Review Article

ASJ Asian Spine J. 2025;19(1): 133-147
https://doi.org/10.31616/asj.2024.0171
PISSN 1976-1902 • eISSN 1976-7846

Endoscopic surgery for multilevel spinal stenosis: a comprehensive meta-analysis and subgroup analysis of uniportal and biportal approaches

Manuel González-Murillo[1,2], Juan Castro-Toral[1], César Bonome-González[3], Juan Álvarez de Mon-Montoliú[1]

[1]Department of Orthopaedic Surgery and Traumatology, Hospital San Rafael, A Coruña, Spain
[2]Department of Orthopaedic Surgery and Traumatology, Traumadrid, Hospital HM Puerta del Sur, Móstoles, Spain
[3]Department of Anesthesiology, Hospital San Rafael, A Coruña, Spain

Received Apr 24, 2024; **Revised** Jun 23, 2024; **Accepted** Jul 14, 2024
Corresponding author: Manuel González-Murillo
Department of Orthopaedic Surgery and Traumatology, Hospital San Rafael, Avenida de las Jubias, 82, 15006 A Coruña, Spain
Tel: +34-981179000, **Fax:** +34-981283688, **E-mail:** doctorgonzalezmurillo@gmail.com

Minimally invasive spine surgery (MIS) has shown promising results, and endoscopic spine surgery has emerged as a less invasive approach. Although studies have examined the effectiveness of endoscopic surgery for spinal stenosis, no meta-analyses have focused on multilevel cases. This meta-analysis aimed to evaluate the efficacy and safety of uniportal and biportal endoscopy in patients with multilevel spinal stenosis. The patient, intervention, comparison, outcomes, and study criteria were established to guide study selection. Four databases were searched. The outcome measures included patient-reported outcome measures (PROMs), radiological and analytical data, complications, surgery time, length of hospital stay, and blood loss. Review Manager ver. 5.4 software (RevMan; Cochrane, UK) was used for the analysis. Heterogeneity was assessed using the chi-square and I^2 tests. Ten studies (n=686) were included. PROMs showed significant improvements in Visual Analog Scale (VAS) scores for back pain (mean difference [MD], 4.07; 95% confidence intervals [CI], 3.72–4.42), leg pain (MD, 5.49; 95% CI, 5.17–5.80), and Oswestry Disability Index (MD, 35.97; 95% CI, 32.46–39.47). MacNab scale results were as follows: excellent (55.37%), good (34.93%), fair (7.58%), and poor (4.06%). C-reactive protein levels did not change significantly; however, hemoglobin levels decreased postoperatively (MD, 1.28; 95% CI, 0.91–1.65). Complications included dural tears (5.46%), hematoma (4.30%), incomplete decompression (3.12%), root injury (2.90%), reoperations/revisions (2.22%), conversion to open or microscopic surgery (1.97%), and transfusions (8.50%). Analysis by levels showed worse VAS leg pain in studies analyzing >30% multilevel stenosis (MD, 4.99; 95% CI, 4.47–5.51 vs. MD, 5.82; 95% CI, 5.63–6.01). Uniportal and biportal endoscopy had similar outcomes, except for a higher incidence of dural tears on biportal endoscopy (uniportal, 3.33%; biportal, 7.05%). This meta-analysis supports endoscopy as an effective and safe option for multilevel lumbar stenoses. It improves long-term pain and functionality, with no significant radiological changes or postoperative inflammation. Complications are few; however, dural tears are more common in biportal endoscopy. Higher multilevel stenosis rates were associated with increased leg pain and a lower likelihood of achieving incomplete decompression.

Keywords: Endoscopic surgery; Spinal stenosis; Multilevel spinal stenosis; Meta-analysis

Introduction

Spinal stenosis is an increasingly prevalent condition, with estimates varying between 11% and 39% of the population, and is expected to increase [1]. It is the most common cause of lower back pain [2]. Placing a significant economic burden on healthcare systems, spinal fusion alone is associated with an annual cost exceeding $22 billion in the United States [3].

The shift toward minimally invasive spinal surgery

(MIS) has yielded promising results. Phan and Mobbs [4] noted that patients undergoing MIS had higher satisfaction rates, lower back pain scores, reduced blood loss, shorter hospital stays, and lower reoperation rates than those who underwent open surgery, highlighting the potential clinical advantages of less invasive approaches. Building on the foundation of MIS, endoscopic spine surgery techniques have emerged as minimally invasive procedures [5]. According to Czigléczki et al. [5], endoscopic techniques minimize posterior muscle damage, which is a significant advantage in patient recovery.

In a meta-analysis examining the specific application of endoscopic surgery for spinal stenosis, which is the most common pathology addressed by this technique, Jiang et al. [6] found that the endoscopic surgery group had significantly better outcomes than the MIS group, such as shorter hospital stays, less intraoperative blood loss, and fewer wound-related complications. However, postoperative clinical scores, satisfaction rates, operation times, and complication rates for dural injury, epidural hematoma, and postoperative transient dysesthesia, and weakness were not significantly different between the two groups. Zhang et al. [7] highlighted another advantage of endoscopic surgery, particularly in older patients with multiple comorbidities, which results in less fibrosis, greater mobility, less pain, and reduced postoperative narcotic use. Endoscopic surgery has two main approaches, namely, uniportal and biportal, and a meta-analysis including three studies with 184 patients found no significant differences in Visual Analog Scale (VAS) pain scores but a small advantage for biportal surgery on the Oswestry Disability Index (ODI). Despite limited evidence, the operative time and complications were comparable between the uniportal and biportal groups [8]. Original studies generally show good and feasible results for surgeons [9]. Furthermore, meta-analyses comparing endoscopic surgery to microscopic surgery revealed mixed results. Two meta-analyses reported that some studies found no differences in effectiveness and safety [10,11], whereas others observed that both uniportal and biportal endoscopies are associated with less pain and lower complication risk [12]. Most meta-analyses included both single- and double-segment surgeries, suggesting the potential benefits of single-segment surgery [13].

However, to date, no meta-analysis has focused on multilevel spinal stenosis by examining only studies involving more than one spinal segment. The sample sizes of these studies were typically small; thus, combining them is crucial in a meta-analysis to increase the statistical power. Furthermore, the low incidence of complications in these studies necessitates data pooling for a more comprehensive analysis. Existing meta-analyses often report statistical differences but fail to address clinically meaningful minimum differences. In addition, these meta-analyses tended to combine studies with varying follow-up periods, which could introduce confounding and limit the generalizability of their findings. A meta-analysis comparing biportal and uniportal endoscopic approaches is needed to provide stronger evidence considering the outcomes in patients with multilevel spinal stenosis. Such a meta-analysis would not only address the aforementioned limitations but also contribute to a greater understanding of the topic by consolidating and analyzing existing data.

Thus, this meta-analysis aimed to evaluate the efficacy and safety of uniportal and biportal spinal endoscopies in patients with multilevel spinal stenosis and identify potential differences between uniportal and biportal endoscopy techniques to determine whether one approach offers superior outcomes in terms of patient-reported outcomes and complications.

Methods

Eligibility criteria

This meta-analysis was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO: CRD42024522972) database and was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Fig. 1) [14]. Patient, intervention, comparison, outcomes, and study design criteria were established a priori to develop the research question and guide the study selection. Specifically, the study population included adult patients with multilevel lumbar spinal stenosis who underwent either uniportal or biportal endoscopic spinal decompression surgery (P). Because this was a pre-post intervention study without a true control or comparison group (I, C), the outcomes of interest focused on evaluating efficacy and safety parameters before and after the surgery (O). Both comparative observational studies and single-arm case series reporting relevant outcome data were included (S).

To enhance the quality and consistency of the synthesized evidence, clear exclusion criteria were applied. Studies with populations who exclusively had one-level lumbar spinal stenosis were excluded. Duplicated publications were omitted to avoid overlapping data. Case reports and case series with <10 patients were also excluded because of the lack of power to detect clinically

meaningful effects. Reviews, letters to the editor, editorials, and conference abstracts were excluded because of their inability to adequately appraise the methodology and extract complete data. Studies that reported overlapping patient data between publications, incomplete reporting of important outcomes, or missing key data were also excluded.

Information sources and search methods for identification of studies

A systematic search was conducted in the PubMed, Embase, Scopus, and Cochrane Collaboration Library databases, with no limitations on publication date or language. The search terms used were "spinal stenosis" AND (uniportal OR biportal). The reference lists of the included studies were also reviewed to identify any additional papers that were not found in the database search. According to the eligibility criteria, two independent reviewers screened all titles and abstracts retrieved from the searches. Full texts of potentially relevant papers were then assessed in duplicate for inclusion, and any discrepancies were discussed until a consensus was reached. A third reviewer was consulted to arbitrate any disagreements if consensus could not be reached between the first two reviewers.

Data extraction and data items

Data were extracted by two independent reviewers, and any inconsistencies were resolved through discussion. In cases of persistent disagreement, a third reviewer was consulted to reach a consensus. The baseline characteristics of the included studies included data on the study name, geographic region, study period, study design type, follow-up duration (months), percentage of patients with multilevel involvement, total number of patients, average age, number of female patients, etiology of the condition, and use of endoscopy. The main outcomes assessed and compared included patient-reported outcome measures (PROMs), including the VAS, ODI, and MacNab criteria. In addition, radiological data, such as disc height and sagittal angle measurements, as well as analytical data, including C-reactive protein (CRP) and hemoglobin levels, were collected. Complications of this procedure have also been documented. Other variables recorded during the data extraction process included surgical time, length of hospital stay (LOS), and blood loss. Furthermore, the minimal clinically important difference (MCID) for each PROM was evaluated, with VAS and ODI having MCIDs of 2.6 [15,16] and 8.1 [15,16], respectively.

Assessment of risk of bias in the included studies

The risk of bias in the included studies was assessed using the methodological index for nonrandomized studies (MINORS) (Supplement 1) [17]. This tool consists of 12 items, with maximum scores of 24 and 16 for comparative and noncomparative studies, respectively. For noncomparative studies, scores of 0–4, 5–7, 8–12, and ≥13 were considered very low, low, fair, and high quality, respectively. In comparative studies, scores of 0–6, 7–10, 11–15, and ≥16 indicated very low, low, fair, and high quality, respectively. Two independent reviewers conducted the assessment, and any discrepancies were resolved through discussion until a consensus was reached [17].

Assessment of results

The results were analyzed using the Review Manager ver. 5.4 software (RevMan; Cochrane, London, UK). For continuous outcomes, mean differences (MDs) with 95% confidence intervals (CIs) were calculated [18]. In dichotomous outcomes where the standard error (SE) was not reported, the incidence was derived using the standard formula: $SE=\sqrt{I\ (1-i)/n}$ and 95% $CI=I\pm1.96\times SE$, where I represents the incidence [19]. Pooled incidences and their corresponding 95% CIs were then calculated using random- and fixed-effect models, as appropriate. Heterogeneity was assessed using the chi-square and I^2 tests, with I^2 values >25%, 50%, and 75% indicating low, moderate, and high heterogeneity, respectively. When no significant heterogeneity was detected, a fixed-effects model was used, whereas when heterogeneity was present, a random-effects model was employed. To extract accurate information from figures in the articles, WebPlotDigitizer ver. 13.1.4 (https://automeris.io/v4/) was employed. Missing data were handled according to the guidelines outlined in the Cochrane Handbook [20].

Risk of bias across the studies

Publication bias assessment was conducted by analyzing funnel plot asymmetry using Review Manager (RevMan, Cochrane). In the funnel plot graph, the effect estimate and SE are represented on the x- and y-axes, respectively. Visual inspection of the funnel plot allowed the identification of potential asymmetries that could indicate the presence of publication bias. Visual interpretation of the funnel plot involved examining

the distribution of studies around the central line. In a symmetric funnel plot, studies must be evenly distributed on both sides of the central line, indicating the absence of publication bias. However, asymmetry in the funnel plot may suggest publication bias, particularly if no small studies had negative results. No formal statistical tests were conducted to assess publication bias.

Additional analyses

Subgroup analyses were planned to examine differences based on the follow-up duration. Sensitivity analyses were conducted to assess the consistency of the results by removing studies with the highest weight. After data extraction, sensitivity analyses were necessarily based on the number of fused levels, as studies included both single-level and multilevel stenoses without separating the results. A cutoff point of 30% was established, classifying studies with >30% of patients with multilevel involvement as one group and studies with <30% as another group. Consequently, the sample was roughly divided in half, with studies above and below this threshold. Sensitivity analyses of the type of endoscopy performed, distinguishing between the uniportal and biportal approaches, were also performed.

Results

Study selection

The initial search yielded 220 studies in total. After excluding studies that were not related to lumbar spinal stenosis, nonendoscopic techniques (biportal or uniportal), single-level studies, duplicated studies, case reports, case series with <10 patients, reviews, letters to the editor, or protocols, 186 studies were eliminated, resulting in 34 studies. After reading the full texts, 25 studies that did not meet the inclusion criteria were excluded. After reviewing the references of the nine included studies, an additional article was added. Finally, 10 articles were included in the meta-analysis (Fig. 1) [5,6,9,21-28].

Risk of bias

The MINORS scale assessment revealed that all three of the three comparative studies were of high quality (Supplement 1). Among the seven included case series, two were rated as having high quality and five had acceptable quality. These studies did not report the number of patients lost to follow-up and prospectively collected data.

Study characteristics

Table 1 shows the baseline characteristics of the included studies. Ten studies with 686 patients were included in the analysis: three were cohort studies (two retrospective and one prospective), and seven were retrospective case series. The follow-up duration ranged from 7 to 26.5 months. The percentage of patients with multilevel stenosis varied from 12.9% to 100%. The mean age ranged from 59.9 to 70.5 years. The number of female patients, etiology, and type of endoscopy performed are shown in Table 2. The mean surgical time was 91.5

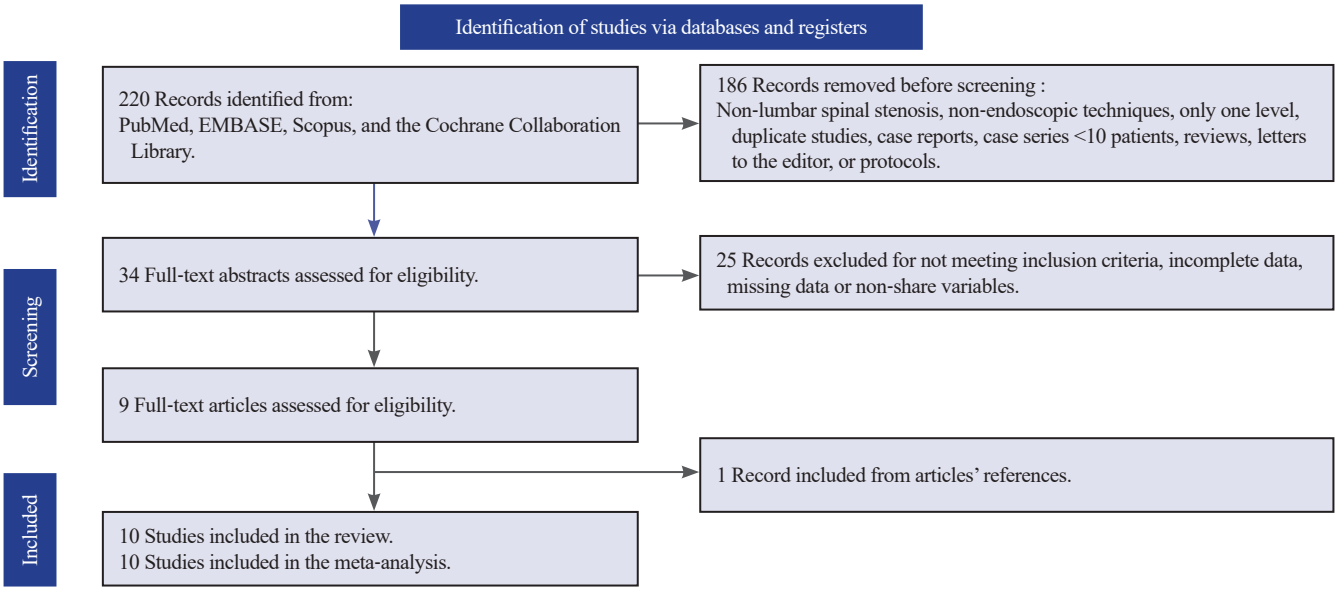

Fig. 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart depicting the study selection process for meta-analysis.

Table 1. Main baseline characteristics of the included studies

Study	Region	Period	Type of study	Follow-up (mo)	No. of multilevel (%)	No. of patients	Age (yr)	No. of females	Etiology	Endoscopy
Choi et al. [21] (2019)	South Korea	2013–2015	Retrospective cohort	25.5	11/35 (31.4)	35	65.4	21	LSS with or without grade I degenerative spondylolisthesis	Biportal
Czigléczki et al. [5] (2020)	Hungary	2019	Retrospective series	7.0	4/21 (19.0)	21	66.5	12	LSS	Biportal
Huang et al. [9] (2020)	Taiwan	2015–2017	Retrospective series	24.0	53/106 (50.0)	106	70.2	61	DLS	Uniportal–unilateral
Kang et al. [22] (2021)	South Korea	2018–2019	Retrospective cohort	15.0	18/47 (38.3)	47	66.9	30	Definite LSS with or without low-grade degenerative spondylolisthesis (grade ≤2), low-grade isthmic spondylolisthesis (grade ≤2), and segmental instability (anterior translation [>3 mm] and/or increasing segmental sagittal motion [>15°]) on plain standing radiographs and magnetic resonance imaging	Biportal–unilateral
Kim et al. [23] (2017)	South Korea	2016	Retrospective series	13.7	4/26 (15.4)	26	62.9	18	LSS	Uniportal–contralateral
Kim et al. [24] (2017) (II)	South Korea	2016	Retrospective series	7.8	8/48 (16.7)	48	62.4	33	LSS	Uniportal–contralateral
Kim et al. [25] (2018)	South Korea	NR	Retrospective series	14.8	4/31 (12.9)	31	70.5	17	LSS	Biportal–unilateral
Lee et al. [26] (2018)	South Korea	2012–2017	Retrospective series	26.5	30/232 (12.9)	213	61.2	152	DLS	Uniportal–unilateral
Wu et al. [27] (2023)	Singapore	2020–2021	Prospective cohort	12.0	U: 7/29 (24.1) B: 7/32 (21.9)	U: 29 B: 32	U: 63.9 B: 64.1	U: 16 B: 16	LSS with Schizas grade C and D, who have failed to achieve symptomatic control with at least 6 weeks of conservative treatment comprising analgesia (NSAIDs), physiotherapy, nerve root blocks, and epidural injections	U: Uniportal–unilateral B: Bilateral–unilateral
Zhang et al. [28] (2023)	China	2020–2021	Retrospective series	19.3	98/98 (100.0)	98	59.9	45	LSS	Biportal–unilateral

LSS, lumbar spinal stenosis; DLS, degenerative lumbar stenosis; NR, not reported; NSAIDs, non-steroidal anti-inflammatory drugs.

Table 2. Surgery time, length of hospital stay, and blood loss

Follow-up	Surgery time (min)	Length of hospital stay (day)	Blood loss (mL)
Huang et al. [9] (2020)	68.9	NR	NR
Kang et al. [22] (2021)	107.5	NR	185.7
Kim et al. [23] (2017)	48.0	1.2	27.0
Kim et al. [25] (2018)	48.7	NR	NR
Lee et al. [26] (2018)	105.3	2.5	NR
Wu et al. [27] (2023)	135.0	0.9	5.7
Zhang et al. [28] (2023)	106.7	8.0	67.7
Total	91.5	3.2	71.5

NR, not reported.

minutes, the mean LOS was 3.2 days, and the mean blood loss was 71.5 mL (Table 2).

PROMs

The VAS scores for back and leg pain showed significant improvements with endoscopy: back pain (MD, 4.07; 95% CI, 3.72–4.42; participants=3,732; studies=29; I^2=92%) (Fig. 2) and leg pain (MD, 5.49; 95% CI, 5.17–5.80; participants=3,940; studies=33; I^2=90%) (Fig. 3). This improvement was significant at all follow-up periods at 1st week, 1st month, 3rd month, 6th month, 12th month, and 24th month, with the highest values observed at the end of the follow-up for both VAS scores for back pain and leg pain. The ODI also showed significant improvement at the end of the follow-up (MD, 35.97; 95% CI, 32.46–39.47; participants=3,604; studies=30; I^2=95%) (Fig. 4). This significant difference was maintained throughout all follow-up periods, with scores improving over time, up to 24 months. Furthermore, in all follow-up periods, the MCID was surpassed for VAS back pain, VAS leg pain, and ODI (Supplement 2).

On the contrary, the results on the MacNab scale were as follows: excellent, 55.37% (95% CI, 34.25%–76.48%; studies=6); good, 34.93% (95% CI, 14.14%–55.73%; studies=6); fair, 7.58% (95% CI, 4.85%–10.31%; studies=6); and poor, 4.06% (95% CI, 2.64%–5.48%; studies=6).

Radiological data

The differences in the disc height were not significant before and after the procedure (MD, −0.53; 95% CI, −3.18 to 2.13; participants=326; studies=2; I^2=97%). Similarly, no significant differences in sagittal angle were found (MD, 0.33; 95% CI, −0.36 to 1.02; participants=326; studies=2; I^2=0%).

Study or subgroup	Pre Mean±SD	Total	Post Mean±SD	Total	Weight (%)	Mean difference IV, random, 95% CI
1.1.1 1st week						
Kim et al. [24] (2017) (II)	5.7±1.1	48	2.5±0.52	48	4.2	3.20 (2.86 to 3.54)
Wu et al. [27] (2023) biportal	4.9±2.5	32	1.4±1.9	32	3.1	3.50 (2.41 to 4.59)
Wu et al. [27] (2023) uniportal	5.5±2.9	29	1.6±2	29	2.7	3.90 (2.62 to 5.18)
Zhang et al. [28] (2023)	7±1.1	98	2.9±0.7	98	4.2	4.10 (3.84 to 4.36)
Subtotal (95% CI)		**207**		**207**	**14.2**	**3.67 (3.03 to 4.30)**
Heterogeneity: tau^2=0.28; χ^2=17.09, df=3 (p=0.0007); I^2=82%						
Test for overall effect: Z=11.37 (p<0.00001)						
1.1.2 1st month						
Choi et al. [21] (2019)	6.8±1	35	3±0.8	35	4.1	3.80 (3.38 to 4.22)
Kang et al. [22] (2021)	6.5±4.4276	47	5.3±1.3623	47	2.7	1.20 (-0.12 to 2.52)
Lee et al. [26] (2018)	5.35±2.22	213	3.05±4.4276	213	3.7	2.30 (1.63 to 2.97)
Wu et al. [27] (2023) biportal	4.9±2.5	32	0.6±1	32	3.3	4.30 (3.37 to 5.23)
Wu et al. [27] (2023) uniportal	5.5±2.9	29	0.7±1	29	3.0	4.80 (3.68 to 5.92)
Subtotal (95% CI)		**356**		**356**	**16.8**	**3.32 (2.28 to 4.35)**
Heterogeneity: tau^2=1.18; χ^2=33.98, df=4 (p<0.00001); I^2=88%						
Test for overall effect: Z=6.28 (p<0.00001)						
1.1.3 3 months						
Huang et al. [9] (2020)	6.8±2.8	106	1.5±1.5	106	3.8	5.30 (4.70 to 5.90)
Kim et al. [24] (2017) (II)	5.7±1.1	48	2±4.4276	48	2.7	3.70 (2.41 to 4.99)
Kim et al. [25] (2018)	5.13±0.8	31	2.61±0.76	31	4.1	2.52 (2.13 to 2.91)
Wu et al. [27] (2023) biportal	4.9±2.5	32	0.6±1.2	32	3.3	4.30 (3.34 to 5.26)
Wu et al. [27] (2023) uniportal	5.5±2.9	29	0.3±1.2	29	3.0	5.20 (4.06 to 6.34)
Zhang et al. [28] (2023)	7±1.1	98	2.1±0.6	98	4.2	4.90 (4.65 to 5.15)
Subtotal (95% CI)		**344**		**344**	**21.1**	**4.31 (3.21 to 5.42)**
Heterogeneity: tau^2=1.74; χ^2=116.72, df=5 (p<0.00001); I^2=96%						
Test for overall effect: Z=7.63 (p<0.00001)						
1.1.4 6 months						
Choi et al. [21] (2019)	6.8±1	35	2.8±1	35	4.0	4.00 (3.53 to 4.47)
Huang et al. [9] (2020)	6.8±4.4276	106	1.8±4.4276	106	2.9	5.00 (3.81 to 6.19)
Kang et al. [22] (2021)	6.5±4.4276	47	3.3±2.3841	47	2.5	3.20 (1.76 to 4.64)
Kim et al. [24] (2017) (II)	5.7±1.1	48	1.75±0.52	48	4.2	3.95 (3.61 to 4.29)
Wu et al. [27] (2023) biportal	4.9±2.5	32	0.4±1	32	3.3	4.50 (3.57 to 5.43)
Wu et al. [27] (2023) uniportal	5.5±2.9	29	0.6±1	29	3.0	4.90 (3.78 to 6.02)
Subtotal (95% CI)		**297**		**297**	**19.9**	**4.15 (3.79 to 4.51)**
Heterogeneity: tau^2=0.06; χ^2=7.24, df=5 (p=0.20); I^2=31%						
Test for overall effect: Z=22.88 (p<0.00001)						
1.1.5 12 months						
Huang et al. [9] (2020)	6.8±4.4276	106	1.5±4.4276	106	2.9	5.30 (4.11 to 6.49)
Kang et al. [22] (2021)	6.5±4.4276	47	2.6±2.7247	47	2.4	3.90 (2.41 to 5.39)
Kim et al. [25] (2018)	5.13±0.8	31	1.52±1.02	31	4.0	3.61 (3.15 to 4.07)
Wu et al. [27] (2023) biportal	4.9±2.5	32	0.6±1	32	3.3	4.30 (3.37 to 5.23)
Wu et al. [27] (2023) uniportal	5.5±2.9	29	0.7±1.4	29	2.9	4.80 (3.63 to 5.97)
Subtotal (95% CI)		**245**		**245**	**15.6**	**4.29 (3.62 to 4.96)**
Heterogeneity: tau^2=0.32; χ^2=9.58, df=4 (p=0.05); I^2=58%						
Test for overall effect: Z=12.56 (p<0.00001)						
1.1.6 24 months						
Huang et al. [9] (2020)	6.8±1.3	106	1.7±1.7	106	4.1	5.10 (4.69 to 5.51)
Lee et al. [26] (2018)	5.35±2.22	213	2.05±1.57	213	4.1	3.30 (2.93 to 3.67)
Zhang et al. [28] (2023)	7±1.1	98	1.8±0.6	98	4.2	5.20 (4.95 to 5.45)
Subtotal (95% CI)		**417**		**417**	**12.5**	**4.54 (3.34 to 5.73)**
Heterogeneity: tau^2=1.08; χ^2=75.78, df=2 (p<0.00001); I^2=97%						
Test for overall effect: Z=7.46 (p<0.00001)						
Total (95% CI)		**1,866**		**1,866**	**100.0**	**4.07 (3.72 to 4.42)**
Heterogeneity: tau^2=0.74; χ^2=332.42, df=28 (p<0.00001); I^2=92%						
Test for overall effect: Z=22.80 (p<0.00001)						
Test for subgroup differences: χ^2=4.96, df=5 (p=0.42); I^2=0%						

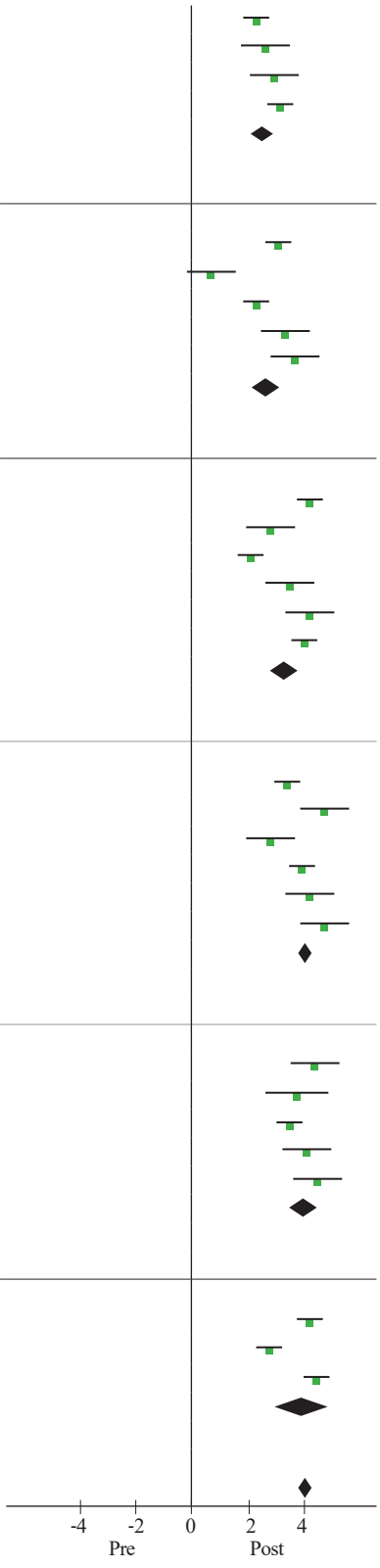

Fig. 2. Forest plot demonstrating Visual Analog Scale back pain. A significant improvement in pain was observed during all the follow-up periods. SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degrees of freedom.

Study or subgroup	Pre Mean±SD	Total	Post Mean±SD	Total	Weight (%)	Mean difference IV, random, 95% CI
1.2.1 1st week						
Kim et al. [23] (2017)	7.7±1	26	2±0.8	26	3.7	5.70 (5.21 to 6.19)
Kim et al. [24] (2017) (II)	7.41±1.07	48	1.89±0.9	48	3.8	5.52 (5.12 to 5.92)
Wu et al. [27] (2023) biportal	6.6±2.3	32	1±1.6	32	2.9	5.60 (4.63 to 6.57)
Wu et al. [27] (2023) uniportal	6.6±2.4	29	1±1.7	29	2.8	5.60 (4.53 to 6.67)
Zhang et al. [28] (2023)	6.8±1.1	98	2.9±0.7	98	4.0	3.90 (3.64 to 4.16)
Subtotal (95% CI)		**233**		**233**	**17.2**	**5.23 (4.27 to 6.19)**
Heterogeneity: tau^2=1.08; χ^2=75.16, df=4 (p<0.00001); I^2=95%						
Test for overall effect: Z=10.65 (p<0.00001)						
1.2.3 3 months						
Choi et al. [21] (2019)	6.3±1.1	35	2.4±0.8	35	3.8	3.90 (3.45 to 4.35)
Kang et al. [22] (2021)	6.3±5.2	47	3±1.7	47	2.0	3.30 (1.74 to 4.86)
Lee et al. [26] (2018)	8.24±1.25	213	3.16±5.2	213	3.4	5.08 (4.36 to 5.80)
Wu et al. [27] (2023) biportal	6.6±2.3	32	0.5±0.9	32	3.1	6.10 (5.24 to 6.96)
Wu et al. [27] (2023) uniportal	6.6±2.4	29	1±1.8	29	2.7	5.60 (4.51 to 6.69)
Subtotal (95% CI)		**356**		**356**	**15.0**	**4.84 (3.86 to 5.83)**
Heterogeneity: tau^2=1.03; χ^2=28.65, df=4 (p<0.00001); I^2=86%						
Test for overall effect: Z=9.62 (p<0.00001)						
1.2.3 3 months						
Huang et al. [9] (2020)	7.6±1.3	106	1.7±1.7	106	3.8	5.90 (5.49 to 6.31)
Kim et al. [23] (2017)	7.7±1	26	1.9±0.7	26	3.7	5.80 (5.33 to 6.27)
Kim et al. [24] (2017) (II)	7.41±1.07	48	2±5.2	48	2.1	5.41 (3.91 to 6.91)
Kim et al. [25] (2018)	7.87±5.2	31	2.55±5.2	31	1.1	5.32 (2.73 to 7.91)
Wu et al. [27] (2023) biportal	6.6±2.3	32	0.2±0.6	32	3.2	6.40 (5.58 to 7.22)
Wu et al. [27] (2023) uniportal	6.6±2.4	29	1.1±2.4	29	2.5	5.50 (4.26 to 6.74)
Zhang et al. [28] (2023)	6.8±1.1	98	2±0.6	98	4.0	4.80 (4.55 to 5.05)
Subtotal (95% CI)		**370**		**370**	**20.4**	**5.61 (5.02 to 6.20)**
Heterogeneity: tau^2=0.41; χ^2=35.25, df=6 (p<0.00001); I^2=83%						
Test for overall effect: Z=18.70 (p<0.00001)						
1.2.4 6 months						
Choi et al. [21] (2019)	6.8±1	35	2.2±0.8	35	3.8	4.60 (4.18 to 5.02)
Huang et al. [9] (2020)	7.6±1.3	106	1.6±5.2	106	2.9	6.00 (4.98 to 7.02)
Kang et al. [22] (2021)	6.3±5.2	47	1.8±1	47	2.1	4.50 (2.99 to 6.01)
Kim et al. [23] (2017)	7.7±1	26	1.8±5.2	26	1.5	5.90 (3.86 to 7.94)
Kim et al. [24] (2017) (II)	7.41±1.07	48	2±1.05	48	3.8	5.41 (4.99 to 5.83)
Wu et al. [27] (2023) biportal	6.6±2.3	32	0.2±0.4	32	3.2	6.40 (5.59 to 7.21)
Wu et al. [27] (2023) uniportal	6.6±2.4	29	0.9±2.2	29	2.6	5.70 (4.52 to 6.88)
Subtotal (95% CI)		**323**		**323**	**19.9**	**5.46 (4.88 to 6.05)**
Heterogeneity: tau^2=0.38; χ^2=21.29, df=6 (p=0.002); I^2=72%						
Test for overall effect: Z=18.27 (p<0.00001)						
1.2.5 12 months						
Huang et al. [9] (2020)	7.6±1.3	106	1.1±5.2	106	2.9	6.50 (5.48 to 7.52)
Kang et al. [22] (2021)	6.3±5.2	47	1.6±0.6	47	2.1	4.70 (3.20 to 6.20)
Kim et al. [25] (2018)	7.87±5.2	31	1.45±5.2	31	1.1	6.42 (3.83 to 9.01)
Wu et al. [27] (2023) biportal	6.6±2.3	32	0.3±0.5	32	3.2	6.30 (5.48 to 7.12)
Wu et al. [27] (2023) uniportal	6.6±2.4	29	0.8±1.7	29	2.8	5.80 (4.73 to 6.87)
Subtotal (95% CI)		**245**		**245**	**12.1**	**6.04 (5.49 to 6.59)**
Heterogeneity: tau^2=0.05; χ^2=4.52, df=4 (p=0.34); I^2=12%						
Test for overall effect: Z=21.55 (p<0.00001)						

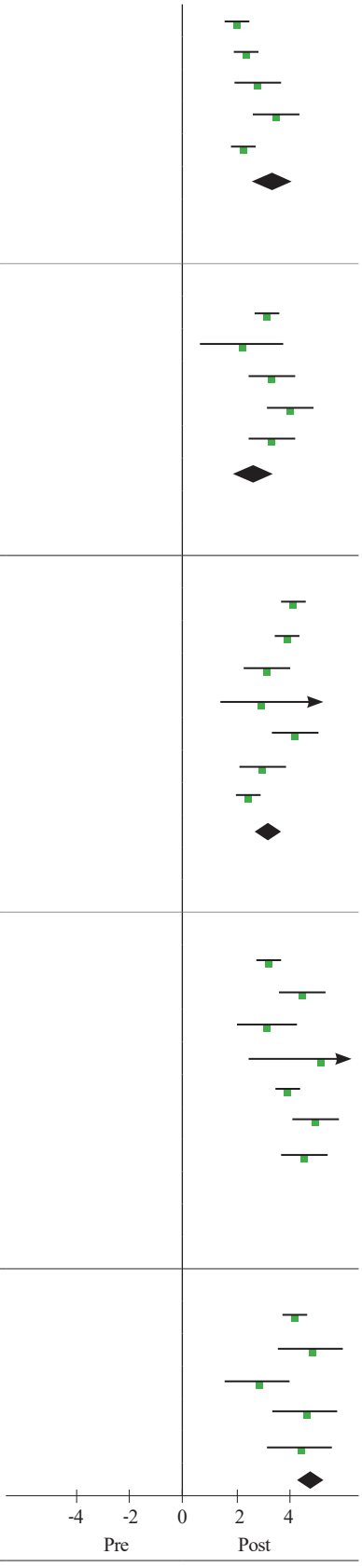

Fig. 3. Forest plot illustrating Visual Analog Scale leg pain during the follow-up period. Endoscopy significantly improved the leg pain. SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degrees of freedom. (Continued on next page.)

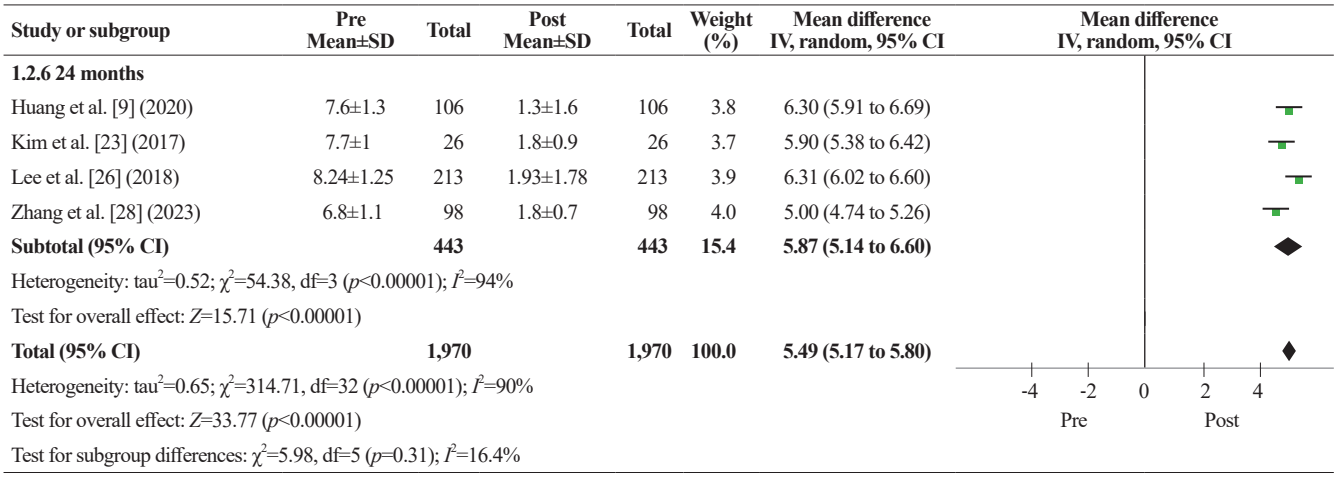

Fig. 3. (Continued; caption shown on previous page).

Laboratory data

The CRP levels did not show significant differences pre- and post-procedure at 2 days (MD, −1.65; 95% CI, −4.92 to 1.62; participants=164; studies=2; I^2=91%), 1 week (MD, −0.01; 95% CI, −0.30 to 0.27; participants=164; studies=2; I^2=46%), and 2 weeks (MD, −0.14; 95% CI, −0.78 to 0.50; participants=164; studies=2; I^2=0%) (Fig. 5). However, a significant decrease in postoperative hemoglobin levels was found (MD, 1.28; 95% CI, 0.91–1.65; participants=164; studies=2; I^2=61%).

Complications

Regarding complications, the incidence of dural tears was 5.46% (95% CI, 2.97%–7.94%; studies=7), hematoma occurred in 4.30% (95% CI, 4.24%–4.36%; studies=3), incomplete decompression was observed in 3.12% (95% CI, 1.32%–4.93%; studies=6), root injury occurred in 2.90% (95% CI, 2.90%–2.90%; studies=2), the reoperation or revision rate was 2.22% (95% CI, 1.34%–3.10%; studies=4), the rate of conversion to open or microscopic surgery was 1.97% (95% CI, 0.20%–3.73%; studies=4), and the transfusion rate was 8.50% (95% CI, 8.42%–8.58%; studies=2).

Analysis by levels

As shown in Table 3, studies that included patients with multilevel stenosis >30% had worse VAS leg pain (MD, 4.99; 95% CI, 4.47–5.51; participants=1,858; I^2=93%) than those with multilevel stenosis <30% (MD, 5.82; 95% CI, 5.63–6.01; participants=2,082; I^2=28%). No differences in the VAS back pain, ODI, or MacNab scale scores were found. No significant differences in CRP levels were observed. Regarding complications, no differences in the rates of terms of dural tears were found, although incomplete decompression was significantly higher in the group with <30% multilevel stenosis (MD, 1.50%; 95% CI, 0.32%–2.68% versus MD, 4.75%; 95% CI, 2.89%–6.61%).

Comparison of uniportal and biportal endocopies

Table 4 shows a comparison between uniportal and biportal endoscopy. No significant differences in VAS back pain, VAS leg pain, ODI, or MacNab scale scores were found between the uniportal and biportal groups. However, dural tears were significantly more frequent in the biportal group (7.05%; 95% CI, 6.18%–7.91%), than in uniportal group (3.33%; 95% CI, 1.31%–5.35%), with no significant differences in the frequency of incomplete decompression.

Publication bias

High publication bias was observed for all variables (Fig. 6). Consistent and significant publication bias was noted across all analyzed variables, indicating a tendency for researchers to selectively publish positive or significant results while potentially neglecting negative or nonsignificant findings.

Discussion

Pain and functionality significantly improved in patients who underwent endoscopy, with higher values at the end of the follow-up period. Excellent or good outcomes were achieved in >90% of the cases. Regarding

Study or subgroup	Pre Mean±SD	Total	Post Mean±SD	Total	Weight (%)	Mean difference IV, random, 95% CI
1.3.1 1st week						
Kim et al. [23] (2017)	64.4±5.8	26	28.8±5.2	26	4.1	35.60 (32.61 to 38.59)
Kim et al. [24] (2017) (II)	65.13±24.21	48	24.21±3	48	3.6	40.92 (34.02 to 47.82)
Wu et al. [27] (2023) biportal	30.4±10.8	32	15.8±12.6	32	3.8	14.60 (8.85 to 20.35)
Wu et al. [27] (2023) uniportal	37.2±11.6	29	14±9.8	29	3.8	23.20 (17.67 to 28.73)
Subtotal (95% CI)		**135**		**135**	**15.4**	**28.57 (17.71 to 39.44)**
Heterogeneity: tau^2=115.24; χ^2=55.89, df=3 (p<0.00001); I^2=95%						
Test for overall effect: Z=5.15 (p<0.00001)						
1.3.2 1st month						
Kang et al. [22] (2021)	55.1±41.211	47	40.2±32.3557	47	2.4	14.90 (-0.08 to 29.88)
Lee et al. [26] (2018)	67.8±15.4	213	30.6±41.211	213	3.8	37.20 (31.29 to 43.11)
Wu et al. [27] (2023) biportal	30.4±10.8	32	3.6±4.5	32	4.0	26.80 (22.75 to 30.85)
Wu et al. [27] (2023) uniportal	37.2±11.6	29	5.3±7.5	29	3.9	31.90 (26.87 to 36.93)
Subtotal (95% CI)		**321**		**321**	**14.1**	**29.74 (23.47 to 36.01)**
Heterogeneity: tau^2=28.30; χ^2=12.54, df=3 (p<0.006); I^2=76%						
Test for overall effect: Z=9.28 (p<0.00001)						
1.3.3 3 months						
Huang et al. [9] (2020)	62±41.211	106	16.5±41.211	106	3.0	45.50 (34.41 to 56.59)
Kim et al. [23] (2017)	64.4±5.8	26	29.2±2.6	26	4.2	35.20 (32.76 to 37.64)
Kim et al. [24] (2017) (II)	65.13±24.21	48	22.9±41.211	48	2.6	42.23 (28.71 to 55.75)
Kim et al. [25] (2018)	66.8±41.211	31	24.1±41.211	31	1.7	42.70 (22.18 to 63.22)
Wu et al. [27] (2023) biportal	30.4±10.8	32	2.7±4	32	4.0	27.70 (23.71 to 31.69)
Wu et al. [27] (2023) uniportal	37.2±11.6	29	5.6±9.5	29	3.8	31.60 (26.14 to 37.06)
Zhang et al. [28] (2023)	69.3±6	98	24.9±4.7	98	4.2	44.40 (42.89 to 45.91)
Subtotal (95% CI)		**370**		**370**	**23.5**	**37.45 (31.04 to 43.86)**
Heterogeneity: tau^2=56.69; χ^2=94.11, df=6 (p<0.00001); I^2=94%						
Test for overall effect: Z=11.45 (p<0.00001)						
1.3.4 6 months						
Huang et al. [9] (2020)	62±41.211	106	14.1±41.211	106	3.0	47.90 (36.81 to 58.99)
Kang et al. [22] (2021)	55.1±41.211	47	40.2±32.3557	47	2.4	14.90 (-0.08 to 29.88)
Kim et al. [23] (2017)	64.4±5.8	26	21.9±41.211	26	2.3	42.50 (26.50 to 58.50)
Kim et al. [24] (2017) (II)	65.13±24.21	48	23.77±3.98	48	3.6	41.36 (34.42 to 48.30)
Wu et al. [27] (2023) biportal	30.4±10.8	32	0.3±0.7	32	4.0	30.10 (26.35 to 33.85)
Wu et al. [27] (2023) uniportal	37.2±11.6	29	1.3±3.1	29	4.0	35.90 (31.53 to 40.27)
Subtotal (95% CI)		**288**		**288**	**19.3**	**35.76 (29.38 to 42.14)**
Heterogeneity: tau^2=41.91; χ^2=22.53, df=5 (p=0.0004); I^2=78%						
Test for overall effect: Z=10.98 (p<0.00001)						
1.3.5 12 months						
Huang et al. [9] (2020)	62±41.211	106	12.2±41.211	106	3.0	49.80 (38.71 to 60.89)
Kang et al. [22] (2021)	55.1±41.211	47	20.6±23.1599	47	2.6	34.50 (20.99 to 48.01)
Kim et al. [25] (2018)	66.8±41.211	31	17.3±41.211	31	1.7	49.50 (28.98 to 70.02)
Wu et al. [27] (2023) biportal	30.4±10.8	32	0.3±0.8	32	4.0	30.10 (26.35 to 33.85)
Wu et al. [27] (2023) uniportal	37.2±11.6	29	2.6±9	29	3.9	34.60 (29.26 to 39.94)
Subtotal (95% CI)		**245**		**245**	**15.2**	**37.22 (30.29 to 44.14)**
Heterogeneity: tau^2=37.08; χ^2=13.94, df=4 (p=0.007); I^2=71%						
Test for overall effect: Z=10.53 (p<0.00001)						
1.3.6 24 months						
Huang et al. [9] (2020)	62±0	106	14.6±0	106		Not estimable
Kim et al. [23] (2017)	64.4±5.8	26	21±4.5	26	4.1	43.40 (40.58 to 46.22)
Lee et al. [26] (2018)	67.8±15.4	213	17.14±15.7	213	4.1	50.66 (47.71 to 53.61)
Zhang et al. [28] (2023)	69.3±6	98	20.2±5.7	98	4.2	49.10 (47.46 to 50.74)
Subtotal (95% CI)		**443**		**443**	**12.5**	**47.76 (43.91 to 51.61)**
Heterogeneity: tau^2=9.93; χ^2=14.94, df=2 (p=0.0006); I^2=87%						
Test for overall effect: Z=24.32 (p<0.00001)						
Total (95% CI)		**1,802**		**1,802**	**100.0**	**35.97 (32.46 to 39.47)**
Heterogeneity: tau^2=75.49; χ^2=527.54, df=28 (p<0.00001); I^2=95%						
Test for overall effect: Z=20.10 (p<0.00001)						
Test for subgroup differences: χ^2=33.00, df=5 (p<0.00001); I^2=84.8%						

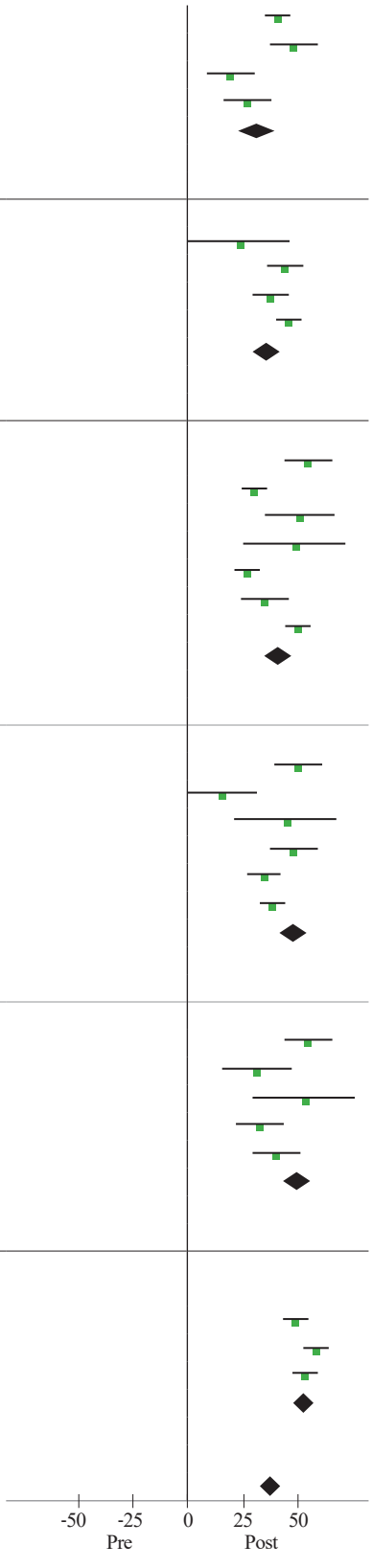

Fig. 4. Forest plot displaying the efficacy of endoscopy compared to the Oswestry Disability Index in all follow-up periods. SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degrees of freedom.

Study or subgroup	Pre Mean±SD	Total	Post Mean±SD	Total	Weight (%)	Mean difference IV, random, 95% CI
1.6.1 2 days						
Choi et al. [21] (2019)	0.19±0.53	35	0.32±0.79	35	30.4	-0.13 (-0.45 to 0.19)
Kang et al. [22] (2021)	0.47±3.0312	47	3.95±6.3009	47	4.4	-3.48 (-5.48 to -1.48)
Subtotal (95% CI)		**82**		**82**	**34.8**	**-1.65 (-4.92 to 1.62)**
Heterogeneity: tau^2=5.08; χ^2=10.53, df=1 (p=0.001); I^2=91%						
Test for overall effect: Z=0.99 (p=0.32)						
1.6.2 1 week						
Choi et al. [21] (2019)	0.19±0.53	35	0.17±0.7	35	31.1	0.02 (-0.27 to 0.31)
Kang et al. [22] (2021)	0.47±3.0312	47	1.66±5.211	47	5.6	-1.19 (-2.91 to 0.53)
Subtotal (95% CI)		**82**		**82**	**36.8**	**-0.27 (-1.29 to 0.74)**
Heterogeneity: tau^2=0.33; χ^2=1.84, df=1 (p=0.17); I^2=46%						
Test for overall effect: Z=0.53 (p=0.60)						
1.6.3 2 weeks						
Choi et al. [21] (2019)	0.19±0.53	35	0.41±2.4	35	16.3	-0.22 (-1.03 to 0.59)
Kang et al. [22] (2021)	0.47±3.0312	47	0.47±2.0095	47	12.1	0.00 (-1.04 to 1.04)
Subtotal (95% CI)		**82**		**82**	**28.4**	**-0.14 (-0.78 to 0.50)**
Heterogeneity: tau^2=0.00; χ^2=0.11, df=1 (p<0.74); I^2=0%						
Test for overall effect: Z=0.42 (p<0.68)						
Total (95% CI)		**246**		**246**	**100.0**	**-0.29 (-0.73 to 0.16)**
Heterogeneity: tau^2=0.14; χ^2=13.32, df=5 (p=0.02); I^2=62%						
Test for overall effect: Z=1.27 (p=0.21)						
Test for subgroup differences: χ^2=0.81, df=2 (p=0.67); I^2=0%						

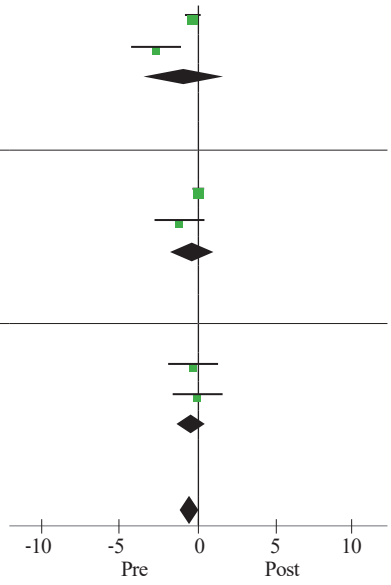

Fig. 5. Forest plot showing the comparison of C-reactive protein levels pre- and post-procedure at different time points. SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degrees of freedom.

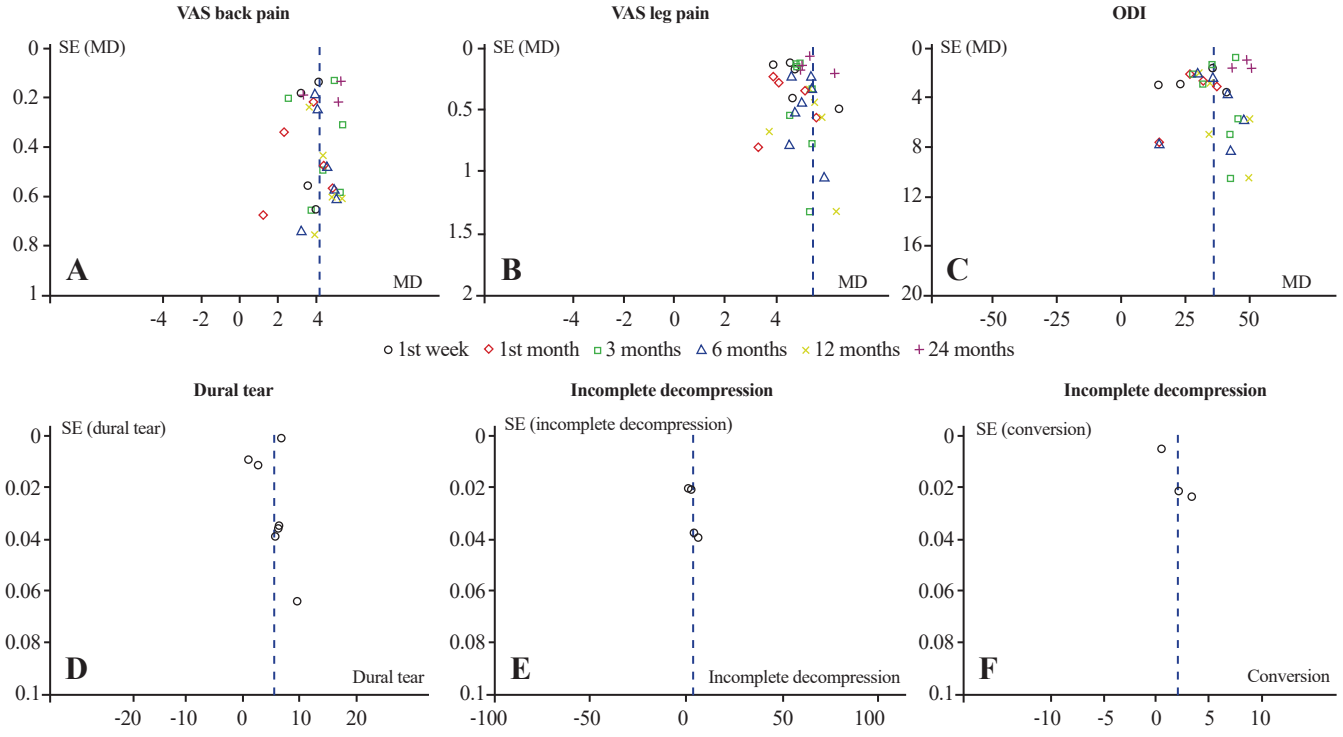

Fig. 6. (A–F) Funnel plot assessing publication bias. The plot displayed asymmetry, as evaluated by the Review Manager (RevMan; Cochrane, UK), with visual inspection suggesting a possible publication bias in the meta-analysis. VAS, Visual Analog Scale; ODI, Oswestry Disability Index; SE, standard error; MD, mean difference.

radiological data, no significant differences were found in the disc height or sagittal angle before and after the intervention. No significant differences in CRP levels were found; however, a significant decrease in postoperative hemoglobin levels was noted. Dural tears were the most frequent intraoperative complication, occur-

Table 3. Sensitivity analysis of the mean difference

Effect size	No. of participants	Random effect model MD (95% CI)	I^2 (%)
Analysis by levels			
VAS back pain			
>30% multilevel	1,788	4.44 (3.98 to 4.90)	90
<30% multilevel	1,944	3.84 (3.49 to 4.19)	81
VAS leg pain			
>30% multilevel	1,858	4.99 (4.47 to 5.51)	93
<30% multilevel	2,082	5.82 (5.63 to 6.01)	28
ODI			
>30% multilevel	1,522	41.38 (36.49 to 46.27)	87
<30% multilevel	2,082	34.68 (30.95 to 38.42)	92
CRP			
>30% multilevel	282	-1.41 (-3.36 to 0.54)	79
<30% multilevel	210	-0.06 (-0.27 to 0.15)	0
Uniportal vs. biportal			
VAS back pain			
Uniportal	2,278	4.29 (3.75 to 4.82)	89
Biportal	1,454	3.89 (3.41 to 4.37)	93
VAS leg pain			
Uniportal	2,486	5.82 (5.63 to 6.02)	41
Biportal	1,454	5.09 (4.65 to 5.53)	89
ODI			
Uniportal	2,486	38.71 (35.06 to 42.35)	89
Biportal	1,118	31.37 (24.66 to 38.09)	97

MD, mean difference; CI, confidence intervals; VAS, Visual Analog Scale; ODI, Oswestry Disability Index; CRP, C-reactive protein.

Table 4. Sensitivity analysis of pooled incidences

Effect size	Random effect model (%) Incidence (95% CI)
Analysis by levels	
Dural tear	
>30% multilevel	3.65 (0.00 to 9.04)
<30% multilevel	6.18 (4.02 to 8.34)
Incomplete decompression	
>30% multilevel	1.50 (0.32 to 2.68)
<30% multilevel	4.75 (2.89 to 6.61)
Excellent	
>30% multilevel	42.05 (0.00 to 85.66)
<30% multilevel	62.03 (47.08 to 76.98)
Poor	
>30% multilevel	3.80 (3.76 to 3.84)
<30% multilevel	4.12 (2.07 to 6.18)
Uniportal vs. biportal	
Dural tear	
Uniportal	3.33 (1.31 to 5.35)
Biportal	7.05 (6.18 to 7.91)
Incomplete decompression	
Uniportal	2.35 (0.00 to 5.19)
Biportal	3.90 (0.37 to 7.43)
Excellent	
Uniportal	46.72 (16.40 to 77.05)
Biportal	72.65 (56.28 to 89.02)
Poor	
Uniportal	3.87 (2.31 to 5.44)
Biportal	4.80 (4.71 to 4.89)

ring in 5.46% of the cases; however, it was resolved in all instances and did not cause permanent harm to the patients. Furthermore, studies of patients with a higher percentage of stenosis experienced severe leg pain, and the incomplete decompression rate was significantly higher in the group with <30% multilevel stenosis. The incidence of dural tears was significantly higher in biportal endoscopy than in uniportal endoscopy.

The results related to PROMs in the present study are consistent with findings from previous studies [6,11]. Clinically significant improvements in the quality of life and pain were observed in all follow-up periods. Although the average VAS and ODI scores could be influenced by outliers, the effectiveness of endoscopy was confirmed by the finding that >90% of patients achieved excellent or good outcomes. The lack of differences in disc height or sagittal angle correction may be caused by the limited number of studies that addressed these variables. In addition, other potential reasons exist, such as the relatively novel nature of endoscopic approaches in spinal surgery, which may present certain technical limitations compared with other surgical methods. Multilevel stenosis is associated with extensive structural changes in the spine. Note that endoscopy in spinal surgery can be performed by different surgeons, which may result in surgical technique variations.

Complications were generally low in this study. A dural tear was observed in 5.46% of the patients; however, all cases resolved without long-term sequelae. In some cases, conversion to open or microscopic surgery was necessary because of bleeding and difficulty in visualization. However, successful management of dural tears using gelfoam and TachoSil sealant has been reported, with no cases of persistent cerebrospinal fluid leakage or cases requiring revision surgery. The frequency of

conversion to open or microscopic surgery was low (<2%), and one of the causes was rupture of the endoscopy lens. Despite the low complications, with small sample sizes, even one or two complications can result in high percentages; thus, the actual rate would be lower. On the contrary, dural tears in other techniques such as microscopy or open surgery have also been observed in up to 7% of cases. Despite the disadvantages of endoscopy, constant irrigation is performed during endoscopy, which helps maintain a wider epidural space and facilitates structural differentiation. Dural tears usually occur during ligamentum flavum resection. Regarding readmission rates, Wu et al. [27] reported a 3% readmission rate in unilateral and bilateral cases, and the reoperation/revision rate was 2.22%, which is low. One of the advantages of endoscopy is its lower tissue aggression. This was observed in the measurement of the levels of CRP, an inflammation marker [29,30], for which no significant differences were found between the preoperative and postoperative levels, suggesting mild aggression. When analyzing the studies separately, a significant increase in CRP levels was observed in the microscopic and open techniques compared with the level in endoscopy. Transfusion was the most frequent complication, although the rate was also low (8.6%). The mean hemoglobin levels also decreased significantly at the end of the follow-up but did not fall <12 g/dL. Despite the low intraoperative blood loss, most studies did not report it. Overall, benefits included early discharge, although they were also dependent on central policies.

In the regression analysis by Kim et al. [23], no significant association was found between the final VAS score and variables such as age, sex, number of levels of spinal decompression, presence of spondylolisthesis, and symptom duration. However, this multiple linear regression analysis was based on a limited sample of 48 patients, which may have affected the ability to detect significant associations. In addition, considering the results of the included studies, >50% of the studies originated from South Korea, indicating extensive experience in spinal surgery in that country. Upon visual inspection of the outcome graphs, studies published in South Korea showed greater improvement in the ODI and a higher proportion of excellent outcomes. Furthermore, these studies reported a lower incidence of dural tears, incomplete decompression, and conversion to open or microscopic surgery. A significantly shorter average surgery duration was also noted in South Korea with an average of 48 minutes compared with other countries with 103.2 minutes. Although two studies reported a slightly higher average age (>70 years), with no apparent differences in terms of efficacy and safety upon visual inspection, age was relatively homogeneous across the included studies. These observations are descriptive and highlight the need for future studies to address these points and consider potential confounding factors to optimize the outcomes of endoscopy in spinal surgery.

This study also compared uniportal and biportal endoscopies in patients with multilevel spinal stenosis and found similar efficacy in pain relief, disability, and patient satisfaction between these techniques; however, biportal endoscopy had a higher incidence of dural tears, which could be attributed to the wider access it provides. One explanation for the higher incidence of dural tears in biportal endoscopy is that this technique has a shorter historical evolution, resulting in a steeper learning curve compared with uniportal endoscopy. Consequently, the incidence of complications may have been slightly higher. Thus, beginners require further learning to experience fewer complications than their masters. In contrast, with the uniportal technique, surgeons require greater skills to perform more complex cases of canal stenosis. Essentially, surgeons performing biportal endoscopy start performing complex stenosis cases earlier, which can increase the likelihood of complications, such as dural tears. Both uniportal and biportal endoscopies demonstrated effective decompression. However, they differ in certain aspects. Uniportal endoscopy offers superior esthetics with higher muscle preservation and a lower rate of conversion to open surgery. Conversely, biportal endoscopy allows for improved triangulation during the procedure. Note that bipolar radiofrequency can be utilized in both uniportal and biportal approaches. Meta-analyses and recent studies support the safety and effectiveness of both techniques, with biportal endoscopy showing greater ease of decompression [31,32] and uniportal endoscopy demonstrating less dural expansion and a smaller facet angle than microscopic endoscopy but a larger facet angle than biportal endoscopy [32].

The learning curve for spinal endoscopy, whether uniportal or biportal, is a crucial factor influencing procedural safety and efficacy and complication rate. Compared with microsurgery or other conventional techniques, endoscopy requires surgeons to become deeply familiar with the spinal anatomy in a three-dimensional environment through indirect visualization, which can be more challenging. For example, according to Kim et al. [33], competence in biportal endoscopy is achieved in approximately 34 cases, and Choi et al. [34] reported a complication rate of 10.3% during the initial learning

period in lumbar discectomy, and competence can be acquired after the first 14 cases. However, these studies did not focus on multilevel spinal stenosis, an area in which anatomical complexity could make the learning curve even more pronounced.

This meta-analysis had some limitations that affected the consistency and robustness of the results. First, the limited number of articles included in the analysis reduced the ability to obtain consistent results for certain variables of interest. Second, the insufficient data collected inhibited meta-regression to explore potential moderating factors. Third, the sensitivity analyses also showed inconsistencies in some cases, which can affect the reliability of the findings. To homogenize the results, several close follow-ups during the first week and first month were grouped, which may have introduced some biases in the interpretation of the results. Fourth, of standard deviations were estimated based on the Cochrane methodology, which can influence the precision of the results. Some complications were not reported in certain studies because of data collection issues or they were not considered relevant, which could result in an overestimation of complications. Fifth, the follow-up time was generally short. Sixth, studies often did not stratify the outcomes according to etiology, making it difficult to discriminate results based on whether the surgery was indicated for spondylolisthesis or disc herniation. Finally, in the comparative analysis between the uniportal and biportal techniques, only variables examined in a sufficient number of articles were included, which may limit the generalizability of the results to other variables of interest. In addition, only one study included patients with multilevel stenosis, whereas the other studies included both single-level and multilevel stenoses without stratifying the results. A cutoff point of 30% was established, classifying studies of patients with >30% multilevel involvement in one group and studies with <30% in another group. This grouping may introduce some heterogeneity in the results and limit the generalized interpretation of the findings, specifically for multilevel stenosis.

Conclusions

To the best of our knowledge, this first meta-analysis evaluating the influence of endoscopy in multilevel stenosis showed a significant improvement in pain and functionality in patients undergoing endoscopy. Furthermore, this improvement was maintained in all follow-up periods, with a more pronounced effect at the end of the follow-up. These findings support the incorporation of endoscopy as a beneficial therapeutic option for managing this condition, allowing surgeons to offer patients a less invasive alternative with positive long-term clinical outcomes. As regards radiological and laboratory data, endoscopy demonstrated a safe profile because no significant differences were noted in the disc height or postoperative sagittal angle, and CRP levels remained stable, indicating a low level of postoperative inflammation. The incidence of complications was low. Different complications were identified, such as dural tears, hematoma, incomplete decompression, root injury, and need for reoperation or revision. These findings inform spine surgeons of the potential risks and complications associated with endoscopy. In the level-specific analysis, studies that included patients with a higher percentage of multilevel stenosis reported higher leg pain scores and a lower incidence of incomplete decompression than studies with a lower percentage of multilevel stenosis. In the comparison between uniportal and biportal endoscopy, no significant differences in the quality of life were found. However, a higher frequency of dural tears was observed with biportal endoscopy than with uniportal endoscopy.

Key Points

- Endoscopy is a safe and effective surgical technique for multilevel spinal stenosis.
- The incidence of complications is low, although biportal endoscopy has a higher incidence of dural tear.
- There are no clinical differences in quality of life between the two endoscopic options.
- Incomplete decompression was significantly higher in the group with less than 30% multilevel stenosis.

Conflict of Interest

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

ORCID

Manuel González-Murillo: https://orcid.org/0000-0002-5205-1382; Juan Castro-Toral: https://orcid.org/0009-0004-2626-356X; César Bonome-González: https://orcid.org/0000-0001-9421-2626; Juan Álvarez de Mon-Montoliú: https://orcid.org/0009-0009-1214-7820

Author Contributions

Conceptualization: JAM, JC, CB, MG. Methodology: JAM, JC, CB, MG. Software: JAM, MG. Validation: IJAM, JC, CB, MG. Formal analysis: JAM, JC, CB, MG. Investigation: JAM, JC, CB, MG. Resources: JAM, JC, CB, MG. Data curation, IJAM, JC, CB, MG. Writing –original draft preparation: JAM, JC, CB, M.G. Writing–review & editing: JAM, JC, CB, MG. Visualization: IJAM, JC, CB, MG. Supervision: JAM, MG. Project administration: JAM, JC, CB, MG. Final approval of the manuscript: all authors.

Supplementary Materials

Supplementary materials can be available from https://doi.org/10.31616/asj.2024.0171. Supplement 1. Assessment of the quality of studies through MINORS. Supplementary 2. Minimally clinical important difference.

References

1. Jensen RK, Jensen TS, Koes B, Hartvigsen J. Prevalence of lumbar spinal stenosis in general and clinical populations: a systematic review and meta-analysis. Eur Spine J 2020;29:2143-63.
2. Hennemann S, de Abreu MR. Degenerative Lumbar Spinal Stenosis. Rev Bras Ortop (Sao Paulo) 2021;56:9-17.
3. Johnson WC, Seifi A. Trends of the neurosurgical economy in the United States. J Clin Neurosci 2018;53:20-6.
4. Phan K, Mobbs RJ. Minimally invasive versus open laminectomy for lumbar stenosis: a systematic review and meta-analysis. Spine (Phila Pa 1976) 2016;41:E91-100.
5. Czigleczki G, Nagy Z, Padanyi C, Banczerowski P. Biportal endoscopic technique in the treatment of spinal stenosis: early clinical experiences and results. Neurol Res 2020;42:1085-8.
6. Jiang Y, Yin J, Nong L, Xu N. Uniportal full-endoscopic versus minimally invasive decompression for lumbar spinal stenosis: a meta-analysis. J Neurol Surg A Cent Eur Neurosurg 2022;83:523-34.
7. Zhang J, Liang D, Xu M, Yan K, Zhang D, Qian W. Comparison of the short-term effects of lumbar endoscopic and microscopic tubular unilateral laminotomy with bilateral decompression in the treatment of elderly patients with lumbar spinal stenosis. Eur J Med Res 2022;27:222.
8. Kaen A, Park MK, Son SK. Clinical outcomes of uniportal compared with biportal endoscopic decompression for the treatment of lumbar spinal stenosis: a systematic review and meta-analysis. Eur Spine J 2023;32:2717-25.
9. Huang YH, Lien FC, Chao LY, Lin CH, Chen SH. Full endoscopic uniportal unilateral laminotomy for bilateral decompression in degenerative lumbar spinal stenosis: highlight of ligamentum flavum detachment and survey of efficacy and safety in 2 years of follow-up. World Neurosurg 2020;134:e672-81.
10. Perez-Roman RJ, Gaztanaga W, Lu VM, Wang MY. Endoscopic decompression for the treatment of lumbar spinal stenosis: an updated systematic review and meta-analysis. J Neurosurg Spine 2021;36:549-57.
11. Kang KB, Shin YS, Seo EM. Endoscopic spinal surgery (BESS and UESS) versus microscopic surgery in lumbar spinal stenosis: systematic review and meta-analysis. Global Spine J 2022;12:1943-55.
12. Pairuchvej S, Muljadi JA, Ho JC, Arirachakaran A, Kongthavonskul J. Full-endoscopic (bi-portal or uni-portal) versus microscopic lumbar decompression laminectomy in patients with spinal stenosis: systematic review and meta-analysis. Eur J Orthop Surg Traumatol 2020;30:595-611.
13. Zhuang HX, Guo SJ, Meng H, Lin JS, Yang Y, Fei Q. Unilateral biportal endoscopic spine surgery for lumbar spinal stenosis: a systematic review and meta-analysis. Eur Rev Med Pharmacol Sci 2023;27:4998-5012.
14. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med 2009;6:e1000100.
15. Parker SL, Godil SS, Shau DN, Mendenhall SK, McGirt MJ. Assessment of the minimum clinically important difference in pain, disability, and quality of life after anterior cervical discectomy and fusion: clinical article. J Neurosurg Spine 2013;18:154-60.
16. Farrar JT, Young JP Jr, LaMoreaux L, Werth JL, Poole MR. Clinical importance of changes in chronic pain intensity measured on an 11-point numerical pain rating scale. Pain 2001;94:149-58.
17. Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J. Methodological index for non-randomized studies (minors): development and validation of a new instrument. ANZ J Surg 2003;73:712-6.
18. Wang J, Han B, Hai Y, Su Q, Chen Y. How helpful is the halo-gravity traction in severe spinal deformity patients?: a systematic review and meta-analysis. Eur Spine J 2021;30:3162-71.
19. Allagh KP, Shamanna BR, Murthy GV, et al. Birth prevalence of neural tube defects and orofacial clefts in India: a systematic review and meta-analysis. PLoS One 2015;10:e0118961.
20. Higgins JP, Thomas J, Chandler J, et al. Cochrane handbook for systematic reviews of interventions. Hoboken (NJ): John Wiley & Sons; 2019.
21. Choi DJ, Kim JE. Efficacy of biportal endoscopic spine surgery for lumbar spinal stenosis. Clin Orthop Surg 2019;11:82-8.
22. Kang MS, You KH, Choi JY, Heo DH, Chung HJ, Park HJ. Minimally invasive transforaminal lumbar interbody fusion using the biportal endoscopic techniques versus microscopic tubular technique. Spine J 2021;21:2066-77.
23. Kim HS, Paudel B, Jang JS, et al. Percutaneous full endo-

scopic bilateral lumbar decompression of spinal stenosis through uniportal-contralateral approach: techniques and preliminary results. World Neurosurg 2017;103:201-9.
24. Kim HS, Patel R, Paudel B, et al. Early outcomes of endoscopic contralateral foraminal and lateral recess decompression via an interlaminar approach in patients with unilateral radiculopathy from unilateral foraminal stenosis. World Neurosurg 2017;108:763-73.
25. Kim JE, Choi DJ, Park EJ. Clinical and radiological outcomes of foraminal decompression using unilateral biportal endoscopic spine surgery for lumbar foraminal stenosis. Clin Orthop Surg 2018;10:439-47.
26. Lee CW, Yoon KJ, Jun JH. Percutaneous endoscopic laminotomy with flavectomy by uniportal, unilateral approach for the lumbar canal or lateral recess stenosis. World Neurosurg 2018;113:e129-37.
27. Wu PH, Chin BZJ, Lee P, et al. Ambulatory uniportal versus biportal endoscopic unilateral laminotomy with bilateral decompression for lumbar spinal stenosis-cohort study using a prospective registry. Eur Spine J 2023;32:2726-35.
28. Zhang Y, Feng B, Su W, et al. Early-effectiveness of unilateral biportal endoscopic laminectomy in treatment of two-level lumbar spinal stenosis. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi 2023;37:706-12.
29. Gewurz H, Mold C, Siegel J, Fiedel B. C-reactive protein and the acute phase response. Adv Intern Med 1982;27:345-72.
30. Sproston NR, Ashworth JJ. Role of C-reactive protein at sites of inflammation and infection. Front Immunol 2018;9:754.
31. Hua W, Liao Z, Chen C, et al. Clinical outcomes of uniportal and biportal lumbar endoscopic unilateral laminotomy for bilateral decompression in patients with lumbar spinal stenosis: a retrospective pair-matched case-control study. World Neurosurg 2022;161:e134-45.
32. Heo DH, Lee DC, Park CK. Comparative analysis of three types of minimally invasive decompressive surgery for lumbar central stenosis: biportal endoscopy, uniportal endoscopy, and microsurgery. Neurosurg Focus 2019;46:E9.
33. Kim JE, Yoo HS, Choi DJ, Hwang JH, Park EJ, Chung S. Learning curve and clinical outcome of biportal endoscopic-assisted lumbar interbody fusion. Biomed Res Int 2020;2020:8815432.
34. Choi DJ, Choi CM, Jung JT, Lee SJ, Kim YS. Learning curve associated with complications in biportal endoscopic spinal surgery: challenges and strategies. Asian Spine J 2016;10:624-9.