Journal of Pain Research

Dovepress
Taylor & Francis Group

Open Access Full Text Article

ORIGINAL RESEARCH

Comparative Evaluation of Efficacy and Complications Between Biportal Endoscopic Lumbar Interbody Fusion and Minimally Invasive Transforaminal Lumbar Interbody Fusion for Lumbar Degenerative Diseases: A Systematic Review and Meta-Analysis

Qianqin Hu[1], Keyi Xiao[2], Jin-Niang Nan[3], Shang-Wun Jhang[4], Chien-Min Chen[4–6,*], Guang-Xun Lin[7,*]

[1]First Department of Orthopedics, Jiangxi Province Hospital of Integrated Chinese and Western Medicine, Nanchang, Jiangxi, People's Republic of China; [2]The School of Clinical Medicine, Fujian Medical University, Fuzhou, Fujian, People's Republic of China; [3]Department of Clinical Medicine, Nanchang Medical College, Nanchang, Jiangxi, People's Republic of China; [4]Division of Neurosurgery, Department of Surgery, Changhua Christian Hospital, Changhua, Taiwan; [5]Department of Leisure Industry Management, National Chin-Yi University of Technology, Taichung, Taiwan; [6]Department of Biomedical Sciences National Chung Cheng University, Chiayi, Taiwan; [7]Department of Orthopedics, The First Affiliated Hospital of Xiamen University, School of Medicine, Xiamen University, Xiamen, Fujian, People's Republic of China

*These authors contributed equally to this work

Correspondence: Chien-Min Chen; Guang-Xun Lin, Email 96015@cch.org.tw; linguangxun@hotmail.com

Objective: To effectuate a comprehensive juxtaposition of the clinical implications, incidence of complications, and successful fusion rates observed in the context of biportal endoscopic lumbar interbody fusion (BE-LIF) and minimally invasive transforaminal lumbar interbody fusion (MI-TLIF).

Methods: The present research initiative involved an exhaustive exploration of pertinent scholarly literature in renowned databases, which lasted until April 2023. The evaluative framework encompassed a diverse array of parameters, including but not limited to operation time, hospitalization, quantification of estimated blood loss, the assessment of outcomes via the application of the Visual Analog Scale (VAS) to gauge pain intensity, and the utilization of the Oswestry Disability Index (ODI) to measure functional impairment.

Results: The current meta-analysis included ten studies with a total of 736 participants. In comparison of the BE-LIF and MI-TLIF techniques, no substantial differences were observed in the parameters studied, included VAS for leg pain ($P > 0.05$), as well as the assessment of complication rates (7.76% versus 7.97%; $P = 0.71$) and fusion rates (89.59% versus 88.60%; $P = 0.90$). However, the early postoperative VAS for back pain ($P < 0.0001$) and the early postoperative ODI score ($P = 0.007$) were significantly lower in the BE-LIF group than in the MI-TLIF group. Additionally, a significant difference in blood loss was observed ($P < 0.0001$), with less blood loss in the BE-LIF group compared to the MI-TLIF group. Furthermore, the complex surgical procedure of BE-LIF resulted in a longer duration of surgery ($P = 0.02$) but shorter hospitalization compared with MI-TLIF ($P < 0.0001$).

Conclusion: Within the context of the management of lumbar degenerative diseases, BE-LIF surgery exhibits clinical effectiveness and incidence of complications comparable to MI-TLIF. In contrast to MI-TLIF, BE-LIF offers distinctive merits, including reduced blood loss, abbreviated hospitalization durations, expedited relief from postoperative back pain, and an accelerated trajectory towards functional recuperation.

Keywords: BESS, biportal endoscopy, lumbar interbody fusion, lumbar degenerative disease, minimally invasive spine surgery, UBE

Received: 11 April 2024
Accepted: 31 March 2025
Published: 26 April 2025

Introduction

Degenerative diseases affecting the lumbar spine can significantly affect patients' mobility and overall quality of life.[1] Among the various treatment modalities, surgery has proven to be an effective approach. One of the widely employed surgical techniques is minimally invasive transforaminal lumbar interbody fusion (MI-TLIF), particularly for the treatment of degenerative conditions of the lumbar spine.[2] Although the tubular spreader used in MI-TLIF surgery is advantageous in protecting the patient's back muscles, it comes with certain limitations.[3] These limitations include restricted space for surgical maneuvering, limited visualization and access to deep structures, and the potential for local muscle ischemia, which may lead to postoperative back pain and muscle strength loss.[4,5] In light of these considerations, further advancements and refinements in surgical techniques are warranted to improve outcomes and minimize potential complications associated with MI-TLIF for degenerative lumbar spine conditions. A comprehensive understanding of these challenges can guide future research efforts and lead to more effective approaches to the treatment of degenerative lumbar spine disorders. Considering these factors, there is a need to further improve and refine surgical techniques to improve outcomes and minimize potential complications.

Over the past few years, there has been a notable rise in the utilization of the biportal endoscopic lumbar interbody fusion (BE-LIF), both within the confines of individual nations and across international boundaries.[6] This rise in popularity can be attributed to the benefits of endoscopic equipment and advances in surgical techniques. In particular, the unilateral biportal endoscopic technique offers distinct advantages due to its use of separate channels for the field of view and surgical instruments.[7] This segregation ensures an unobstructed field of view, facilitating ease of instrument manipulation and allowing sufficient nerve decompression during the procedure.[8]

This study aims to establish a clinical benchmark for managing degenerative lumbar spine conditions by conducting a comparative analysis of the clinical efficacy, complications, and fusion rates associated with two surgical approaches: BE-LIF and MI-TLIF. By evaluating these key outcomes, we seek to determine the relative strengths and limitations of each technique, thereby informing surgical decision-making in the treatment of degenerative lumbar spine disease.

Materials and Methods

Search Strategy

We conducted a systematic review of the literature following the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA).[9] Our search strategy was designed to identify and gather randomized controlled trials (RCTs) and nonrandomized cohort studies that compared the effectiveness of two techniques in treating lumbar degenerative disease. Our search covers relevant papers that were retrieved from reputable databases (including PubMed, Web of Science, Cochrane Library, and China National Knowledge Infrastructure) published in English or Chinese. The search duration extended from the inception of these databases up to April 15, 2023. In order to enhance search sensitivity, we utilized the following keyword combinations: the first search string (#1) captured terms encompassing various UBE concepts and techniques, including "unilateral biportal endoscopic", "UBE", "BESS", "biportal endoscopic spine surgery", "two portal endoscopic", "BE-LIF", "UBE-LIF", and "biportal endoscopic lumbar interbody fusion", along with their free words. The second search string (#2) targeted terms specific to MI-TLIF, such as "minimally invasive transforaminal lumbar interbody fusion", "MI-TLIF", and "MIS-TLIF", also including their free words. The Boolean operators "OR" and "AND" were used to combine terms within and across each string, respectively. By employing this approach, our aim was to collect an extensive and representative body of evidence for our academic paper. Additionally, relevant studies were identified through the examination of reference lists.

The initial selection of the search results involved independent evaluations of titles and abstracts by two researchers. Subsequently, potentially relevant articles were further assessed for their content. In cases where differences in opinion arise, a third party is consulted to reach a consensus.

Inclusion and Exclusion

The inclusion criteria encompassed the following conditions: 1) all pertinent clinical articles or original research (including RCTs and cohort studies), 2) articles that conducted comparisons between the two techniques in human subjects, and 3) studies that provided data on clinical, perioperative, or postoperative evaluation measures, as well as information on complications and fusion rates, all evaluated concurrently.

Exclusion criteria were defined as follows: 1) studies with single-arm designs lacking comparative groups, 2) studies lacking pertinent data, and 3) duplicate studies, including multiple articles of similar type originating from the same affiliation, in which case only the article with the highest case count was considered for inclusion.

Quality Assessment

Two separate reviewers assessed the methodological quality of each study incorporated into this meta-analysis. The assessment of non-randomized controlled trials (non-RCTs) was conducted employing the Newcastle-Ottawa Scale (NOS). The evaluation encompassed three key domains: selection, comparability, and exposure/outcome. According to this rating scale, studies that met a predetermined threshold of five "stars" or more were considered eligible for inclusion in our review.[10] This rigorous evaluation process aimed to ensure the inclusion of high-quality studies and to improve the reliability of our meta-analysis results.

Data Extraction

Two reviewers independently collected data using established data extraction protocols. The following data was collected from each study: author names, publication year, geographical location, study design, case count, diagnostic criteria, surgical level, specific surgical procedure details, as well as patient demographics encompassing age, sex, and duration of follow-up. The primary outcomes of interest encompassed Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) scores. These evaluations were carried out at three distinct time points: preoperatively, in the early postoperative period (within one day to one month after surgery), and at the final follow-up. Secondary outcomes included perioperative variables such as operative duration, hospitalization, and blood loss, in addition to complications.

Statistical Analysis

Data analysis was performed using Review Manager 5.4 (Cochrane Collaboration, Oxford, UK). For continuous data, we utilized mean differences and 95% confidence intervals (CIs). Dichotomous variables in the comparison research were assessed using odds ratios (ORs) or risk ratios. Weighted mean differences (WMDs) or standard mean differences were employed to evaluate continuous variables.

To assess heterogeneity, we performed the x^2 and I^2 tests. If the p-value was greater than 0.1 or I^2 was less than 50%, we considered the studies homogeneous and applied a fixed-effects model. However, when I^2 exceeded 50%, a random-effects model was utilized. Statistical significance was denoted by a p-value of less than 0.05.

We visually presented the findings and pooled impact estimates using forest plots, allowing a graphical representation of the results of numerous studies.

Results

Study Results and Quality Evaluation

Initially, a total of 339 studies were identified during the initial search. Following the evaluation of titles and abstracts, 326 articles were deemed ineligible for inclusion, resulting in 13 articles that underwent a comprehensive and thorough review. Following a meticulous evaluation, ten of these papers met the predefined inclusion criteria and were included in the present analysis.[8,11–19]

The ten studies that met the inclusion criteria were retrospective comparative cohort studies. In terms of methodological quality, all ten studies examined in this analysis were rated moderate to high, based on the NOS assessment (Table 1).

Characteristics

In total, ten studies were included, comprising 736 patients, of whom 307 were men and 429 were women. A cohort comprising 347 patients (137 males: 170 females) underwent BE-LIF, while an additional 389 patients (170 males: 259

https://doi.org/10.2147/JPR.S472975

Table 1 Quality Assessment of the Included Studies

Studies	Selection				Comparability	Exposure			Total Scores (of 9☆)
	Is the Case Definition Adequate?	Representativeness of the Cases	Selection of Controls	Definition of Controls	Comparability of Cases and Controls on the Basis of the Design or Analysis	Ascertainment of Exposure	Same Method of Ascertainment for Cases and Controls	Non-Response Rate	
Gatam 2021[11]	☆		☆	☆	☆☆	☆	☆		7
Heo 2019[12]	☆		☆	☆	☆☆	☆	☆		7
Jiang 2022[13]	☆		☆	☆	☆☆	☆	☆		7
Kang 2021[14]	☆	☆	☆	☆	☆☆	☆	☆	☆	9
Kim 2021[15]	☆	☆	☆	☆	☆☆	☆	☆		8
Kong 2022[16]	☆		☆	☆	☆☆	☆	☆		7
Song 2023[8]	☆		☆	☆	☆☆	☆	☆		7
Yang 2023[17]	☆		☆	☆	☆☆	☆	☆		7
Yu 2023[18]	☆		☆	☆	☆☆	☆	☆		7
Zhu 2021[19]	☆		☆	☆	☆☆	☆	☆		7

Notes: The scale comprises eight items and uses a star-based semi-quantitative scoring system. With the exception of the Comparability domain (maximum 2 stars), each of the remaining items can receive a maximum of 1 star.

females) underwent MI-TLIF. The studies were carried out in various countries, including three in south Korea, six in China, and one in Indonesia. The mean age of the patients in both groups was 57.95 years (BE-LIF) and 58.35 years (MI-TLIF). The L4-L5 level was the most frequently treated spinal segment. A summary of demographic information is presented in Table 2.

Table 2 Characteristics of the Included Studies

Study (Year)	Study Design	Country	Follow-Up (months)	Technique	Number (M/F)	Age, Years	Operation Level	Complication	Macnab
Gatam 2021[11]	Retrospective	Indonesia	12	BE-LIF	72 (26/46)	55.1 ± 5.12	L3–4(8); L4–5(56); L5–S1(8)	Dural tear (3)	NR
			12	MI-TLIF	73 (28/45)	52.3 ± 6.13	L3–4(10); L4-5(48); L5-S1(15)	Postoperative infection (2); Cage subsidence (2)	NR
Heo 2019[12]	Retrospective	South Korea	13.4 ± 2.5	BE-LIF	23 (7/16)	61.4 ± 9.4	L3–4(3); L4–5(17); L5–S1(3)	Epidural hematoma (1); Cage subsidence (1)	NR
			13.4 ± 2.5	MI-TLIF	46 (19/27)	63.5 ± 10.5	L3–4(4); L4-5(29); L5-S1 (13)	Dural Tear (1); Epidural hematoma (1); Superficial wound infection (1); Deep vein thrombosis (1); Cage subsidence (2)	NR
Jiang 2022[13]	Retrospective	China	3	BE-LIF	25 (9/16)	63.28 ± 8. 51	NR	NR	NR
			3	MI-TLIF	25 (8/17)	59.68 ± 10.38	NR	NR	NR
Kang 2021[14]	Retrospective	South Korea	14.5 ± 2.3	BE-LIF	47 (17/30)	66.87 ± 10.41	L2–3(4); L3–4(7); L4–5(34); L5–S1(20)	Incomplete decompression (1), Hematoma (2), Dural tear (3)	NR
			15.78 ± 3.16	MI-TLIF	32 (17/15)	66.38 ± 9.45	L2–3(1); L3–4(9); L4–5(22); L5–S1(11)	Incomplete decompression (2), Hematoma (1), Dural tear (1), Infection (1)	NR
Kim 2021[15]	Retrospective	South Korea	27.2 ± 5.4	BE-LIF	32 (17/15)	70.5 ± 8.26	L2–3(1); L3–4(3); L4–5(20); L5–S1(8)	Epidural hematoma (1), Transient palsy (1)	84.40%
			31.5 ± 7.3	MI-TLIF	55 (25/30)	67.3 ± 10.7	L3–4(2); L4–5(46); L5–S1(7)	Epidural hematoma (1), Transient palsy (2)	85.40%
Kong 2022[16]	Retrospective	China	14.7 ± 2.5	BE-LIF	35 (13/22)	55.1	L2–3(1); L3–4(5); L4–5(17); L5–S1(10); L4-S1(2)	Dural tear (1), Hematoma (1)	NR
			15.0 ± 3.4	MI-TLIF	40 (18/22)	56	L1-2(1); L2–3(4); L3–4(7); L4–5(15); L5–S1(12); L4-S1(1)	Dural tear (1), Hematoma (1), Infection (1)	NR

(*Continued*)

Table 2 (Continued).

Study (Year)	Study Design	Country	Follow-Up (months)	Technique	Number (M/F)	Age, Years	Operation Level	Complication	Macnab
Song 2023[8]	Retrospective	China	14.04± 1.51	BE-LIF	25(9/16)	52.36 ± 10.69	L3-4(2); L4-5(13); L5-S1 (10)	Mild decrease in lower limb strength (1)	88.00%
			14.79± 1.59	MI-TLIF	24(8/16)	56.38 ± 10.53	L3-4(2); L4-5(10); L5-S1 (12)	Transient lower limb numbness (3); Transient muscle strength decline (1)	83.30%
Yang 2023[17]	Retrospective	China	12	BE-LIF	30(12/18)	49. 3 ± 3. 5	L3–4(6); L4–5(15); L5–S1(9)	Dural tear (1); Nerve root injury (1)	86.70%
			12	MI-TLIF	35(20/15)	22. 3 ± 1. 4	L3–4(7); L4–5(21); L5–S1(7)	Nerve root injury (1); Epidural hematoma (1)	88.60%
Yu 2023[18]	Retrospective	China	38.96 ± 3.17	BE-LIF	23 (11/12)	60.8	L3–4(3); L4–5(11); L5–S1(9)	Dural tear (1), Cage subsidence (2)	NR
			39.50 ± 3.35	MI-TLIF	18 (8/10)	60.7	L3–4(3); L4–5(8); L5–S1(7)	Dural tear (2), Cage subsidence (1), Infection (1)	NR
Zhu 2021[19]	Retrospective	China	15.29 ± 1.98	BE-LIF	35 (16/19)	50.94 ± 12.12	L4–5(28); L5–S1(7)	Transient lower extremity numbness (2)	91.40%
			16.12 ± 2.59	MI-TLIF	41 (19/22)	53.44 ± 14.37	L3–4(2); L4–5(25); L5–S1(14)	Transient lower extremity numbness (2); Epidural hematoma (1)	87.80%

Abbreviations: BE-LIF, biportal endoscopic lumbar interbody fusion; MI-TLIF, minimally invasive transforaminal lumbar interbody fusion; NR, not report.

Perioperative Parameters

Nine individual studies[8,12–19] presented findings related to mean operating times. In particular, the analysis indicated that the average operation time in the BE-LIF group was significantly longer compared to the MI-TLIF group (WMD: 17.00; 95% CI: 2.70, 31.31; $I^2 = 97\%$; $P = 0.02$; Figure 1A).

Data concerning the duration of hospitalization were extracted from seven distinct studies,[13–19] and a comprehensive analysis of these datasets revealed a noteworthy pattern. Specifically, it was evident that the MI-TLIF group exhibited a statistically significant increase in postoperative hospitalization in comparison to the BE-LIF group (WMD: −1.36; 95% CI: −2.01, −0.70; $I^2 = 77\%$; $P < 0.0001$; Figure 1B).

Estimates of blood loss were obtained from a total of seven individual studies,[8,12–14,16,18,19] thus forming the basis for a comprehensive analysis. Interestingly, the collective findings consistently indicated a discernible trend in which the mean estimated blood loss associated with the BE-LIF group remained significantly lower than that recorded within the MI-TLIF group (WMD: −85.81; 95% CI: −113.88, −57.73; $I^2 = 98\%$; $P < 0.0001$; Figure 1C).

In the context of this comprehensive investigation, a total of three distinct studies[14,16,18] have meticulously documented and analyzed hemoglobin levels. It is noteworthy the result of this meticulous analysis, which collectively demonstrates the absence of a statistically significant distinction between preoperative hemoglobin levels (WMD: −1.18; 95% CI: −4.21, 1.84; $I^2 = 0\%$; $P = 0.44$; Figure 2A) and postoperative hemoglobin levels when comparing the two groups (WMD: 4.55; 95% CI: −2.21, 11.32; $I^2 = 80\%$; $P = 0.19$; Figure 2B).

In addition, it should be noted that three studies[8,13,14] have thoroughly documented postoperative C-reactive protein (CRP) levels. Interestingly, a thorough examination of these studies demonstrated that postoperative CRP levels were

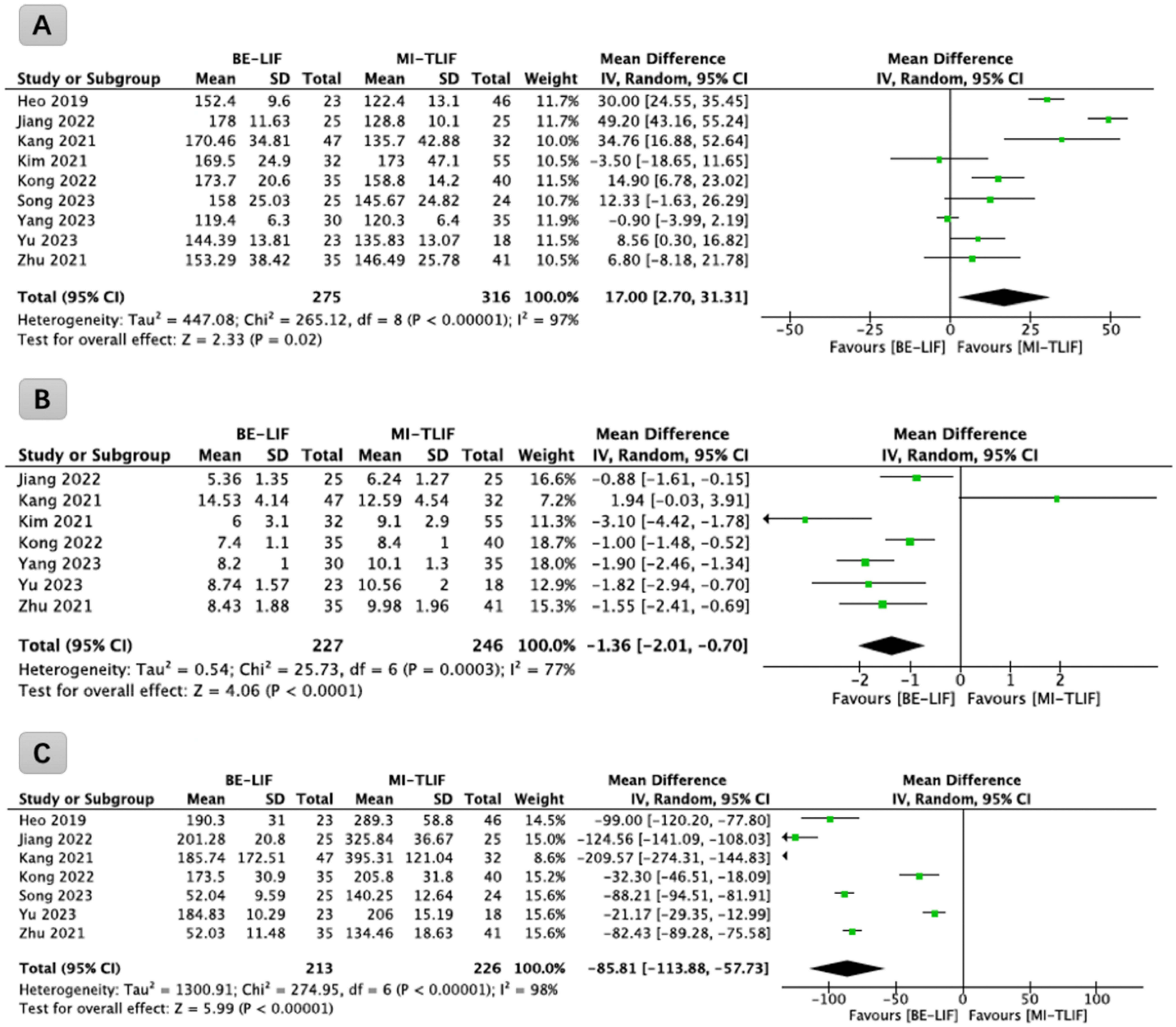

Figure 1 Forest plots comparing operative time (**A**), length of hospital stays (**B**), and estimated blood loss (**C**) between BE-LIF and MI-TLIF.
Abbreviations: BE-LIF, biportal endoscopic lumbar interbody fusion; MI-TLIF, minimally invasive transforaminal lumbar interbody fusion.

significantly lower in BE-LIF compared to MI-TLIF (WMD: −5.33; 95% CI: −8.04, −2.63; I^2 = 90%; P = 0.0001; Figure 2C).

Kang et al[14] discerned a noteworthy association in their investigation, wherein the utilization of BE-LIF was linked to a distinctly reduced volume of postoperative drainage in comparison to MI-TLIF. The quantitative assessment revealed drainage volumes of 163.81 ± 121.04 mL for BE-LIF and 225.81 ± 101.40 mL for MI-TLIF, with a statistically significant difference denoted by a p-value of 0.016. Furthermore, Kang et al[14] observed comparable transfusion rates between the two groups, with 4 out of 47 cases in the BE-LIF group and 5 out of 32 cases in the MI-TLIF group undergoing transfusion, which yielded a non-significant p-value of 0.614.

Clinical Outcomes

Four independent studies contributed data on preoperative VAS for back scores for both groups. The collective findings consistently deviated from the null line, demonstrating a statistically significant distinction in the mean VAS scores before surgery between the two cohorts. Evaluation of postoperative back VAS scores was impeded due to baseline irregularities.

https://doi.org/10.2147/JPR.S472975

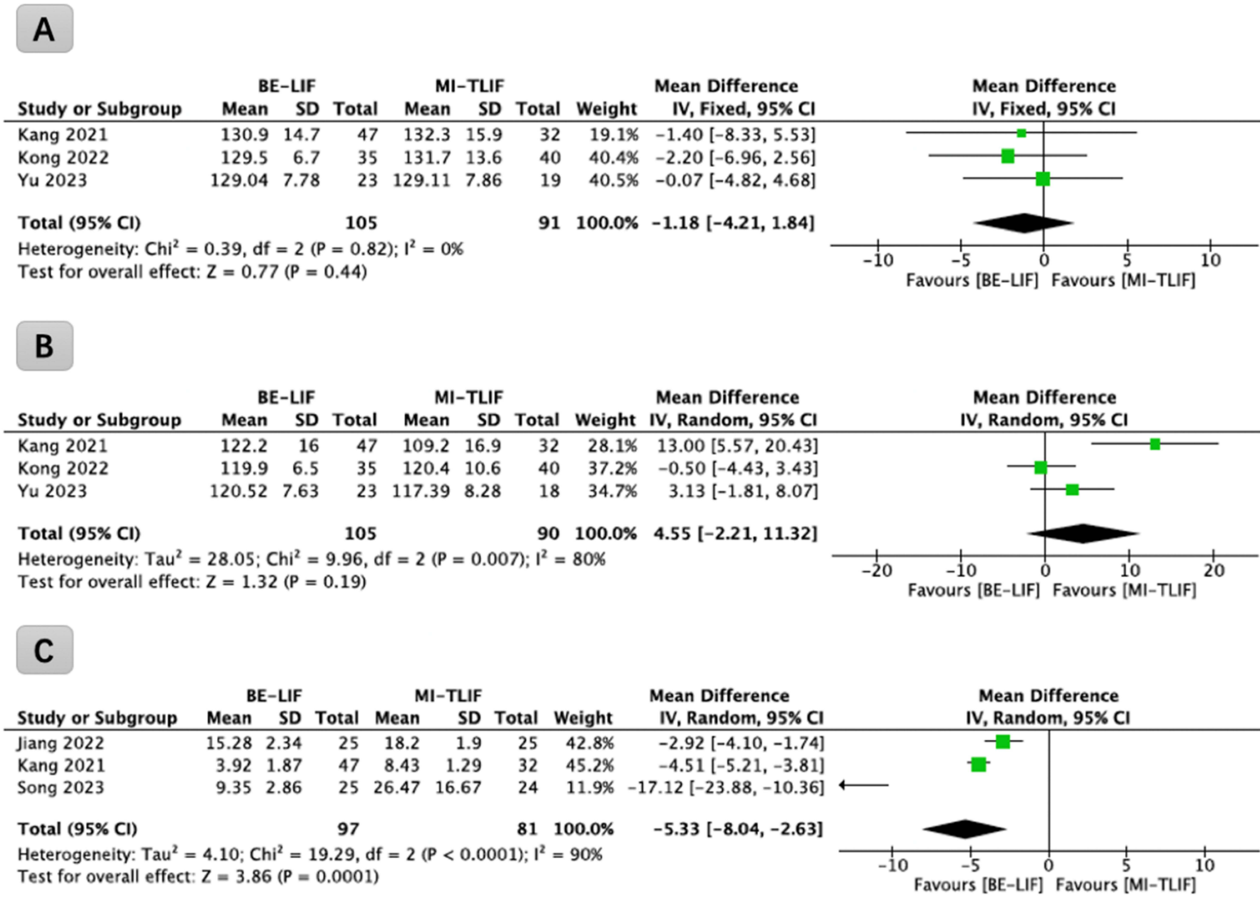

Figure 2 Forest plots for comparison of hemoglobin levels at preoperative (**A**), and postoperative (**B**) between BE-LIF and MI-TLIF. Forest plots comparing postoperative C-reactive protein levels (**C**) between BE-LIF and MI-TLIF.
Abbreviations: BE-LIF, biportal endoscopic lumbar interbody fusion; MI-TLIF, minimally invasive transforaminal lumbar interbody fusion.

Upon exclusion of the study conducted by Kong et al,[16] there was no significant difference in mean preoperative back VAS scores between the two groups, concurrently with the absence of heterogeneity in all selected studies. Consequently, the final analysis incorporated three studies[8,15,19] to ensure rigor and coherence in our investigation. Comparative analysis of the average VAS scores related to preoperative back pain between the BE-LIF and MI-TLIF groups did not produce statistically significant findings (WMD: −0.30; 95% CI: −0.67, 0.08; $I^2 = 0\%$; P = 0.12; Figure 3A). It should be noted that a statistically significant disparity emerged in VAS scores pertaining to early postoperative back pain, favoring the BE-LIF group over the MI-TLIF group (WMD: −1.32; 95% CI: −1.67, −0.96; $I^2 = 48\%$; $P < 0.0001$; Figure 3B). However, no statistically significant differences were detected between the two groups during the final follow-up evaluation (WMD: −0.13; 95% CI: −0.39, 0.13; $I^2 = 0\%$; P = 0.34; Figure 3C).

Five studies[8,12,15,16,19] included in this analysis provided VAS scores for the assessment of leg pain. The preoperative comparison between the two groups did not show statistically significant differences in leg pain scores (WMD: 0.14; 95% CI: −0.07, 0.34; $I^2 = 0\%$; P = 0.20; Figure 4A). Similarly, there were no notable differences between the two groups in relation to leg pain scores shortly after surgery (WMD: −0.14; 95% CI: −0.33, 0.04; $I^2 = 0\%$; P = 0.13; Figure 4B) or at the final follow-up assessment (WMD: −0.24; 95% CI: −0.64, 0.15; $I^2 = 75\%$; P = 0.23; Figure 4C).

A total of eight studies contributed data on ODI.[8,12,13,15–19] The preoperative ODI scores did not demonstrate statistically significant differences between the BE-TLIF and MI-TLIF groups (WMD: 0.04; 95% CI: −0.96, 1.03; $I^2 = 0\%$; P = 0.94; Figure 5A). ODI scores in the early postoperative period were significantly lower in patients who underwent BE-TLIF than in those who underwent MI-TLIF (WMD: −3.98; 95% CI: −6.86, −1.09; $I^2 = 93\%$; P = 0.007;

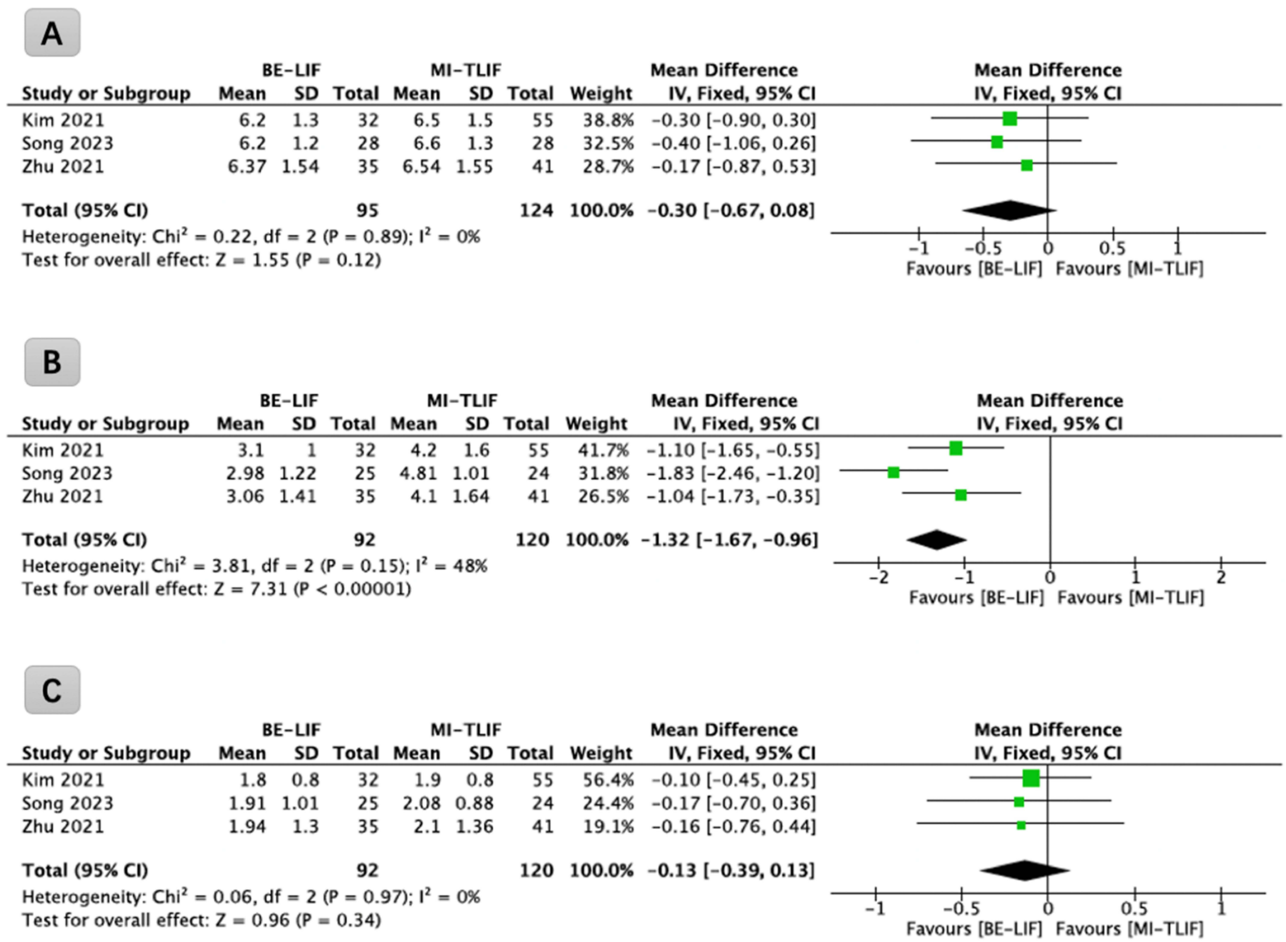

Figure 3 Forest plots for comparison of VAS for back at preoperative (**A**), early postoperative (**B**), and final follow-up (**C**) between BE-LIF and MI-TLIF.
Abbreviations: VAS, visual analog scale; BE-LIF, biportal endoscopic lumbar interbody fusion; MI-TLIF, minimally invasive transforaminal lumbar interbody fusion.

Figure 5B). However, at the final follow-up assessment, there was no significant difference in ODI scores between the two groups (WMD: −0.30; 95% CI: −0.76, 0.16; I^2 = 0%; P = 0.21; Figure 5C).

Four separate studies have provided a comprehensive overview of surgical satisfaction, evaluated using the modified Macnab criteria. In the cohort subjected to the BE-LIF procedure, a notable 87.63% of the patients demonstrated the achievement of outcomes classified as "good" or "excellent". A comparable figure of 86.28% was observed within the MI-TLIF group (Table 2).

Radiological Parameters

A comprehensive analysis encompassing data from eight distinct studies sheds light on the fusion rates observed.[11,12,15–20] Within this context, a meticulous examination revealed a notable absence of statistically significant distinctions between the BE-LIF group (OR: 1.03; 95% CI: 0.62, 1.71; I^2 = 0%; P = 0.90; Figure 6), boasting a fusion rate of 89.59% (284 out of 317 cases), and the MI-TLIF group, reflecting a fusion rate of 88.60% (311 out of 351 cases).

Furthermore, three studies have documented that no statistically significant differences in radiologic parameters such as disc height and lumbar lordotic angle between the two groups, both before and after the surgical interventions (Supplementary Figure 1).

Complications

Data extracted from a total of nine distinct studies offered information on the occurrence of complications. However, meticulous analysis of these data indicated the absence of statistically significant disparities between the BE-LIF and MI-

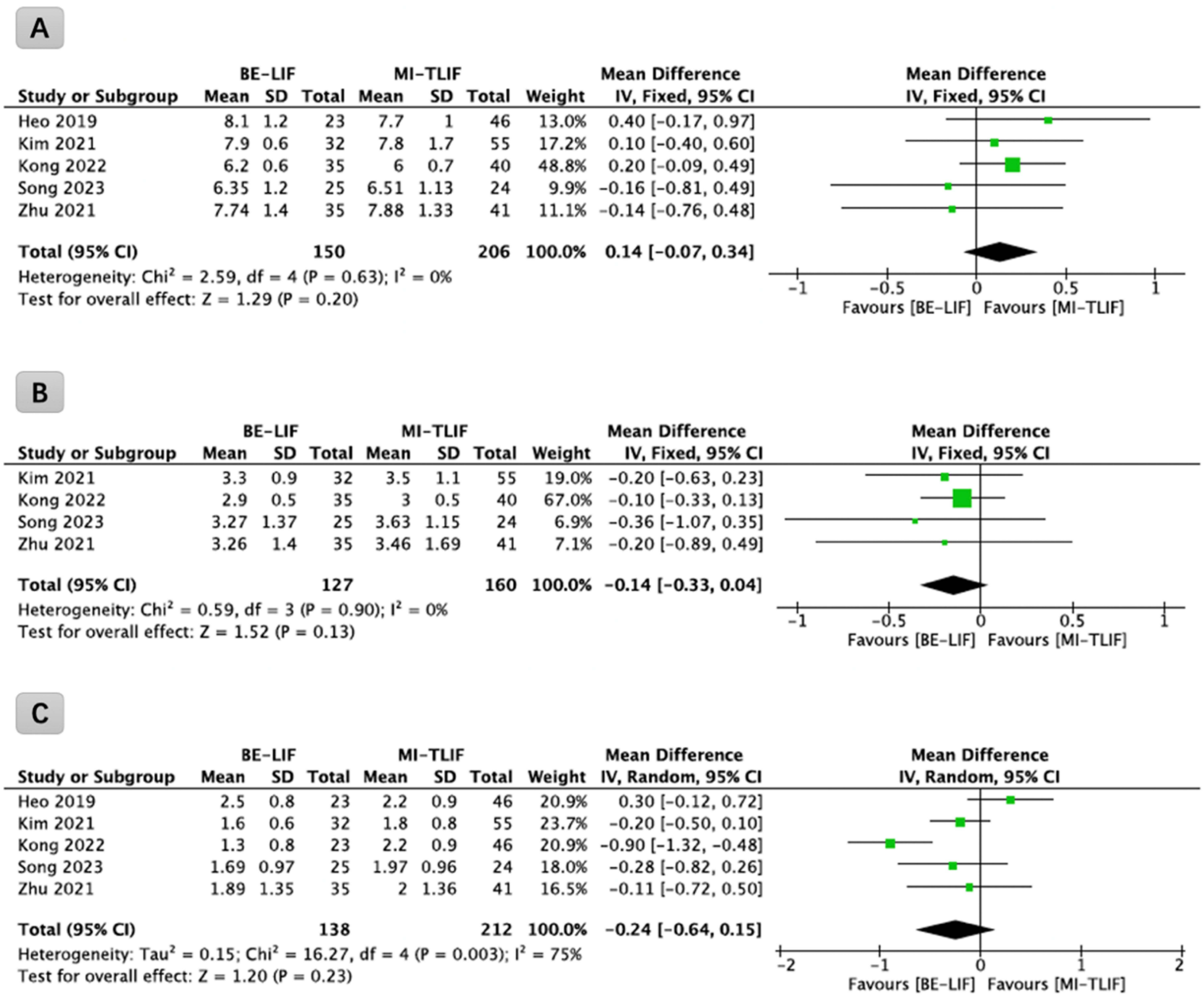

Figure 4 Forest plots for comparison of VAS for leg at preoperative (**A**), early postoperative (**B**), and final follow-up (**C**) between BE-LIF and MI-TLIF.
Abbreviations: VAS, visual analog scale; BE-LIF, biportal endoscopic lumbar interbody fusion; MI-TLIF, minimally invasive transforaminal lumbar interbody fusion.

TLIF groups. A comprehensive breakdown of the reported complications is presented in Table 1 for reference. In particular, the complications rates observed in the BE-LIF and MI-TLIF groups were recorded at 7.76% (25 out of 322) and 7.97% (29 out of 364), respectively, which were not statistically different (OR: 0.90; 95% CI: 0.51, 1.57; I^2 = 0%; P = 0.71; Supplementary Figure 2).

Among these complications, dural tears and hematomas emerged as the most frequent surgical complications (Supplementary Figure 3A and B). Furthermore, it should be mentioned that the incidence of cage subsidence did not show statistically significant differences between the two aforementioned groups (Supplementary Figure 3C).

Sensitivity Analysis and Publication Bias

Sensitivity analyses were conducted using RevMan 5.4 software to assess the robustness of the combined results for all evaluation indicators. The findings revealed that the results of the meta-analysis of VAS scores related to back pain were significantly influenced by the study by Kong et al,[16] suggesting that this particular outcome was lacking robustness. Conversely, the results of the meta-analysis for the remaining evaluation indicators demonstrated greater stability and reliability.

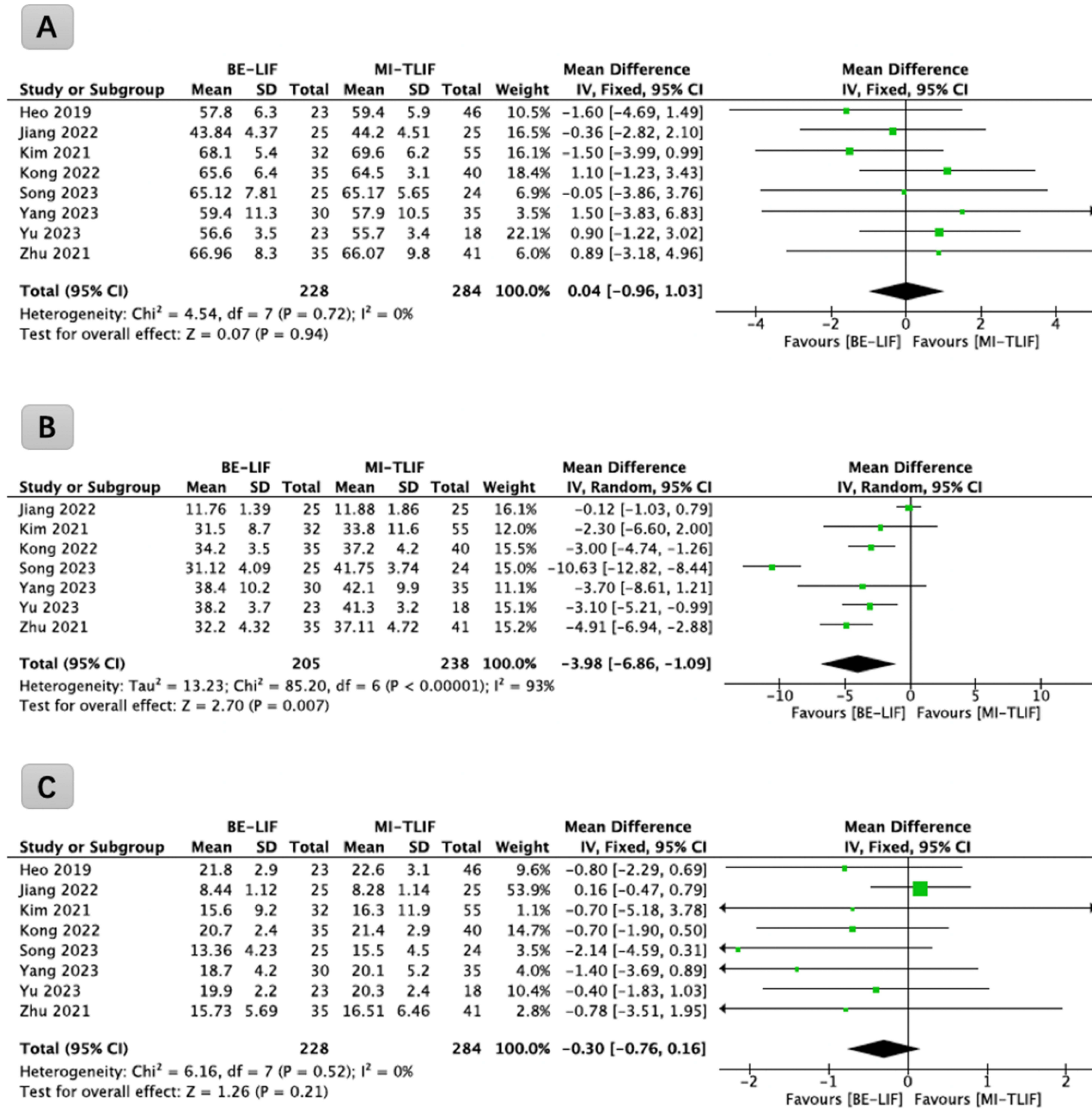

Figure 5 Forest plots for comparison of ODI at preoperative (**A**) early postoperative (**B**), and final follow-up (**C**) between BE-LIF and MI-TLIF.
Abbreviations: ODI, Oswestry Disability Index; BE-LIF, biportal endoscopic lumbar interbody fusion; MI-TLIF, minimally invasive transforaminal lumbar interbody fusion.

This study encompassed a total of ten articles and an evaluation of publication bias was conducted using postoperative complications as an illustrative example. It should be noted that the scatter plot within the funnel plot displayed a degree of general symmetry. The quantitative analysis indicated that there was a slight presence of publication bias. However, it should be noted that this bias was somewhat inevitable, mainly due to the predominant inclusion of research results originating from Chinese or Korean authors (Figure 7).

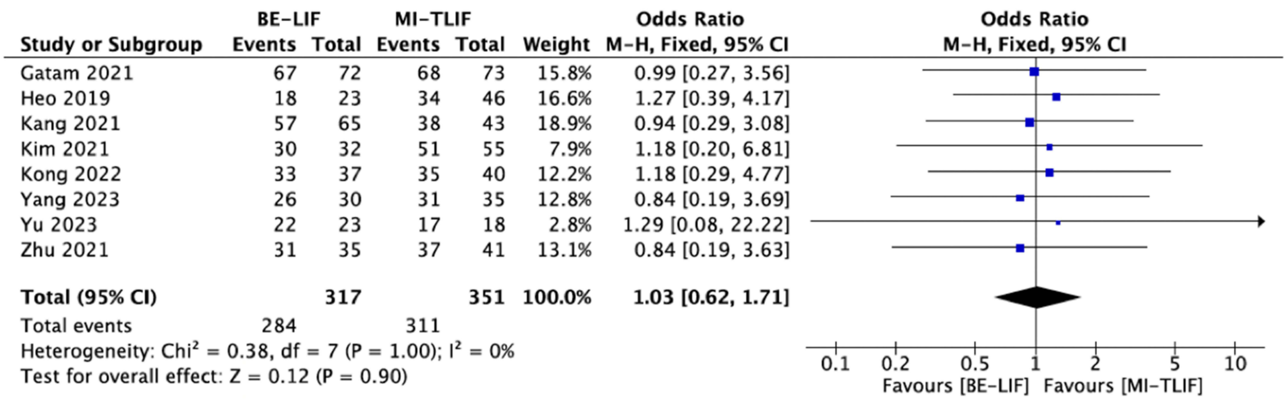

Figure 6 Forest plot for comparisons of fusion rates between BE-LIF and MI-TLIF.
Abbreviations: BE-LIF, biportal endoscopic lumbar interbody fusion; MI-TLIF, minimally invasive transforaminal lumbar interbody fusion.

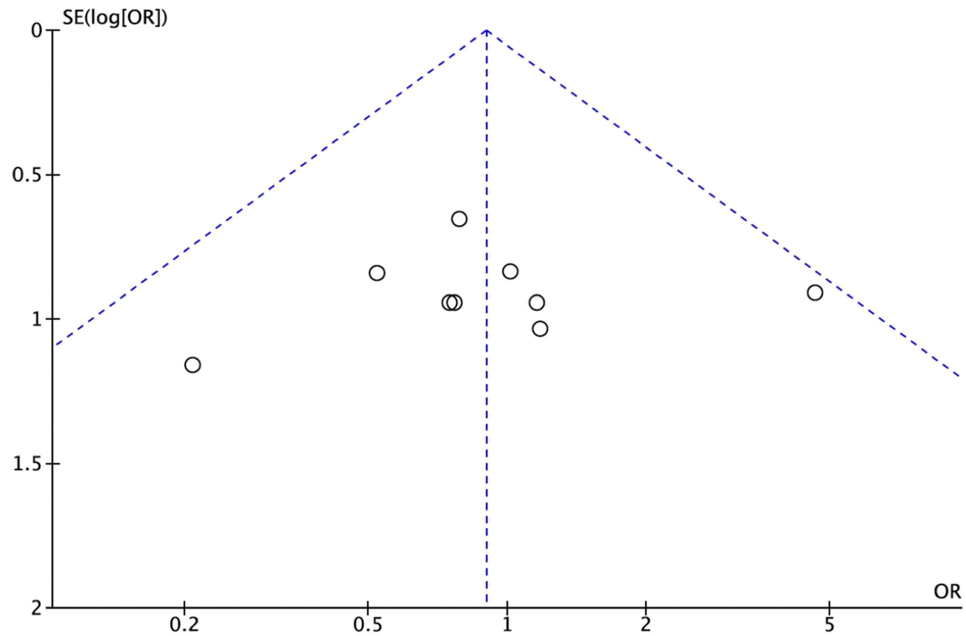

Figure 7 Funnel plots of complications.

Discussion

Degenerative afflictions of the lumbar spine are among the most prevalent spinal disorders affecting the elderly demographic, a prevalence that steadily increases in concordance with the growing ageing population.[21–23] Surgical intervention has emerged as the main therapeutic resource within the scope of addressing this disease. Conventional posterior decompression and fusion, although effective in alleviating lumbar degenerative pathologies, are not without drawbacks. The requisite incisions, integral to this procedure, can precipitate a decrease in innervation within the paravertebral musculature. Consequently, a litany of postoperative complications, including but not limited to lumbar pain, muscle atrophy in the operated segment, restenosis attributable to epidural fibrosis, increased degeneration in adjacent segments, and even surgical insufficiency, may ensue.[24,25]

In response to the aforementioned predicaments, the field of minimally invasive spine surgery has undergone a precipitous evolution. A notable exemplar is the MI-TLIF, which is a derivative of the traditional TLIF approach imbued with minimally invasive principles. In stark contrast to its conventional open lumbar surgery counterpart, the

Wiltse approach, as adopted by MI-TLIF, obviates the tendency to superfluous muscular support and stripping, thus reducing paraspinal muscle impairment.[26] Furthermore, this approach demonstrates a superior capacity to preserve paraspinal muscle attachment sites, protecting the innervation of the paraspinal musculature, as well as selected ligamentous structures.[27] However, the procedure is not without drawbacks. The depth of the surgical channel and the limited ability of the spreader blade to fully segregate all tissues contribute to the susceptibility of soft tissues infiltrating the surgical field. The excessive traction exerted by the spreader blade on the paravertebral muscles has the potential to induce localized muscle ischemia, thus impeding the trajectory toward postoperative recovery. At the same time, the manipulation of the endplate must be based on tactile sensation, which lacks direct visual confirmation.[28] This, in turn, leads to susceptibility to inadequate cartilage endplate handling or inadvertent bony endplate impairment.[29] Moreover, given the metallic composition characterizing the surgical channel, the utilization of intraoperative fluoroscopy, facilitated by a C-arm X-ray apparatus, may inadvertently encumber the unobstructed observation of anatomical structures.

The advent of BE-LIF, resulting from the confluence of minimally invasive paradigms and technological advances, has gained increasing traction within clinical practice. BE-LIF, characterized by its dual-channel configuration, encompasses an endoscopic conduit facilitating a continuous irrigation system and affording a surgical field, coupled with an operative channel.[20] This amalgamation leads to an expanded endoscopic field of vision that encourages increased operational flexibility. The ability to seamlessly accommodate traditional open surgical instruments eliminates the need to purchase specialized endoscopic instruments.[30] This pragmatic feature augments equipment utilization, thereby streamlining the surgical process and concomitantly truncating the learning curve for surgical practitioners.[31] Consequently, this not only fosters enhanced intraoperative operability but also engenders fiscal prudence by curtailing healthcare expenditure.

Perioperative Data and Learning Curve

Within the purview of our comprehensive meta-analysis, a notable observation has emerged, delineating a pronounced distinction in operative temporal requirements between BE-LIF and MI-TLIF. The intrinsic requirements of BE-LIF spinal surgery require distinctive manual orchestration, in which one hand is assigned to secure the endoscope and maintain an unobstructed visual domain, while the other hand is tasked with adept maneuvering within the confines of a delimited surgical workspace.[32] It is imperative to maintain an uninterrupted intraoperative fluid conduit, further increasing the complexity, as the endoscope is instrumentalized to execute intricate procedures that encompass laminectomies, discectomies, and endplate preparations.[33] These procedural intricacies, coupled with the inherent constraints, plausibly contribute to the protracted procedural duration characterizing the BE-LIF approach.

Moreover, our investigation yielded an intriguing finding suggesting that intraoperative bleeding in BE-LIF procedures is notably lower than that observed in MI-TLIF. However, it is imperative to exercise caution in interpreting the accuracy of these estimations regarding bleeding volumes. Given that BE-LIF employs a water-based technique, precisely quantifying the extent of bleeding poses challenges, thereby rendering it plausible that the bleeding volume may approximate or slightly lower that encountered in MI-TLIF. This inference is supported by the analysis of pre- and postoperative hemoglobin levels, which revealed no statistically significant disparity between the two cohorts.

Furthermore, an ancillary facet meriting consideration is the potential influence of the learning curve on the temporal requirements of BE-LIF surgery, particularly in its nascent phases. Acquisition of proficiency within the BE-LIF realm exhibits an early trajectory typified by steep inclines. As substantiated by previous inquiries, a notable nadir in operative time commensurate with the execution of approximately 34 cases marks the plateau of surgical acumen acquisition.[31] During this initial phase, an increased allocation of surgical time is attributed to the preparatory preoperative stages. However, after reaching this plateau, a prominent abbreviation in operational time becomes evident, signifying increased procedural efficiency. Given these intricacies, it becomes incumbent on medical practitioners to cultivate adeptness in unilateral dual channel endoscopic methodologies, facilitating the passage to the pinnacle of the learning curve. Concurrently, a profound assimilation of the nuanced attributes characterizing the microscopic visual domain assumes paramount significance.

The parsimonious bleeding observed in the context of BE-LIF surgery may be due to several contributing factors. The engagement of saline irrigation fluid during surgical decompression and vertebral bone grafting introduces a measure of hydraulic pressure, which is instrumental in the effectuation of compression and hemostasis. Furthermore, the optical imaging system increases the dimensions of the surgical field, thereby accommodating the amelioration of minute vascular oozing. In particular, the judicious application of plasma electrocoagulation for hemostatic ends increases the overall efficacy of bleeding control.

Improved Clinical Outcomes

During the initial period after surgery, assessments using VAS scores indicated a significant reduction in back pain scores within the BE-LIF group, as opposed to the MI-TLIF group, and this disparity attained statistical significance. This disparity can potentially be attributed to the comprehensive disruption of muscles, nerves, minor vascular networks, and ligaments that MI-TLIF necessitates. This consequential disruption causes evident postoperative low back pain, muscular atrophy within the treated segment, and a discernible decrease in the stability of the lumbar spine. Furthermore, the protracted period of postoperative convalescence associated with MI-TLIF contributes to this differential. Conversely, BE-LIF is characterized by an ability to optimize the preservation of an intact spinal architecture, thus ensuring the maintenance of postoperative spinal stability.[34] This distinction underscores BE-LIF's capacity to minimize the deleterious sequelae observed in the context of MI-TLIF. However, when reaching the final follow-up appointment, discernible statistical variance in VAS scores was absent between the two cohorts. The evidence observed implies that BE-LIF may confer certain advantages in terms of prompt alleviation of postoperative pain, relative to the MI-TLIF approach. However, these potential benefits seem to wane over time, given the comparable VAS scores observed in both groups during the ultimate follow-up assessment. These findings underscore the crucial consideration of temporal aspects when performing pain evaluations, along with the necessity to consider enduring outcomes, when scrutinizing the efficacy of these distinct surgical modalities in mitigating back pain associated with lumbar spine afflictions.

During the initial postoperative phase, ODI scores exhibited a significant reduction within the BE-LIF cohort of patients compared to their counterparts who underwent MI-TLIF. Importantly, this observed disparity attained a noteworthy degree of statistical significance. However, after reaching the culmination of the final follow-up assessment, the discernible differentiation in ODI scores between the two patient cohorts stopped to retain statistical significance. A plausible rationale for this juxtaposition may lie in the more pronounced compromise inflicted on the posterior soft tissue muscles during MI-TLIF procedures as opposed to those of BE-LIF nature. Moreover, it is imperative to properly acknowledge that even within the ambit of minimally invasive approaches, ongoing dilation of the lumbar musculature remains a necessary procedural component.

Furthermore, the notion of a possible detrimental influence on spinal fusion arising from the continuous lavage of graft material and osteogenic progenitor cells within the implantation site through a perfusion system during BE-LIF has been postulated. Our study has determined that within the BE-LIF group, the fusion rate achieved a commendable 89.59%, which is notably higher than the fusion rate of 88.60% observed in the MI-TLIF group. However, it is important to note that this observed difference did not attain statistical significance. This conveys that lumbar interbody fusion performed within the framework of UBE methodology has the ability to produce a fusion rate that is both appreciable and comparable, thus substantiating its viability as a means to achieve satisfactory fusion outcomes.

Complications

In this current meta-analysis, we investigate the occurrence of complications related to both procedures. In particular, the manifest complication rates of both cohorts of 7.76% and 7.97% for BE-LIF and MI-TLIF, respectively, with no statistically significant differentiation between the groups. Of particular note, dural tears and hematomas emerge as the predominant surgical complications within both cohorts.

Dural tears are attributed to multiple factors, including severe spinal canal stenosis and pronounced adhesions between the ligamentum flavum and the dura mater.[35] In the cases where a unilateral approach is used for bilateral decompression and dissection, the interaction between these structures can lead to dural injury.[36] It is imperative to recognize that the perioperative period, especially during the formative phases of acclimatization to the biportal endoscopic technique, harbors an elevated susceptibility to complications. This vulnerability is rooted in challenges pertaining to structural identification within the intraoperative field of vision, the management of recurrent herniated discs characterized by substantial adhesions, and manipulative practices that confer a heightened risk of dural tears. Due to these complexities, those new to the biportal endoscopic technique are advised to exercise meticulous caution when navigating the initial stages of the procedure. This requires the judicious application of instrumentation, complemented by meticulous identification of structures within the operative field, in order to prevent the inadvertent occurrence of dural tearing.[37] In the event that an intraoperative dural tear is detected, it is prudent to promptly attenuate the hydrodynamic pressure and accelerate the procedural conclusion.

Epidural hematomas are attributed to blood seepage from osseous surfaces subsequent to decompression, with symptomatic relief typically ensuing through conservative management approaches. The appearance of nerve root traction injuries is associated with factors such as intraoperative nerve root edema, substantial adhesions between the nucleus pulposus and the nerve root, and the extraction of the nucleus pulposus leading to inadvertent nerve root traction.[38,39]

Limitations

1. This meta-analysis encompassed solely retrospective investigations, with regrettably no inclusion of prospective studies or RCTs.
2. All articles included in the research were based on Asian populations, which may imply that the findings may not be generally applicable to other populations globally. This aspect may limit the generalizability of the results and must be considered when interpreting the findings.
3. Given the novelty of the BE-LIF procedure explored within this study, inherent measurement biases in parameters such as operative time and blood loss are acknowledged. Concurrently, disparities in follow-up protocols may introduce variations in complication and fusion rates at the terminal follow-up assessment.
4. The current study, characterized by a constrained sample size and abbreviated follow-up duration, necessitates extended longitudinal monitoring to ascertain the potential for long-term subsidence of the interbody fusion device.
5. It is noteworthy that there is no objective quantitative assessment quantifying the extent of muscle damage, which contributes to the limitations of the study.
6. The general quality of the included studies potentially influences the impact and implications of this investigation. Rigorous and high-quality prospective studies are necessary to support these findings.

Conclusion

The clinical outcomes of BE-LIF in treating lumbar degenerative disease were similar to those of MI-TLIF, with no significant differences observed in leg pain VAS scores, complication rates, or fusion rates. However, BE-LIF showed a clear advantage in early postoperative back pain VAS scores, and patients experienced faster recovery after surgery. Additionally, intraoperative blood loss was significantly lower in the BE-LIF group compared to the MI-TLIF group, although the complexity of the BE-LIF procedure led to a slightly longer operative time. Despite this, the hospitalization period for BE-LIF was notably shorter than for MI-TLIF. It is important to note that these findings require further validation through a large, multicenter, prospective randomized controlled trial to confirm the accuracy and generalizability of the study's conclusions.

Data Sharing Statement

The datasets are presented within the manuscript.

Ethics Approval

This is a meta-analysis study, so ethics committee approval was not required.

Acknowledgment

The author (G.X.L.) wishes to acknowledge the financial support of the "Xiamen Health High-Level Talent Training Program". We are grateful to Xiuhong Chen for reconfirming the data and final proofreading of the manuscript.

Funding

This research was funded by the Natural Science Foundation of Fujian Province (Grant Number: 2021J05282); funded by the Xiamen Municipal Bureau of Science and Technology (Grant Number: 3502Z20224033). The funders had no role in the design of the study, collection, analysis or interpretation of the data, or preparation of the manuscript.

Disclosure

The authors report no conflicts of interest in this work.

References

1. Mayoral Rojals V, Amescua Garcia C, Denegri P, Narvaez Tamayo MA, Varrassi G. The invasive management of pain: diagnosis and new treatment options. *Cureus*. 2023;15(7):e42717. doi:10.7759/cureus.42717
2. Ahn Y, Lee S, Kim WK, Lee SG. Learning curve for minimally invasive transforaminal lumbar interbody fusion: a systematic review. *Eur Spine J*. 2022;31(12):3551–3559. doi:10.1007/s00586-022-07397-3
3. Ma T, Zhou T, Gu Y, Zhang L, Che W, Wang Y. Efficacy and safety of percutaneous transforaminal endoscopic surgery (PTES) compared with MIS-TLIF for surgical treatment of lumbar degenerative disease in elderly patients: a retrospective cohort study. *Front Surg*. 2022;9:1083953. doi:10.3389/fsurg.2022.1083953
4. Chen H, Zheng G, Bian Z, et al. Comparison of minimally invasive transforaminal lumbar interbody fusion and endoscopic lumbar interbody fusion for lumbar degenerative diseases: a retrospective observational study. *J Orthop Surg Res*. 2023;18(1):389. doi:10.1186/s13018-023-03875-6
5. Lin GX, Xu WB, Kotheeranurak V, Chen CM, Deng ZH, Zhu MT. Comparison of oblique and transforaminal approaches to lumbar interbody fusion for lumbar degenerative disease: an updated meta-analysis. *Front Surg*. 2022;9:1004870. doi:10.3389/fsurg.2022.1004870
6. Xu WB, Kotheeranurak V, Zhang HL, et al. Is biportal endoscopic spine surgery more advantageous than uniportal for the treatment of lumbar degenerative disease? A meta-analysis. *Medicina*. 2022;58(11). doi:10.3390/medicina58111523
7. Zhu H, Yang Q, Xiang Z, Shang H. Unilateral biportal endoscopic technique for lumbar disc herniation. *Asian J Surg*. 2023:S1015–9584.
8. Song X, Ren Z, Cao S, Zhou W, Hao Y. Clinical efficacy of bilateral decompression using biportal endoscopic versus minimally invasive transforaminal lumbar interbody fusion for the treatment of lumbar degenerative diseases. *World Neurosurg*. 2023;173:e371–e377. doi:10.1016/j.wneu.2023.02.059
9. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Rev Esp Cardiol*. 2021;74(9):790–799. doi:10.1016/j.recesp.2021.06.016
10. Zhu MT, Hu BS, Chen CM, Liu HQ, Lin GX. Comparison of full endoscopic lumbar diskectomy using the transforaminal approach versus interlaminar approach for L5-S1 lumbar disk herniation treatment: a meta-analysis. *J Neurol Surg a Cent Eur Neurosurg*. 2023;85(5):501–512. doi:10.1055/a-2053-8365
11. Gatam AR, Gatam L, Mahadhipta H, Ajiantoro A, Luthfi O, Aprilya D. Unilateral biportal endoscopic lumbar interbody fusion: a technical note and an outcome comparison with the conventional minimally invasive fusion. *Orthop Res Rev*. 2021;13:229–239. doi:10.2147/ORR.S336479
12. Heo DH, Park CK. Clinical results of percutaneous biportal endoscopic lumbar interbody fusion with application of enhanced recovery after surgery. *Neurosurg Focus*. 2019;46(4):E18. doi:10.3171/2019.1.FOCUS18695
13. Jiang C, Huang Y, Zuo H, Sun Y, Sun J. Clinical effect of unilateral biportal endoscopic lumbar interbody fusion and minimally invasive transforaminal lumbar interbody fusion on single-segment lumbar stenosis with instability. *Acta Aca Med Sini*. 2022;44(4):563–569.
14. 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(12):2066–2077. doi:10.1016/j.spinee.2021.06.013
15. Kim JE, Yoo HS, Choi DJ, Park EJ, Jee SM. Comparison of minimal invasive versus biportal endoscopic transforaminal lumbar interbody fusion for single-level lumbar disease. *Clin Spine Surg*. 2021;34(2):E64–E71. doi:10.1097/BSD.0000000000001024
16. Kong F, Zhou Q, Qiao Y, et al. Comparison of unilateral biportal endoscopic transforaminal lumbar interbody fusion versus minimally invasive tubular transforaminal lumbar interbody fusion for lumbar degenerative disease. *Chin J Repar Reconstr Surg*. 2022;36(5):592–599.
17. Yang K, Peng S, Chang L, Shen X. Unilateral biportal endoscopic lumbar interbody fusion versus minimally invasive transforaminal lumbar interbody fusion for the treatment of single-segment lumbar degenerative disease. *Shandong Med J*. 2023;63(8):71–74.
18. Yu Y, Wang Y, Xie Y, Xu J, Chen Y, Fan X. Comparison of mid-term effectiveness of unilateral biportal endoscopy-transforaminal lumbar interbody fusion with minimally invasive surgery-transforaminal lumbar interbody fusion assisted with three-dimensional microscope in treating lumbar spondylolisthesis. *Chin J Repar Reconstr Surg*. 2023;27(1):52–58.
19. Zhu J, Hao Y, Ren Z, et al. Preliminary study of unilateral biportal endoscopic lumbar interbody fusion for the treatment of degenerative spinal disease. *Chin J Spine Spinal Cord*. 2021;31(11):1026–1033.
20. Kang MS, Heo DH, Kim HB, Chung HT. Biportal endoscopic technique for transforaminal lumbar interbody fusion: review of current research. *Int J Spine Surg*. 2021;15(suppl 3):S84–S92. doi:10.14444/8167
21. Mazurek M, Kulesza B, Golebiowska N, Tyzo B, Kura K, Szczepanek D. Factors predisposing to the formation of degenerative spondylolisthesis-a narrative review. *Medicina*. 2023;59(8). doi:10.3390/medicina59081430
22. He Y, Wang H, Yu Z, Yin J, Jiang Y, Zhou D. Unilateral biportal endoscopic versus uniportal full-endoscopic for lumbar degenerative disease: a meta-analysis. *J Orthop Sci*. 2022;29(1):49–58. doi:10.1016/j.jos.2022.10.019
23. Lin GX, Jhang SW, Chen CM. An effectiveness evaluation of nucleo-annuloplasty for lumbar discogenic lesions using Disc-FX: a scoping review. *Medicina*. 2023;59(7). doi:10.3390/medicina59071291
24. Teng I, Han J, Phan K, Mobbs R. A meta-analysis comparing ALIF, PLIF, TLIF and LLIF. *J Clin Neurosci*. 2017;44:11–17. doi:10.1016/j.jocn.2017.06.013
25. Mobbs RJ, Phan K, Malham G, Seex K, Rao PJ. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. *J Spine Surg*. 2015;1(1):2–18. doi:10.3978/j.issn.2414-469X.2015.10.05

26. Zhu HF, Fang XQ, Zhao FD, et al. Comparison of oblique lateral interbody fusion (OLIF) and minimally invasive transforaminal lumbar interbody fusion (MI-TLIF) for treatment of lumbar degeneration disease: a prospective cohort study. *Spine*. 2022;47(6):E233–E242. doi:10.1097/BRS.0000000000004303
27. Garg B, Mehta N. Minimally invasive transforaminal lumbar interbody fusion (MI-TLIF): a review of indications, technique, results and complications. *J Clin Orthop Trauma*. 2019;10(Suppl 1):S156–S162. doi:10.1016/j.jcot.2019.01.008
28. Wong AP, Smith ZA, Stadler JA, et al. Minimally invasive transforaminal lumbar interbody fusion (MI-TLIF): surgical technique, long-term 4-year prospective outcomes, and complications compared with an open TLIF cohort. *Neurosurg Clin N Am*. 2014;25(2):279–304. doi:10.1016/j.nec.2013.12.007
29. Chen X, Lin GX, Rui G, et al. Comparison of perioperative and postoperative outcomes of minimally invasive and open TLIF in obese patients: a systematic review and meta-analysis. *J Pain Res*. 2022;15:41–52. doi:10.2147/JPR.S329162
30. Heo DH, Son SK, Eum JH, Park CK. Fully endoscopic lumbar interbody fusion using a percutaneous unilateral biportal endoscopic technique: technical note and preliminary clinical results. *Neurosurg Focus*. 2017;43(2):E8. doi:10.3171/2017.5.FOCUS17146
31. 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(1):8815432. doi:10.1155/2020/8815432
32. Choi CM. Biportal endoscopic spine surgery (BESS): considering merits and pitfalls. *J Spine Surg*. 2020;6(2):457–465. doi:10.21037/jss.2019.09.29
33. Ahn Y, Lee S. Uniportal versus biportal endoscopic spine surgery: a comprehensive review. *Expert Rev Med Devices*. 2023;20(7):549–556. doi:10.1080/17434440.2023.2214678
34. Zheng B, Zhang XL, Li P. Transforaminal interbody fusion using the unilateral biportal endoscopic technique compared with transforaminal lumbar interbody fusion for the treatment of lumbar spine diseases: analysis of clinical and radiological outcomes. *Oper Neurosurg*. 2023;24(6):e395–e401. doi:10.1227/ons.0000000000000641
35. Heo DH, Lee DC, Kim HS, Park CK, Chung H. Clinical results and complications of endoscopic lumbar interbody fusion for lumbar degenerative disease: a meta-analysis. *World Neurosurg*. 2021;145:396–404. doi:10.1016/j.wneu.2020.10.033
36. Eun DC, Lee YH, Park JO, et al. A comparative analysis of bi-portal endoscopic spine surgery and unilateral laminotomy for bilateral decompression in multilevel lumbar stenosis patients. *J Clin Med*. 2023;12(3):1033. doi:10.3390/jcm12031033
37. Lin GX, Yao ZK, Zhang X, Chen CM, Rui G, Hu BS. Evaluation of the outcomes of biportal endoscopic lumbar interbody fusion compared with conventional fusion operations: a systematic review and meta-analysis. *World Neurosurg*. 2022;160:55–66. doi:10.1016/j.wneu.2022.01.071
38. Xie YZ, Shi Y, Zhou Q, et al. Comparison of the safety and efficacy of unilateral biportal endoscopic lumbar interbody fusion and uniportal endoscopic lumbar interbody fusion: a 1-year follow-up. *J Orthop Surg Res*. 2022;17(1):360. doi:10.1186/s13018-022-03249-4
39. Park DY, Upfill-Brown A, Curtin N, et al. Clinical outcomes and complications after biportal endoscopic spine surgery: a comprehensive systematic review and meta-analysis of 3673 cases. *Eur Spine J*. 2023;32(8):2637–2646. doi:10.1007/s00586-023-07701-9