed. In the random effect meta-analysis, the change of VAS neck was not significantly different (MD, 0.88; 95% CI, -0.49 to 2.25; p = 0.209) between the 2 groups. In the fixed-effect meta-analysis, the change of VAS arm was not significantly different (MD, -0.07; 95% CI, -0.41 to 0.27; p = 0.695), and in the random-effects meta-analysis, the change of VAS arm was not also significantly different (MD, -0.06; 95% CI, -0.43 to 0.32; p = 0.756) between the 2 groups (Supplementary Fig. 2).

5. Complications

Table 3 shows complications of the UBE-PCF and FE-PCF of the studies included in the meta-analysis. The overall incidence of complications of the UBE-PCF was 6.2% (24 of 390). The most common complication was dura tear (2.1%, 8 of 390). The second most common complication was both transient root palsy (0.8%, 3 of 390) and epidural hematoma (0.8%, 3 of 390).

The overall incidence of complications of the FE-PCF was 8.3% (14 of 168). The most common complication was dura tear (3.6%, 6 of 168). The second most common complication was both transient root palsy (2.4%, 4 of 168). No postoperative infection was reported in both UBE-PCF and FE-PCF in all

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Table 3. Complications of the UBE-PCF and FE-PCF of the studies included in the meta-analysis

Study	Overall		Dural tear		Transient root palsy		Epidural hematoma		Infection		Others	
	Events	Incidence	Events	Incidence	Events	Incidence	Events	Incidence	Events	Incidence	Events	Incidence
UBE-PCF												
Park et al.[21] 2017	0/13	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Song et al.[22] 2020	1/7	14.3%	1	14.3%	0	0%	0	0%	0	0%	0	0%
Kim et al.[20] 2022	4/30	13.3%	1	3.3%	1	3.3%	0	0%	0	0%	2	6.7%
Jung and Kim[17] 2022	1/109	0.9%	0	0%	0	0%	0	0%	0	0%	1	0.9%
Kang et al.[19] 2022	4/33	12.1%	1	3%	0	0%	1	3%	0	0%	2	6.1%
Heo et al.[16] 2023	2/12	16.7%	0	0%	1	8.3%	0	0%	0	0%	1	8.3%
Kang et al.[18] 2023	4/49	8.2%	0	0%	0	0%	2	4.1%	0	0%	2	4.1%
Wang et al.[23] 2023	3/89	3.4%	2	2.2%	0	0%	0	0%	0	0%	1	1.1%
Zhang et al.[24] 2023	0/12	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Zhong et al.[25] 2024	5/36	13.9%	3	8.3%	1	2.8%	0	0%	0	0%	1	2.8%
Total	24/390	6.2%	8	2.1%	3	0.8%	3	0.8%	0	0%	10	2.6%
FE-PCF												
Kim et al.[20] 2022	3/38	7.9%	0	0%	2	5.3%	0	0%	0	0%	1	2.6%
Kang et al.[19] 2022	3/32	9.4%	1	3.1%	1	3.1%	0	0%	0	0%	1	3.1%
Wang et al.[23] 2023	4/65	6.2%	1	1.5%	1	1.5%	0	0%	0	0%	2	3.1%
Zhong et al.[25] 2024	4/33	12.1%	4	12.1%	0	0%	0	0%	0	0%	0	0%
Total	14/168	8.3%	6	3.6%	4	2.4%	0	0%	0	0%	4	2.4%

UBE, unilateral biportal endoscopic; FE, full-endoscopic; PCF, posterior cervical foraminotomy.

studies included in the meta-analysis.

The overall incidence of complications was lower in the UBE-PCF (6.2%) than that in the FE-PCF (8.3%), but in both the fixed and random-effects meta-analysis, there was no significant difference (odds ratio [OR], 0.91; 95% CI, 0.43–1.95; $p = 0.813$) (Fig. 3). The incidence of dura tear was also lower in the UBE-PCF (2.1%) than in the FE-PCF (3.6%), but there was also no significant difference (OR, 0.97; 95% CI, 0.32–2.98; $p = 0.957$). The incidence of transient root palsy was also lower in the UBE-PCF (0.8%) than in the FE-PCF (2.4%), but there was no significant difference (OR, 1.65; 95% CI, 0.38–7.29; $p = 0.506$).

6. Publication Bias

Supplementary Fig. 3 shows funnel plots of studies reporting the UBE-PCF regarding NDI, VAS neck, and VAS arm. The p-values of the Egger test for studies reporting the UBE-PCF were 0.930 for the NDI, 0.013 for the VAS neck, and 0.118 for the VAS arm of UBE-PCF. Supplementary Fig. 4 showed funnel plots of comparative studies between the UBE-PCF and FE-PCF regarding NDI, VAS neck, VAS arm, and overall complications. The p-values of the Egger test for comparative studies between the UBE-PCF and FE-PCF were 0.080 for the NDI, 0.061 for the VAS neck, 0.018 for the VAS arm, and 0.832 for the overall complications.

DISCUSSION

1. Key Findings

In this meta-analysis, the UBE-PCF significantly improved clinical outcomes. The improvements in clinical outcomes were not significantly different between the UBE-PCF and FE-PCF. In overall complications, there was no significant difference in the incidence between the UBE-PCF and FE-PCF.

2. Clinical Efficacy of the UBE-PCF for Unilateral Radiating Arm Pain

A previously published meta-analysis reported the improvement of NDI (MD, 20.30; 95% CI, 18.81–21.79), VAS neck (MD, 4.16; 95% CI, 2.70–5.61), and VAS arm (MD, 5.31; 95% CI, 4.50–6.12) following microscopic PCF.[27] This was similar to our results, and it was not unexpected because UBE-PCF and microscopic PCF were essentially almost the same procedure in terms of neural decompression, including surgical steps and surgical instruments. One of the differences between the 2 operations is the operative view; the UBE-PCF has a more magnified view than microscopic surgery because of the endoscopic

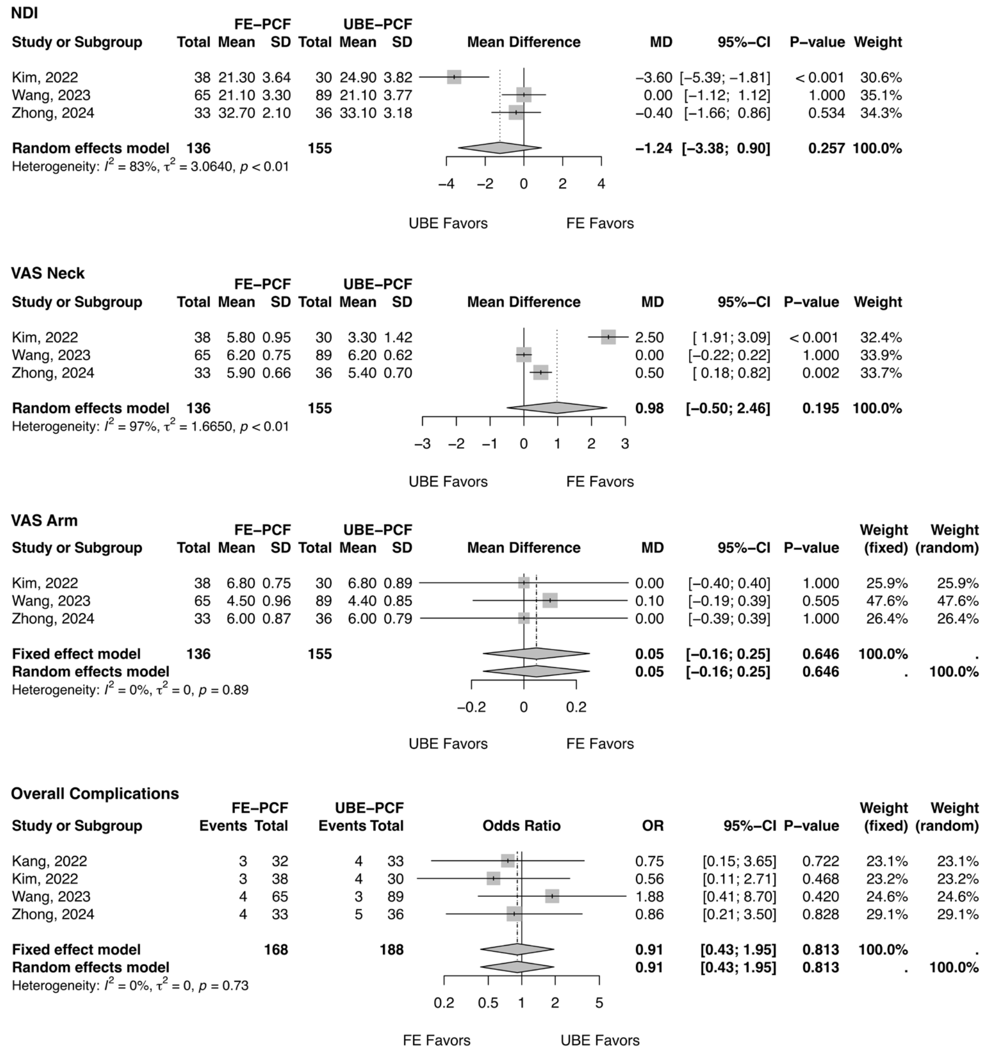

Fig. 3. Forest plots for the clinical outcomes and complications of the UBE-PCF and FE-PCF. Mean differences of NDI, VAS neck, and VAS arm were not significantly different between the UBE-PCF and FE-PCF, with p-values of 0.257, 0.195, and 0.646, respectively. Odds ratio of overall complications was not significantly different between UBE-PCF and FE-PCF with a p-value of 0.813. UBE, unilateral biportal endoscopic; FE, full-endoscopic; PCF, posterior cervical foraminotomy; MD, mean difference; SD, standard deviation; CI, confidence interval; NDI, neck disability index; VAS, visual analogue scale.

view, which is similar to the arthroscopic view of orthopedic surgery of the knee and shoulder. Furthermore, continuous irrigation by normal saline is another difference between the 2 operations. Due to continuous irrigation, the UBE-PCF would obtain more clear view than microscopic PCF because continuous irrigation washes out the blood and tamponade the epidural bleeding by the hydrostatic pressure of normal saline inflow. Therefore, the neural structure and the dural sac were visualized clearly to ensure complete neural decompression.

3. The UBE-PCF Versus FE-PCF

The surgical goal of both UBE-PCF and FE-PCF for unilateral radiating pain due to cervical HIVD or foraminal stenosis is sufficient neural decompression for relieving the pain. Therefore, when sufficient neural decompression was achieved, clinical outcomes would not differ, regardless of which operation was performed, UBE-PCF or FE-PCF. However, it may be postulated that immediate postoperative neck pain would be less in the FE-PCF than in the UBE-PCF. Because the number of working and endoscopic portals is different between the 2 operations. In the FE-PCF, the endoscope and instruments are moved in the same coaxial fashion due to characteristics of uniportal surgery. On the contrary, in the UBE-PCF, the endoscope and instruments are manipulated independently in separate portals (dual

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portals): the endoscopic portal and the working portal, respectively. Because more portals are needed in UBE-PCF than in the FE-PCF, more posterior neck muscle dissection occurred in the UBE-PCF. In addition, in the pathway of portal through the posterior neck, there are various muscles, including the trapezius, splenius capitis, semispinalis capitis, splenius cervicis, and multifidus muscles. Therefore, impact of dual portal compared to uniportal would be significant in the posterior neck muscles. To evaluate the impact of dual portal compared to uniportal in the immediate postoperative neck pain, we compared the postoperative one day VAS neck following UBE-PCF and FE-PCF, and there was no significant difference in the random-effects meta-analysis (MD, 0.88; 95% CI, -0.49 to 2.25; $p = 0.209$). However, only 2 studies were included in the meta-analysis.[20,25] Although Kang et al. reported that postoperative 2 days VAS neck was significantly lower in the FE-PCF (2.55 ± 0.96) than in the UBE-PCF (3.04 ± 0.79) with a p-value of 0.005, the study of Kang et al.[19] was not included in the meta-analysis for immediate postoperative VAS neck due to insufficient data. Therefore, although the number of portals may significantly impact immediate postoperative neck pain, it may not be demonstrated in the statistical analysis due to the small number of studies.

4. Dural Tears

In this study, dura tear was the most common complication in both UBE-PCF (2.1%) and FE-PCF (3.6%). A previous meta-analysis regarding complications of endoscopic spinal surgery also reported that dura tear was the most frequent complication.[37] CSF leakage due to a dura tear can cause various complications, such as headache, nausea, pesudomeningocele, intracranial hypotension, intracranial hemorrhage, subdural hematoma, meningitis, and rootlet herniation and transection.[37-40] Postoperative absolute bed rest due to CSF leakage may cause medical complications such as pneumonia, pulmonary thromboembolism, or deep venous thrombosis. Furthermore, a dura tear during the operation may be troublesome and cause incomplete neural decompression. Moreover, due to the characteristics of endoscopic spine surgery as a fluid-medium surgery, a dural tear could cause seizures because continuous saline irrigation leads to intrathecal fluid inflow through the dural tear.[41,42] Therefore, it is mandatory to prevent and manage dural tears appropriately to prevent CSF leakage and saline inflow into thecal sac and to avoid these complications. Dural repair in the setting of endoscopic surgery is challenging due to the narrow corridor to the dural tear and limited instrument manipulation. Various endoscopic technique was introduced to manage dural tears.[38,43-47] Application of a dural sealant patch (TachoSil, Takeda Austria GmbH, Linz, Austria) could address dural tear. Nam et al.[47] suggested a double layer dural sealant packing technique for dural tears. Heo et al.[43] reported primary dural repair using sutureless nonpenetrating vascular clips via biportal endoscopic surgery. Although these techniques would be effective methods to manage dural tears, conversion to open spine surgery may be warranted for the primary suture of dural tears in some cases.[45] However, muscle dissection of open spine surgery makes more dead space than endoscopic spine surgery and would promote the formation of pseudomeningocele. Shin et al. reported primary suture technique in the setting of endoscopic spine surgery using an endoscopic curette.[46]

5. Transient Root Palsy

Postoperative transient root palsy was the second most common complications in both UBE-PCF (0.8%) and FE-PCF (2.4%). Although the incidence of transient root palsy was lower in the UBE-PCF than in the FE-PCF, there was no significant difference between both groups (OR, 1.65; 95% CI, 0.38–7.29; $p = 0.506$). Wu et al.[48] reported that the incidence of transient root palsy was significantly higher ($p = 0.002$) in the FE-PCF (4.5%; 95% CI, 2.8%–7.2%) than in the microendoscopic PCF (1.5%; 95% CI, 0.9%–2.5%) in their meta-analysis. They hypothesized the reason of higher incidence of transient root palsy in the FE-PCF; a steeper learning curve of FE-PCF lead to more probing of nerve root which may cause irritation of nerve root and subsequent transient root palsy. Furthermore, due to restricted operative view in the FE-PCF, nerve root retraction would be more excessive. These reasons would be also applicable in the reason why the incidence of transient root palsy was higher in the FE-PCF than in the UBE-PCF.

Another factor may contribute to transient root palsy in advanced surgeons with optimal learning curves of FE-PCF. In the FE-PCF, root retraction could be caused by less bone resection compared to UBE-PCF. During endoscopic spine surgery, water inflow may press down the neural element and may seem fully decompressed. However, less bone resection may compress the nerve root while the dural sac shifts posteriorly after the operation is finished. Furthermore, nerve root traction may occur because of the rotating motion of the bevel ended tip of working channel during drilling and discectomy, even though the working channel is manipulated gently.

6. Postoperative Infection

No postoperative infection was reported in all studies included in this meta-analysis in the UBE-PCF and FE-PCF. Continuous irrigation would contribute to a lower postoperative infection rate. Kang et al. published an article that compared the prevalence of intraoperative contamination of ligamentum flavum and nucleus pulposus between biportal endoscopic transforaminal lumbar interbody fusion (TLIF) and open TLIF.[49] They reported that open TLIF was an independent risk factor for positive cultures, and continuous wound irrigation of biportal endoscopic TLIF showed significantly lower positive cultures. This finding would also apply in both UBE-PCF and FE-PCF in the same context as continuous irrigation of biportal endoscopic TLIF.

7. Increased Intracranial Pressure

Another concern of endoscopic spine surgery in the cervical spine is that continuous fluid pressure may induce increased intracranial pressure (IICP) due to the proximity between the brain and cervical epidural space. Because IICP could cause serious complications, such as nausea, vomiting, headache, or seizure.[50-52] However, no studies in this meta-analysis reported complications related to IICP. Two previous articles assessed "cervical epidural pressure" during biportal endoscopic "lumbar" discectomy.[53,54] Baseline cervical epidural pressures were 16.7 ± 9.1 mmHg and 14.8 ± 2.8 mmHg, and maximum cervical epidural pressures were 45.2 ± 21.9 mmHg and 32.9 ± 8.1 mmHg in each study, respectively. Maximum cervical epidural pressure was measured when epidural space was exposed following laminectomy. Although maximum cervical epidural pressures were significantly increased ($p < 0.05$) from baseline pressure, no patients reported a neurologic deficit associated with IICP. Although no previous articles reported cervical epidural pressure during biportal endoscopic cervical spine surgery, Hong et al.[55] reported water dynamics in UBE lumber spine surgery in a prospective, proficiency-matched, *in vivo* study. They measured the water pressure of the epidural space using a water column manometer. The mean water pressure of the epidural space was 12.3 ± 6.7 mmHg. Although the water pressure of epidural space might differ between the cervical and lumbar areas due to differences in canal diameter and area, we believe it would not be significantly different. Because water dynamics of the UBE spine surgery in terms of continuous inflow and outflow are identical between the cervical and lumbar regions. Furthermore, the results of previous studies imply that cervical epidural space could endure maximal cervical epidural pressure of 45.2 ± 21.9 mmHg and 32.9 ± 8.1 mmHg.[53,54] Given these results comprehensively, the UBE-PCF would not cause IICP as long as outflow is maintained. Therefore, optimal maintenance of the water outflow in the cervical spine is imperative.

In the cervical spine, it is crucial to maintain optimal water pressure and ensure fluent water outflow due to its spinal cord-level characteristics. We have to be very careful about the water outflow because water outflow may be obscured by a multi-layer of neck muscles. Therefore, sufficient fascia release is mandatory for fluent water outflow when making a working portal of UBE-PCF. Regarding water outflow, the placement of a semitubular retractor in the working portal can enhance water outflow. Hong et al.[55] reported that epidural water pressure was significantly lower with the semitubular retractor (6.92 ± 2.16 mmHg) than without the semitubular retractor (17.26 ± 5.57 mmHg) ($p < 0.01$). During UBE-PCF, the poor outflow of irrigation saline can be manifested as a blurred operative field on the endoscopic view. Therefore, surgeons could notice poor outflow by blurred operative field. Furthermore, surgeons and assistants should repeatedly check the fluent water outflow from the working portal to ensure optimal water outflow.

Regarding water pressure, an automated pressure-controlled pump system can be used in the UBE-PCF to ensure and maintain optimal water pressure.[18,19] Kang et al.[19] used a pressure-controlled pump to set the water pressure to 30–40 mmHg before exposure to the epidural space and 30 mmHg after exposure to prevent IICP.

8. Limitations

This study has several limitations. First, a relatively small number of studies were included to compare the UBE-PCF and FE-PCF (3 comparative studies). Furthermore, although statistical analysis showed that postoperative one day neck pain was not significantly different (MD, 0.88; 95% CI, -0.49 to 2.25; $p = 0.209$) between the UBE-PCF and FE-PCF, it is intuitive that FE-PCF would have less postoperative pain due to the nature of uniportal than UBE-PCF which have a dual portal. In addition, most included studies were case series, and there was no randomized controlled trial comparing the UBE-PCF and FE-PCF because UBE-PCF had recently adopted surgical methods for treating cervical HIVD or foraminal stenosis. The first UBE-PCF case series was published in 2017.[21] After more studies have been published that compare UBE-PCF and FE-PCF, an updated meta-analysis would be warranted.

Potential bias is another limitation of our study. Two case series of UBE-PCF and one comparative study of UBE-PCF and FE-PCF include two-level PCF. Multilevel PCF would have more muscle injury than single-level PCF due to the number of

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portals and manipulation of instruments in different directions. However, a number of operative levels could not be considered during the synthesis of clinical outcomes. A heterogeneous number of operative levels (single or 2 levels) may be a confounding factor for clinical outcomes. Publication bias is another bias in this meta-analysis. The NDI did not show significant publication bias in the studies reporting UBE-PCF ($p=0.93$) and comparative studies between UBE-PCF and FE-PCF ($p=0.08$). On the contrary, the VAS neck in the studies reporting UBE-PCF ($p=0.013$) and the VAS arm ($p=0.018$) in the comparative studies showed publication bias.

CONCLUSION

In this meta-analysis, we included 10 studies to evaluate the clinical efficacy and complications of the UBE-PCF and 4 to compare it with FE-PCF. We found that the UBE-PCF significantly improved neck and radiating arm pain. Regarding clinical outcomes and complications, the UBE-PCF and FE-PCF were not significantly different. Given these findings, the UBE-PCF would be an advantageous surgical option comparable to FE-PCF for unilateral radiating arm pain.

NOTES

Supplementary Materials: Supplementary Figs. 1-4 can be found via https://doi.org/10.14245/ns.2448430.215.

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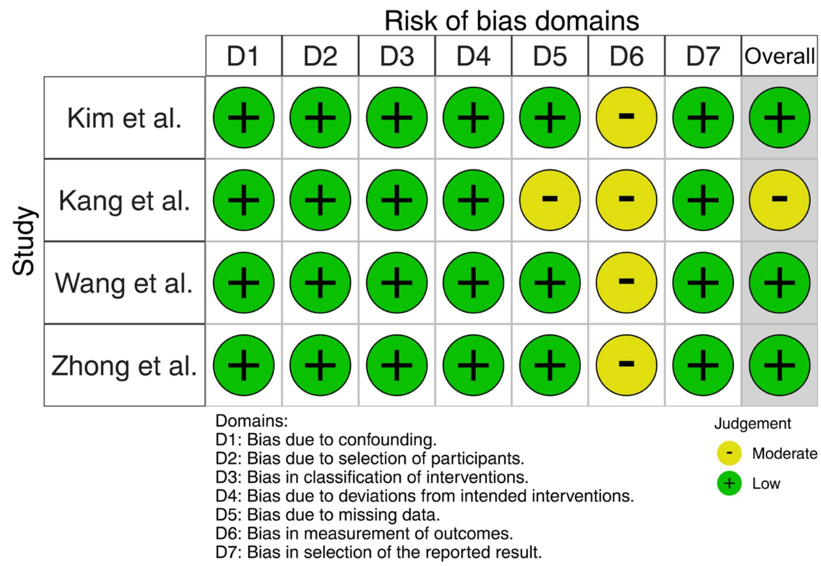
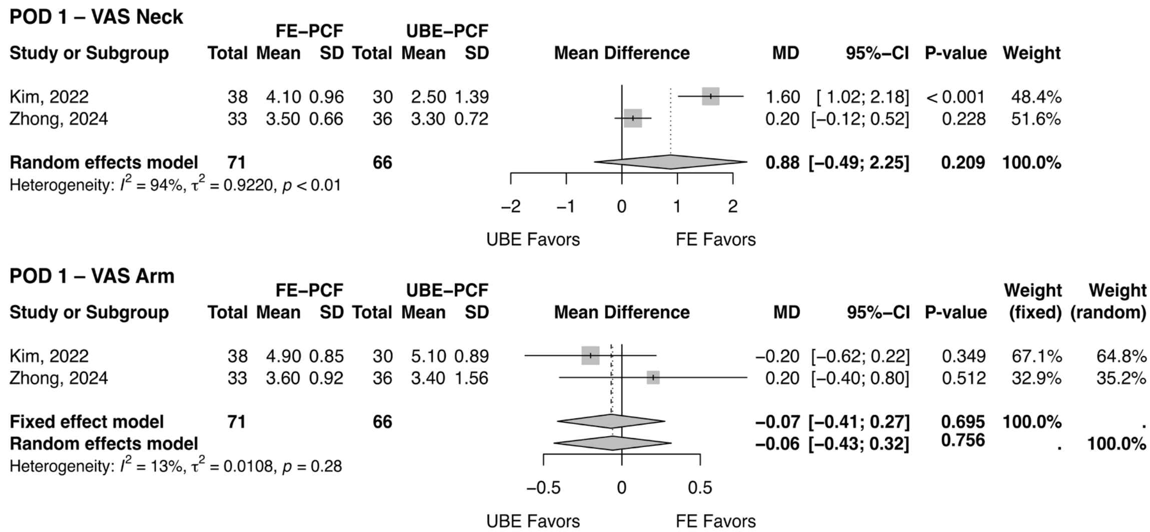


Supplementary Fig. 1. Risk of bias assessment using the ROBINS-I (Risk Of Bias In Nonrandomized Studies of Interventions) tool.



Supplementary Fig. 2. Forest plots for the clinical outcomes of the UBE-PCF and FE-PCF at postoperative 1 day. Mean differences of VAS neck, and VAS arm were not significantly different between the UBE-PCF and FE-PCF ($p > 0.05$). UBE, unilateral biportal endoscopic; FE, full-endoscopic; PCF, posterior cervical foraminotomy; MD, mean difference; SD, standard deviation; CI, confidence interval; POD, postoperative day; VAS, visual analogue scale.

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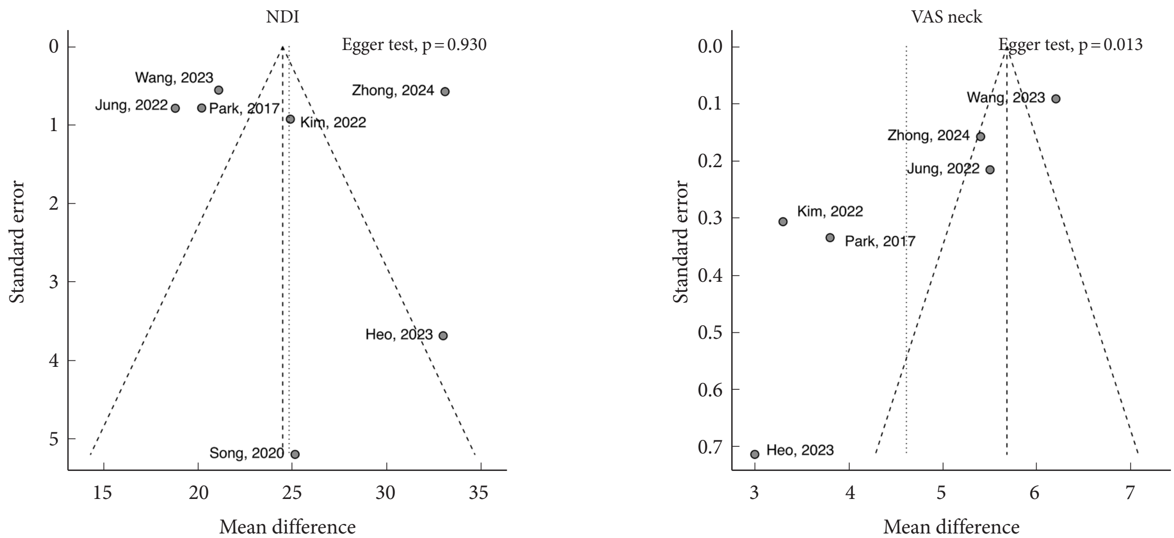
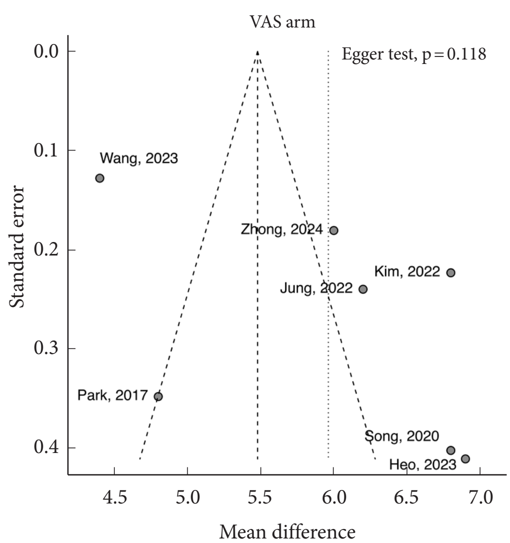
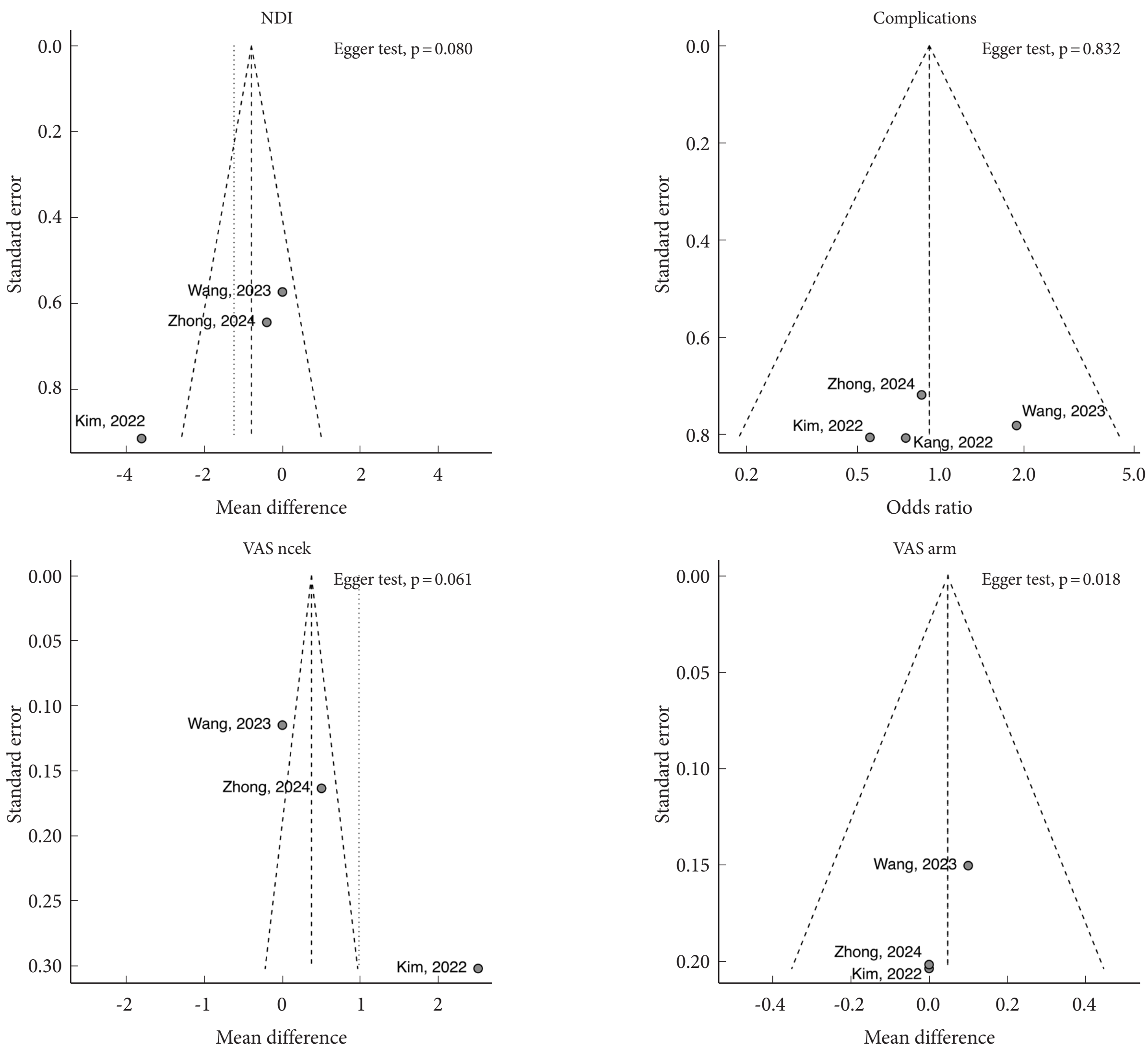




Supplementary Fig. 3. Funnel plots for the clinical outcomes of the UBE-PCF. UBE, unilateral biportal endoscopic; PCF, posterior cervical foraminotomy; NDI, neck disability index; VAS, visual analogue scale.



Supplementary Fig. 4. Funnel plots for the clinical outcomes and complications of the UBE-PCF and FE-PCF. UBE, unilateral biportal endoscopic; FE, full-endoscopic; PCF, posterior cervical foraminotomy; NDI, neck disability index; VAS, visual analogue scale.

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