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Meta-Analysis of Learning Curve in Endoscopic Spinal Surgery: Impact on Surgical Outcomes

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

Abstract

Study Design: Systematic review and meta-analysis.

Objective: This meta-analysis aimed to evaluate the learning curve in endoscopic spinal surgery, including the time to mastery and challenges faced by novice surgeons, to improve learning and surgical outcomes.

Methods: Data extraction included the learning curve period and a comparison of surgeons with more experience or late period of the learning curve (late) and surgeons with less experience and in the early period of the learning curve (early) with respect to demographic, surgical, hospitalization, functional, and complication variables. Statistical analysis was performed using Review Manager 5.4.1 software.

Results: This meta-analysis included 16 studies (n = 1902). The average number of cases required to reach the learning curve was 32.5 ± 10.5. The uniportal technique required fewer cases (30.1 ± 10.2) than biportal technique (38.7 ± 10.3). There were no significant differences in demographic variables, operation level, or duration of symptoms between the advanced and novice surgeons. Advanced surgeons showed better outcomes in VAS leg pain at less than 6 months (SMD 0.18, 95% CI 0.01-0.34) and >6 months (SMD 0.14, 95% CI 0.02-0.27), as well as VAS back pain at > 6 months (SMD 0.16, 95% CI 0.04-0.29). The incidence of total complications was significantly higher in the novice surgeon group. The specific complications did not differ significantly between the 2 groups.

Conclusions: The average number of cases required to reach the learning curve was 32.5 ± 10.5. Experienced surgeons had shorter surgery and fluoroscopy times, better outcomes in leg and back pain, and a lower incidence of complications than novice surgeons.

Keywords

learning curve, endoscopy, spinal surgery, meta-analysis

Introduction

Spinal surgery is a complex and challenging field that requires technical skill and experience to achieve optimal outcomes.[1] As surgeons delve into this field, they encounter a learning process known as the "learning curve in spinal surgery." This curve represents the trajectory of skill acquisition and improvement in surgical outcomes as surgeons gain experience and mastery of the specific techniques used in spinal interventions. There are as many learning curves as there are surgical techniques.

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

Corresponding Author:
Manuel González-Murillo, MD, Department of Orthopaedic Surgery and Traumatology, Hospital San Rafael, Avenida de las Jubias, 82, A Coruña 15006, Spain.
Email: doctorgonzalezmurillo@gmail.com

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Currently, there is growing interest in the use of spinal endoscopy as a less invasive alternative to open spinal surgery.[2] Spinal endoscopy has shown promising results in terms of shorter surgical times, reduced blood loss, decreased postoperative pain, shorter hospital stay, and lower rates of revision surgery.[2] However, this technique requires experience and training to become familiar with and accustomed to endoscopic visualization.

The learning curve is a recurrent topic in the literature on spinal endoscopy and has been mentioned as one of the key aspects in mastering this technique.[3-7] However, there is no adequate consensus on the number of cases required to achieve proficiency in spinal endoscopy.[3-7] Some studies suggest that approximately 20 cases are needed for posterior cervical foraminotomy[3] and 34 cases for lumbar intervertebral fusion.[4] Other reports indicate that more experienced surgeons perform the procedures in a third less time than in the early stages of their learning.[5] In addition to the reduction in surgical time, other advantages associated with mastering spinal endoscopy have also been observed. These include a lower rate of complications[8] and reduced postoperative pain measured using a Visual Analog Scale (VAS).[9]

For those taking their first steps in spinal endoscopy, specific challenges have been identified, such as lack of support and fear of potential complications.[10] Addressing these challenges comprehensively in a scientific article could provide valuable insights for novice surgeons and help to alleviate their concerns.

Quantifying and understanding the learning curve in spinal surgery is crucial as this information will be useful in guiding and measuring the progress of novice surgeons. Therefore, the aim of this study was to evaluate the time required to achieve mastery in spinal endoscopic surgery, specifically focusing on uniportal and biportal techniques, and to identify the most common challenges encountered by surgeons in the early stages compared to experienced surgeons. This knowledge is expected to contribute to better learning and improvement in surgical outcomes in the field of spinal surgery.

Methods

Eligibility Criteria

The protocol for this meta-analysis was registered in the PROSPERO (CRD42024541636). The PRISMA guidelines[11] and PICOS search strategy were followed. Patients included in the study underwent biportal, or uniportal endoscopic surgery for spinal stenosis. The intervention group consisted of surgeons who were in the early period of the learning curve or had less experience, with the term "early" defined differently in each study based on the operative time. The comparator group consisted of surgeons with more experience or who were in the late period of the learning curve. The main outcomes assessed were the time required for the learning curve and the differences in efficacy and safety outcomes between novice and experienced surgeons. Comparative studies or series that established a period for the learning curve and compared 2 types of surgeons were included in the analysis.

Exclusion criteria were applied to ensure the quality and relevance of the studies included in our manuscript. Duplicate studies, case reports, and letters to editors were excluded to avoid redundancy and prioritize comprehensive research findings. Studies published >10 years ago were also excluded, as recommended by experts in the field, considering the potential changes in endoscopic standards over time that could influence the results. Additionally, techniques, such as tubular endoscopy and microscopy, were excluded to maintain homogeneity in the study sample. Studies lacking relevant variables or with incomplete or missing data were also excluded to ensure data reliability and completeness.

Information Sources and Search Methods for Identification of Studies

A comprehensive search was conducted in the PubMed, Embase, Scopus, and Cochrane Library databases to identify relevant studies. No language restrictions were applied, and a filter was applied to include articles published within the last 10 years based on expert recommendations in the field. The search terms are detailed in Supplemental File 1. Two authors independently screened studies for eligibility. In cases of discrepancies, a third author was involved in the decision-making process to reach consensus.

Data Extraction and Data Items

Data extraction was performed by 2 authors, and a third author was involved in resolving discrepancies to reach a consensus. The extracted characteristics of the included studies encompassed several aspects. The primary variable of interest was the learning curve, which was evaluated based on the number of cases required to gain experience. Demographic variables included sex, mean age, BMI, number of patients who smoked, operation level, and duration of symptoms; surgical and hospitalization variables encompassed surgery time, length of hospital stay (LOS), and fluoroscopy time. Functional outcomes were assessed using the visual analog scale (VAS) for leg pain, VAS for back pain, and Oswestry Disability Index (ODI). Complications were also collected to evaluate safety outcomes.

Assessment of Risk of Bias in Included Studies

The risk of bias in the included studies was assessed using the Methodological Index for Non-Randomized Studies (MINORS) (Supplemental Table 1 12). The MINORS tool consists of 12 items with a maximum score of 24 for comparative studies and 16 for non-comparative studies. For non-comparative studies, scores ranging from 0 to 4, 5-7, 8-12, and ≥13 were categorized as very low, low, fair, and high quality, respectively. In comparative studies, scores ranging

from 0 to 6, 7 to 10, 11 to 15, and ≥16 were categorized as very low, low, fair, and high, respectively.[12]

In clinical trials, the Cochrane Review Manager tool was used to assess the risk of bias. This tool allows for the assessment of various domains of bias, including randomization, allocation concealment, blinding of participants and outcome assessors, incomplete outcome data, selective outcome reporting, and other sources of bias. Each domain is evaluated and categorized as having a "low risk of bias," "uncertain risk of bias," or "high risk of bias" based on the information provided in the study.

Assessment of Results

Statistical analysis was conducted using the Review Manager 5.4 software. For continuous outcomes, the mean differences with 95% confidence intervals were calculated. Dichotomous outcomes were analyzed using odds ratios (ORs) with 95% confidence intervals. Heterogeneity among studies was evaluated using the Chi2 and I2 tests. I2 values greater than 25%, 50%, and 75% were considered indicative of low, moderate, and high heterogeneity, respectively. A fixed-effects model was used when no significant heterogeneity was detected, whereas a random-effects model was used in the presence of heterogeneity. To extract data from the figures, WebPlotDigitizer version 4.5 was utilized to ensure accurate data acquisition. In cases of missing data, guidelines provided in the Cochrane Handbook were followed to address this issue appropriately.[13]

Risk of Bias Across the Studies

Publication bias was assessed using funnel plot asymmetry analysis conducted using Review Manager software. The effect estimate is plotted on the *x*-axis, while the standard error is plotted on the *y*-axis. A visual inspection of the funnel plot was performed to examine potential asymmetry, indicating potential publication bias. Formal statistical tests were not performed to assess publication bias.

Additional Analyses

Subgroup analyses were conducted regarding the follow-up time for the VAS and ODI variables to obtain preoperative results at less than 6 months and at more than 6 months.

In the sensitivity analyses, the methodology involved removing studies with the highest weight to evaluate the impact on the results. This approach allows an examination of the robustness and sensitivity of the findings by assessing how the exclusion of influential studies affects the overall outcome.

Results

Study Selection

The initial database search yielded a total of 410 results. After excluding case reports, letters to editors, protocols, duplicates, and studies published less than 10 years ago, 154 studies were removed, resulting in 256 remaining studies. Upon reviewing the titles and abstracts, 217 studies were excluded because they did not focus on endoscopy, utilized tubular endoscopy, or were not centered on the learning curve, leaving 39 studies. After a thorough examination of the full text, 23 studies were eliminated because they did not focus on the learning curve, did not share relevant variables, or contained incomplete or missing data, resulting in 16 studies. No additional studies were included in the reference lists. Ultimately, 16 studies were included in the meta-analysis (Figure 1).[5,7,9,10,14-25]

Study Characteristics

Table 1 shows the baseline characteristics of the included studies. Sixteen studies with a total of 1902 patients were included in the analysis. The country with the highest number of published studies was Korea (7/16, 43.8%), followed by the USA (3/16, 18.8%). The ages of the patients ranged from 23.4 to 67.6 years. The follow-up period varied from 6.0 to 44.0 months. Thirteen studies utilized uniportal endoscopy and 3 used biportal endoscopy. Regarding funding for the studies, only 3 received financial support, none of which was related to the endoscopy industry. Two studies did not report their funding status, and the remaining studies declared no funding. The number of male participants and their etiologies are listed in Table 1. Among the nonrandomized studies (14 studies), the quality was high in 8/14 studies and acceptable in 6/14 studies. The clinical trial had an acceptable quality, with the limitation of unblinding the patients owing to the nature of both procedures.[16] Finally, a survey was conducted.[10]

Learning Curve

Table 2 displays the results of the cases needed to reach the learning curve of experience, as evidenced by a significant decrease in surgical time. The average learning curve was 32.5 ± 10.5 cases, with a minimum requirement of 18 cases and a maximum of 50 cases. The uniportal technique demonstrated a lower number of cases required to gain more experience, with an average of 30.1 ± 10.2 cases, followed by the biportal technique with 38.7 ± 10.3 cases.

Demographic Outcomes

Regarding whether different demographic variables were more frequent in 1 group or another, there were no significant differences in terms of sex (OR 1.03, 95% CI 0.80 to 1.32; participants = 1036; studies = 7; I2 = 0%) (Figure 2A), average age (MD −0.69, 95% CI −2.43 to 1.04; participants = 981; studies = 6; I2 = 7%) (Figure 2B), BMI (MD -0.32, 95% CI −1.19 to 0.55; participants = 1092; studies = 5; I2 = 46%) (Figure 2C), or smoking status (OR 1.37, 95% CI 0.93 to 2.03; participants = 556; studies = 6; I2 = 1%) (Figure 2D). There were also no significant differences in terms of the operation

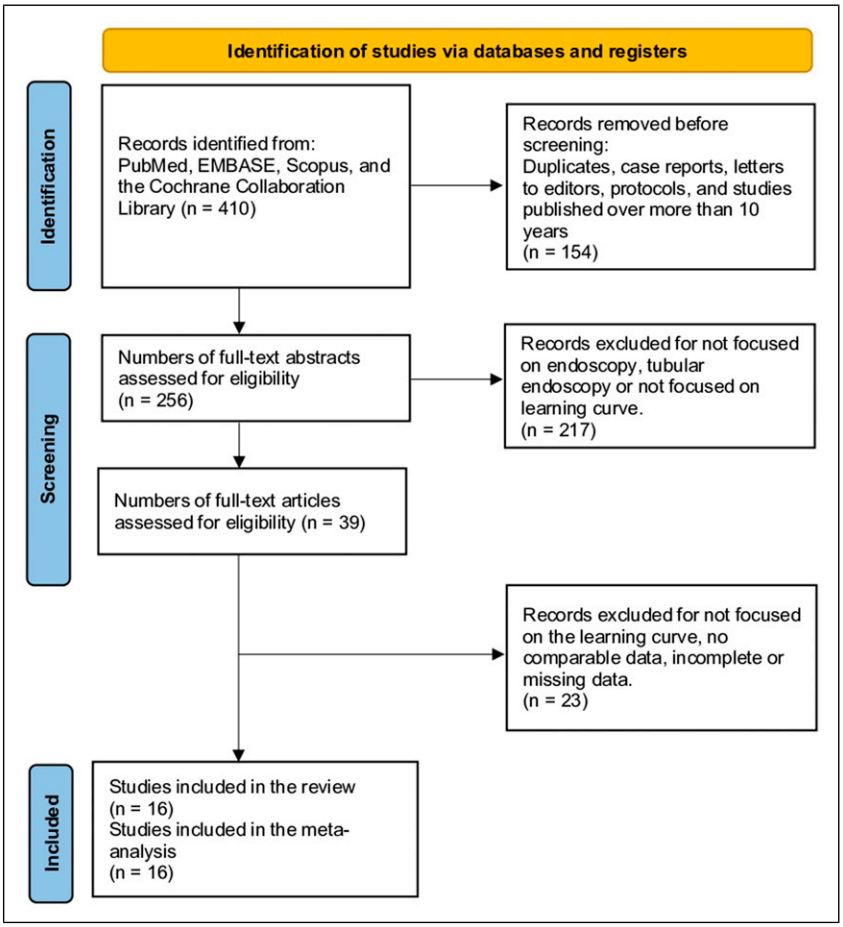

Figure 1. Study selection flow diagram (Preferred reporting items for systematic reviews and meta-analyses).

level between the groups (OR 1.21, 95% CI 0.75 to 1.97; participants = 556; studies = 6; I2 = 33%). The duration of symptoms also did not show any significant differences (SMD 0.11, 95% CI −0.02 to 0.25; participants = 832; studies = 3; I2 = 0%). The sensitivity analysis did not result in changes in the direction of the studies.

Surgery and Hospitalization Outcomes

The surgery time was significantly shorter in the advanced stage group (MD 28.51, 95% CI 12.19 to 44.83; participants = 1464; studies = 10; I2 = 99%) (Figure 3A). There were no significant differences in terms of stay (LOS) (SMD 0.17, 95% CI −0.03 to 0.36; participants = 443; studies = 5; I2 = 21%) (Figure 3B). Fluoroscopy time was significantly shorter in the advanced group (SMD: 0.54, 95% CI 0.37 to 0.70; participants = 610; studies = 3; I2 = 11%) (Figure 3C). The sensitivity analysis did not result in changes in the direction of the studies.

Visual Analogue Scale and Oswestry Disability Index

There were no significant differences in preoperative VAS leg pain (SMD 0.10, 95% CI −0.03 to 0.23; participants = 942; studies = 5; I2 = 0%) (Figure 4A). However, the advanced group with more experience showed significantly better outcomes in VAS leg pain at less than 6 months (SMD 0.18, 95% CI 0.01 to 0.34; participants = 570; studies = 3; I2 = 44%) (Figure 4B) and at more than 6 months (SMD 0.14, 95% CI 0.02 to 0.27; participants = 997; studies = 6; I2 = 0%) (Figure 4C). VAS back pain did not show significant differences preoperatively (SMD 0.10, 95% CI −0.03 to 0.23; participants = 942; studies = 5; I2 = 0%) (Figure 5A) or at less than 6 months (SMD 0.10, 95% CI −0.06 to 0.27; participants = 570; studies = 3; I2 = 0%) (Figure 5B). However, at more than 6 months, the group with more experience showed significantly better results (SMD 0.16, 95% CI 0.04 to 0.29; participants = 997; studies = 6; I2 = 23%) (Figure 5C). The sensitivity analysis revealed inconsistencies in the VAS leg pain results but not in the VAS back pain results. In contrast, the preoperative Oswestry Disability Index (ODI) did not show significant differences (SMD 0.11, 95% CI −0.10 to 0.33; participants = 914; studies = 4; I2 = 51%) (Figure 6A). There were no significant differences at less than 6 months (SMD 0.15, 95% CI -0.02 to 0.32; participants = 535; studies = 2; I2 = 0%) (Figure 6B) or >6 months (SMD 0.10, 95% CI −0.03 to 0.23; participants = 914; studies = 4; I2 = 0%)

Table 1. Main Baseline Characteristics of the Included Studies.

Study	Region	Period	Type of Study	Follow-Up (months)	n patients (Early/Late)	Age (Early/Late)	n Male (Early/Late)	Etiology	Endoscopy	Funding
Ahn et al. 2015[9]	Korea	2012 to 2014	Retrospective cohort	12.0	35 (15/20)	25.4/23.4	35 (15/20)	1 level LDH	Uniportal	NR
Choi et al. 2016[14]	Korea	2015	Prospective serie	NR	68	58.0	28	LDH and LSS	Biportal	No
Fleiderman et al. 2022[15]	Chile	2013 to 2020	Retrospective cohort	44.0	20/19	46.5/53.9	14/10	LDH	Uniportal	No
Gadjradj et al. 2022[16]	The Netherlands	2016 to 2019	RCT	12.0	143/161	45.5/45.5	94/76	LDH	Uniportal	Yes (NER)
Kotheeranurak et al. 2022[10]	Thailand	2020 to 2022	Survey	NA	NA	NA	NA	NR	Uniportal	No
Lee et al. 2018[5]	Korea	2012 to 2017	Retrospective serie	26.5	213	61.2	61	Degenerative lumbar central or lateral recess stenosis	Uniportal	No
Maayan et al. 2023[17]	USA	2020 to 2022	Retrospective cohort	24.0	55 (31/24)	65.3/64.6	33 (19/14)	Single-level LDH	Uniportal	No
Olinger et al. 2023[18]	USA	2017 to 2019	Prospective cohort	6.0	90	45.0	NR	LDH	Uniportal	No
Park et al. 2018[7]	Korea	2017 to 2018	Retrospective cohort	NR	60 (30/30)	67.6	31	LSS	Biportal	No
Pérez et al. 2023[19]	Korea	NR	Retrospective cohort	34.0	163 (113/50)	53.6	88	LDH, LSS, recurrence, facet cyst, fibrosis	Biportal	No
Ransom et al. 2020[20]	USA	NR	Retrospective serie	38.6	40	57.4	22	Sciatica-type low back and leg pain without instability	Uniportal	No
Saravi et al. 2023[21]	Austria	2016 to 2021	Retrospective cohort	NR	205 (137/68)	60.2/61.6	105	LSS	Uniportal	Yes (NER)
Son et al. 2020[22]	Korea	From 2014	Retrospective cohort	12.0	48 (25/23)	38.4/39.2	31 (16/15)	LDH	Uniportal	No
Son et al., 2020 (II)[23]	Korea	From 2012	Retrospective cohort	12.0	27	42.9	16	LDH	Uniportal	No
Sun et al. 2020[24]	China	2016 to 2018	Retrospective cohort	12.0	480 (240/240)	43.9/44.2	263 (128/135)	Sigle-level LDH	Uniportal	Yes (NER)
Yang et al. 2019[25]	China	2015 to 2016	Retrospective cohort	25.4	75 (35/40)	57.5/60.4	44 (20/24)	LSS	Uniportal	NR

Abbreviations: LDH: Lumbar disc herniation; LSS: Lumbar spinal stenosis; NA: Not applicable: NER: Non endoscopy related; NR: Not reported.

(Figure 6C). Sensitivity analysis did not change the direction of the studies.

Complications

Table 3 presents the complications associated with the study. The group with less experience had a significantly higher incidence of complications than the other groups. There were no significant differences in terms of specific complications, such as dural tear, incomplete decompressions, recurrence, revisions, conversion to open/microscopic surgery, or nerve root injury. The sensitivity analysis did not result in changes in the direction of the results.

Publication Bias

No publication bias was observed in the main variables (Figure 7).

Discussion

This study analyzed the learning curve of endoscopic spinal surgery and compared the results between groups with different levels of experience. The uniportal technique required fewer cases to acquire experience. In addition, the group with more experience had shorter surgical times and better results in terms of pain. The less experienced group had a higher

Table 2. Learning Curve Based on the Cases Required to Achieve Competence.

Technique	All Techniques	Biportal	Uniportal
Mean	32.5	38.7	30.1
SD	10.5	10.3	10.2
Min	18.0	30.0	18.0
Max	50.0	50.0	50.0

overall incidence of complications. It is important to highlight that all but 2 of the studies, which did not report their funding, were conducted without any financial support from the industry.

According to the literature, a learning curve was observed in other minimally invasive techniques, such as unilateral microscopic laminectomy surgery, with an average of approximately 29 cases required to acquire experience.[26] Minimally invasive surgery (MIS) techniques generally

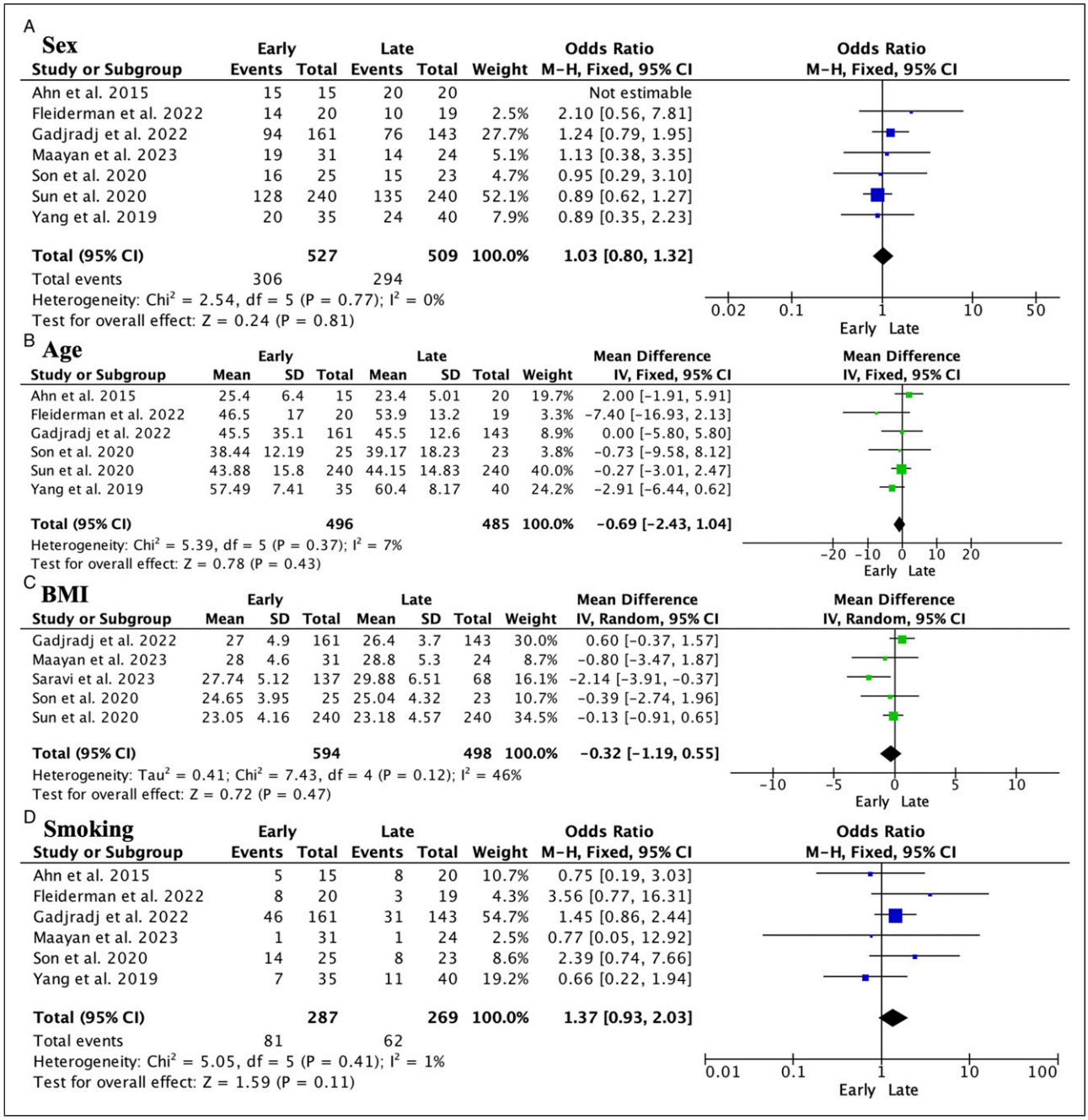

Figure 2. Forest plots showing the comparison between "early" vs "late" surgeons with respect to demographic variables. There were no significant differences in sex (A), age (B), BMI (C), or smoking status (D).

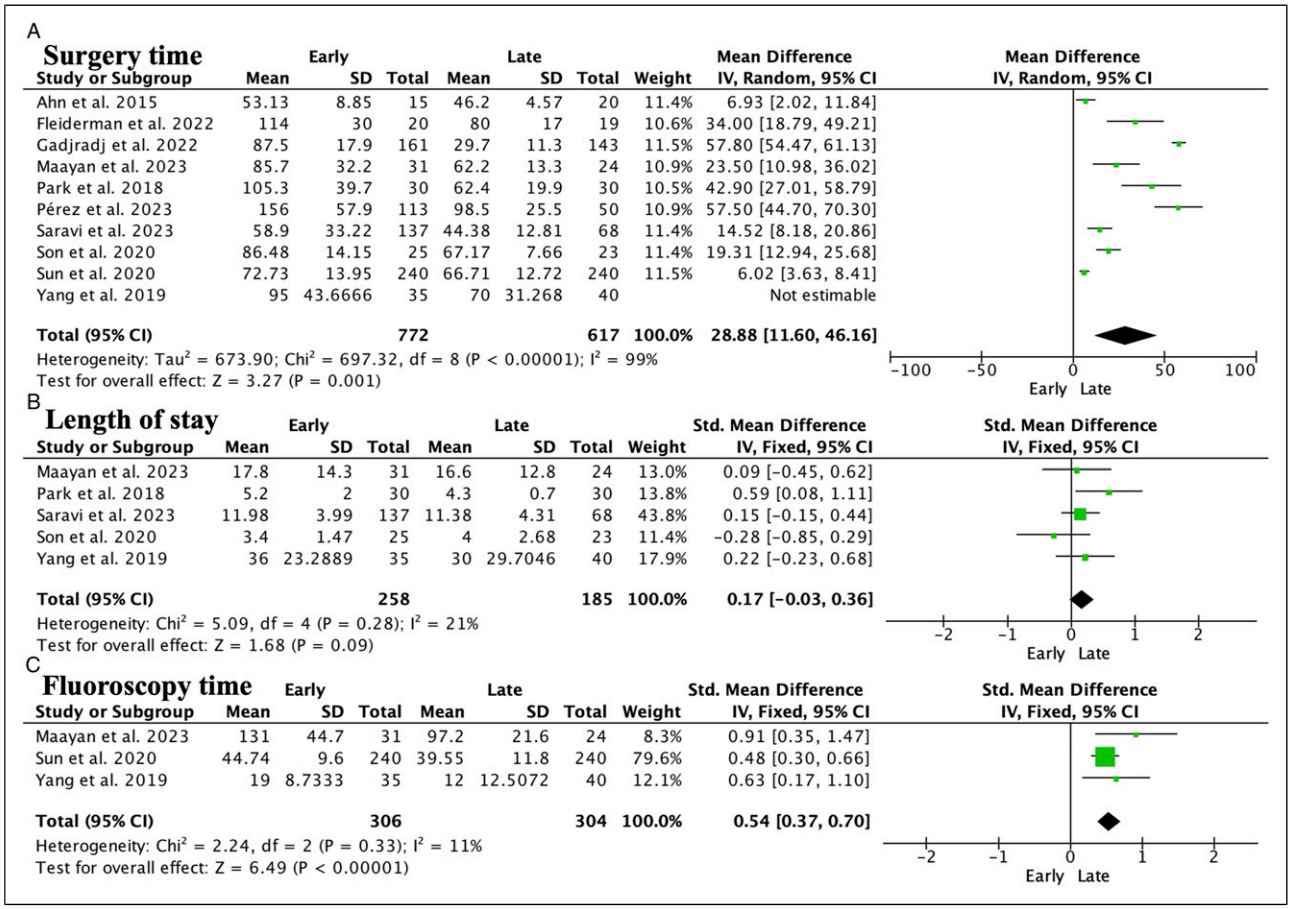

Figure 3. Forest plots showing surgical and hospitalization variables. "Late" surgeons had significantly shorter surgery time (A). There were no significant differences in the length of the hospital stay (B). Fluoroscopy time was significantly shorter in the "late" surgeons (C).

require 20-30 cases to reach the learning curve, highlighting the importance of proper case selection during the initial period.[27] In the transforaminal lumbar interbody fusion (TLIF) technique, approximately 31.3 cases were required to reach the learning curve.[28] Compared to data reported in the literature on microscopic surgery, our study found a similar learning time to achieve mastery in endoscopic surgery.[29,30]

The evolution of uniportal endoscopic surgery has been remarkable, with significant advancements in the development of specialized instruments and enhanced transfer of experience from master's to trainee. This increased experience and technological improvements have contributed to a considerable reduction in the learning curve of the surgeons. In comparison, biportal surgery has also made progress, but it has a shorter history and less accumulated experience than uniportal surgery. However, it is important to note that biportal surgery has been primarily indicated for cases of spinal canal stenosis, a more challenging pathology to manage than hernias, which have been more commonly treated with uniportal surgery according to original studies.

This study focused on the last 10 years of research on the learning curve of endoscopic spinal surgery. When examining studies spanning a longer period of time, it was found that this learning curve can extend up to case number 72, according to a study by Morgenstern et al in 2007.[31] Additionally, another study conducted by Hsu et al in 2013 identified that approximately 33 cases were required to reach the learning curve.[32] It is important to note that this study specifically focused on endoscopic lumbar spinal surgery. However, when considering studies that focused on the cervical spine, a slightly lower learning curve was observed, with an average of 20-28 cases, according to the limited available studies.[3,33]

Overall, significantly higher complications were observed in the group of surgeons with less experience than in the group of experienced surgeons, although the complication rates were low in both groups (5% vs 2%, respectively). Existing complications, such as incidental dural tears or nerve root injuries, were mostly mild and did not have negative consequences for the patients. No significant differences were found in other complications, although their frequency was very low, and the statistical power to detect differences may be limited owing to the small sample size and the lack of inclusion of these variables in most studies. It is important to highlight the significance of meta-analysis in evaluating

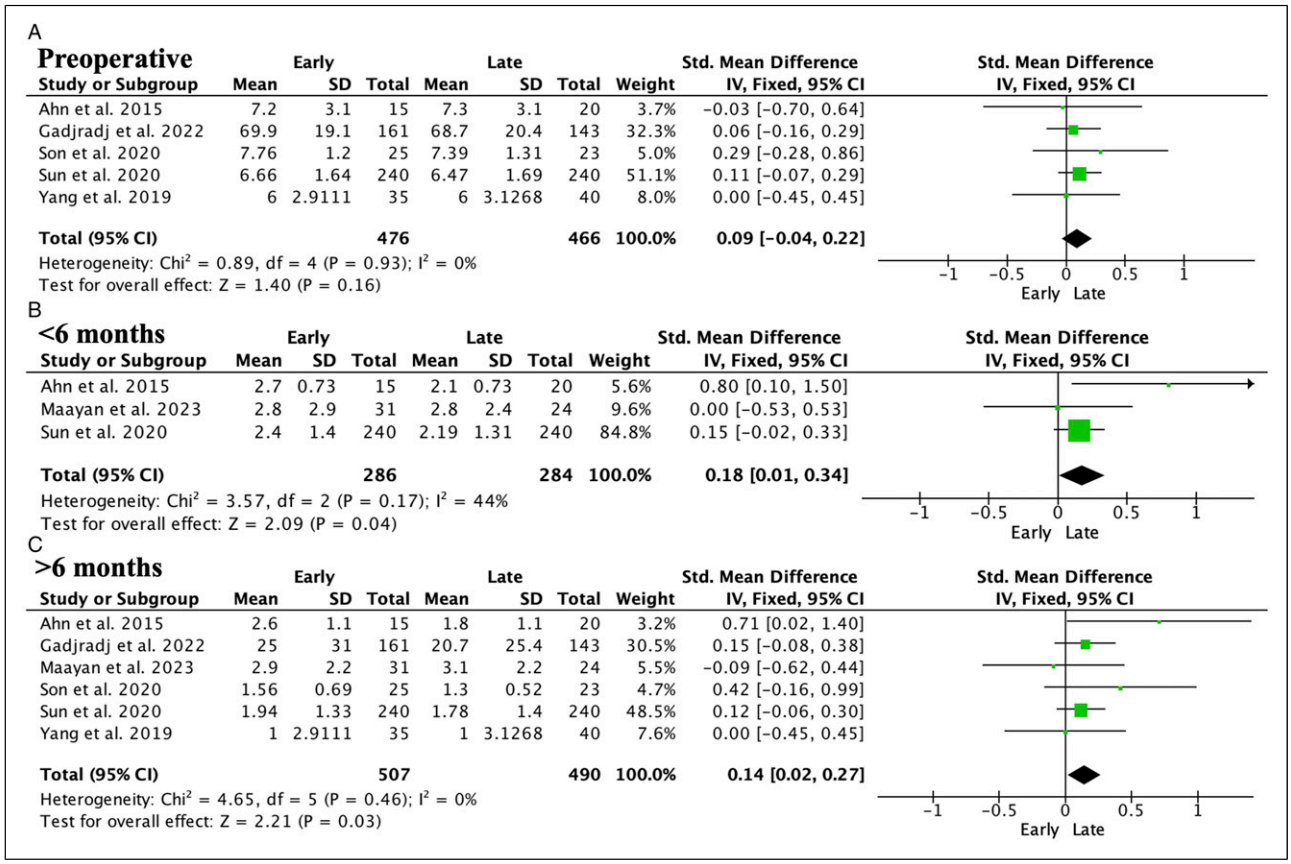

Figure 4. Forest plots showing VAS leg pain. Late surgeons showed no significant differences preoperatively (A), but instead showed significantly better results at less than 6 months (B) and >6 months (C).

complications, as individual articles present low complication rates, but when combined, the power of the analysis increases. However, the complication rate was significantly lower in the experienced surgeons group. However, no significant differences were observed regarding specific complications separately, probably because of the small sample size, as few studies included these variables. In addition, novice surgeons may encounter challenges when it comes to identifying and fully removing structures such as the contralateral ligamentum flavum or structures in the proximal region during endoscopic spinal surgery. These findings emphasize the significance of establishing a proper learning curve and the importance of thorough training and education to minimize complications associated with this technique. It is worth noting that within the first 100 endoscopies, a failure rate of approximately 10% has been observed, including instances of residual disc fragments leading to early reherniation and requiring reintervention.[34]

In this study, significant differences were found in terms of visual analog scale (VAS) pain scores less than or more than 6 months after endoscopic spinal surgery. These differences may be attributed to longer operative times or more intense manipulation of the nerve root during surgery, as surgeons need to familiarize themselves with the anatomy to achieve better visualization.[35] Another approach used by some surgeons is the application of lidocaine to the disc annulus at a volume of 1-2 cm³ to alleviate pain.[6] However, in our study, no significant differences were found in terms of symptomatology measured by the VAS scale and Oswestry Disability Index (ODI) at the preoperative level between the surgeon groups. It is possible that patients with more pronounced symptoms should be operated upon by surgeons with more experience, taking this into account. Additionally, no significant differences were observed in the symptom duration between the groups. However, experienced surgeons were able to significantly reduce pain compared with surgeons in the early stages of their training. However, no significant differences were found in terms of ODI, which assesses function. This could indicate that patients operated on by less experienced surgeons experienced more pain; however, this pain did not significantly affect their ability to perform daily activities.

For novice surgeons, it is crucial to follow a comprehensive set of recommendations to ensure safe and effective endoscopic procedures (Table 4).[3,5,6,9,14,20,24,25,32,36,37] It is crucial to follow a series of recommendations to improve the performance of endoscopic procedures. First, it is essential to study anatomy using cadavers, which provides a better understanding of anatomical reality during interventions.

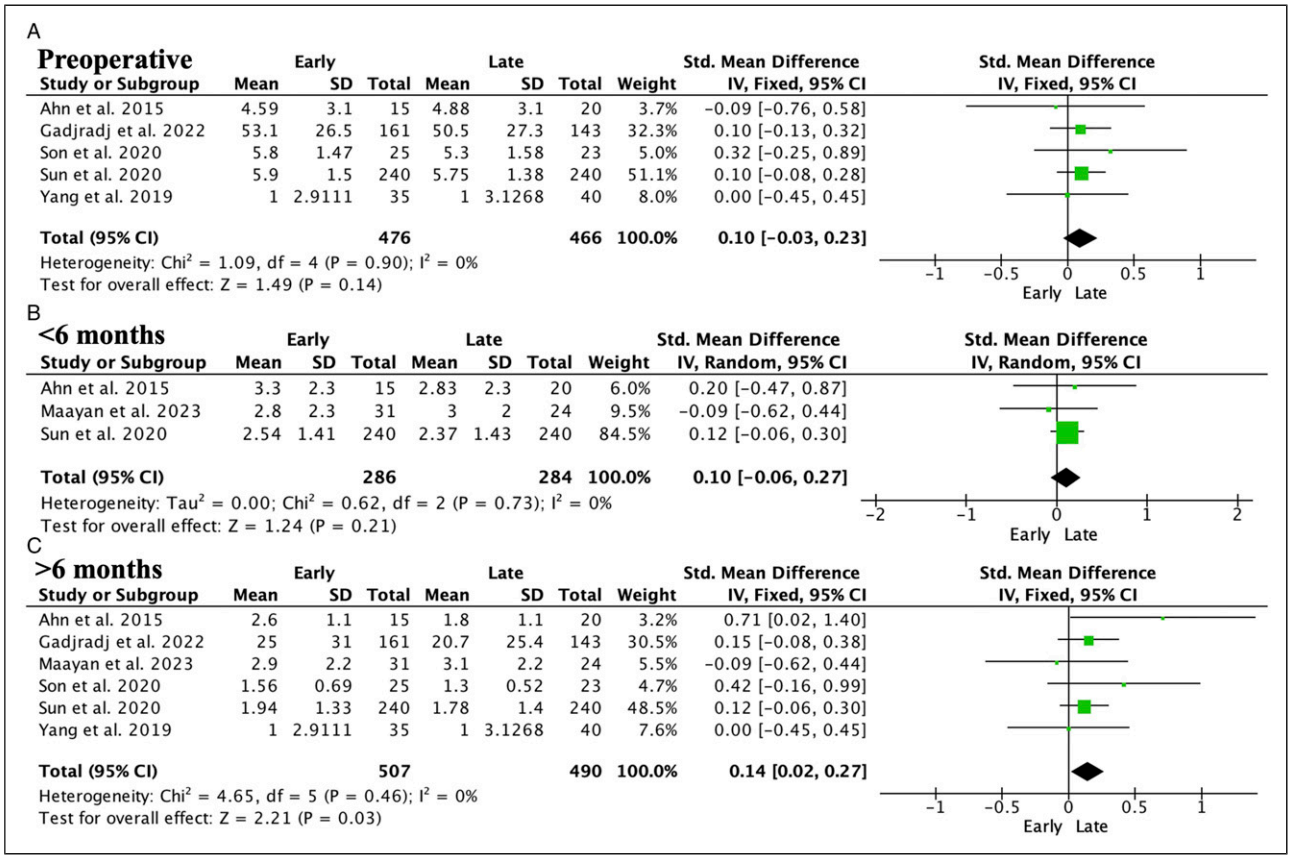

Figure 5. Forest plots showing VAS back pain. Late surgeons showed no significant differences preoperatively (A) or at less than 6 months (B) but showed significantly less pain at more than 6 months (C).

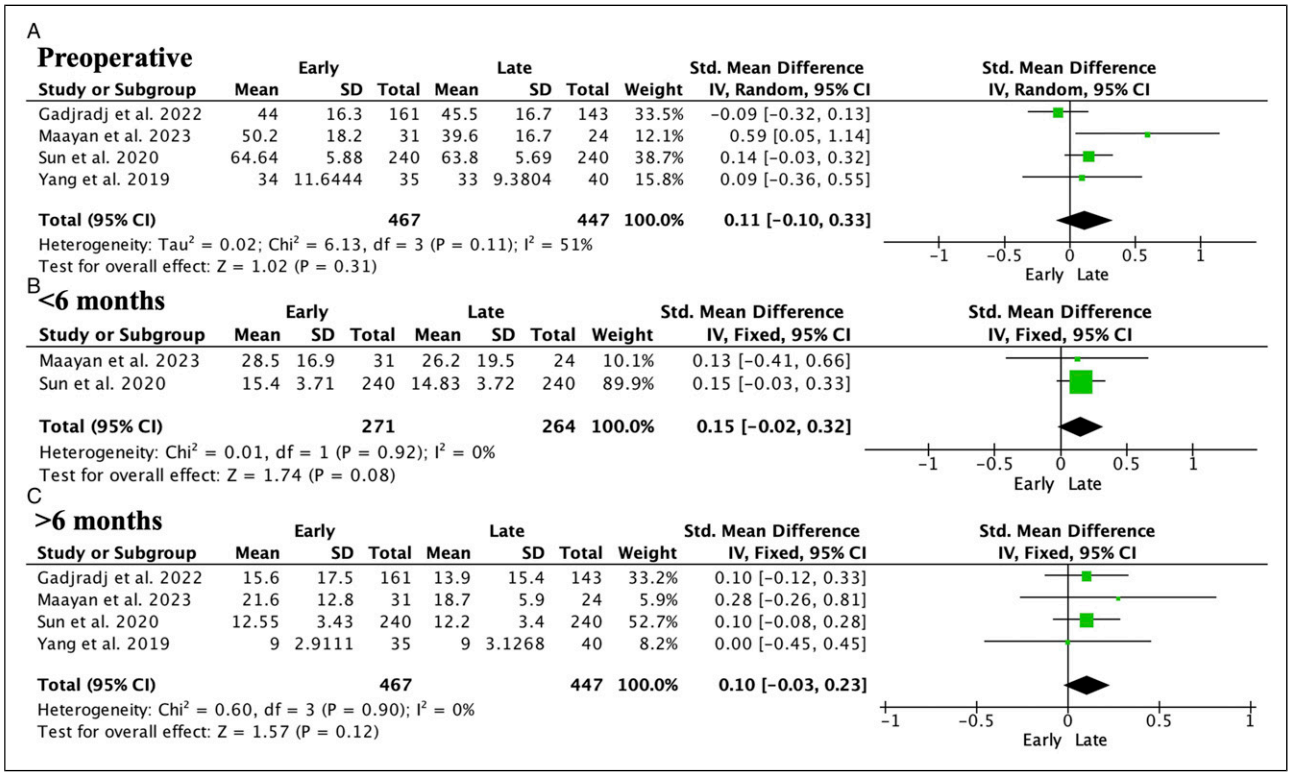

Figure 6. Forest plot showing ODI. There were no significant differences preoperatively (A), at less than 6 months (B), or at > 6 months (C).

Table 3. Complications.

Effect Size	n Participants	Fixed effect Model (OR 95% CI)	I^2 (%)
Total complications	502	OR 3.11, 95% CI 1.03 to 9.36	0
Dural tear	467	OR 1.47, 95% CI 0.24 to 9.15	0
Incomplete decompression	163	OR 6.32, 95% CI 0.73 to 54.38	0
Recurrence	87	OR 1.14, 95% CI 0.33 to 4.03	58
Revisions	391	[a]OR 1.52, 95% CI 0.20 to 11.45	74
Conversion to open/micro surgery	352	OR 1.34, 95% CI 0.23 to 7.69	17
Nerve root injury	352	OR 9.84, 95% CI 0.50 to 193.62	0

[a]Random effect model.

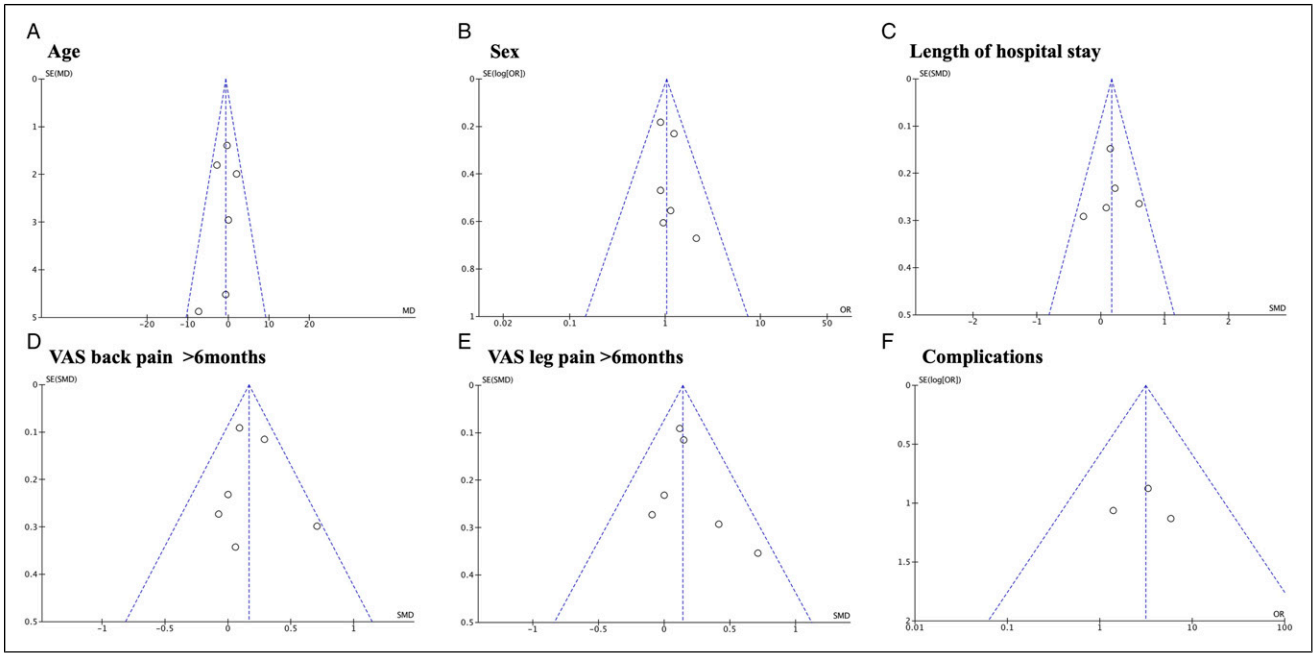

Figure 7. Funnel plot assessing publication bias.

Additionally, it is crucial to participate in surgical workshops and observe experienced surgeons to acquire practical skills and understand the dynamics of the operating room. Integrating into residency programs and attending weekly case conferences promotes discussions and continuous learning. Careful case selection, starting with simpler situations before addressing more complex cases, is important. Moreover, expert supervision during the initial procedures ensures proper technique application and the effective management of complications. Other crucial aspects include thorough preoperative planning, learning of percutaneous techniques, precise needle manipulation, and adherence to specific recommendations for procedure initiation. Caution should also be exercised during manipulation and dissection, temporary repair of dural tears, avoidance of neural structural damage with bipolar radiofrequency, and utilization of navigation systems to improve efficiency and reduce surgical times. By following these recommendations, better performance of endoscopic procedures can be achieved.

The use of navigation systems significantly reduces the learning curve and decreases various surgical times, including fluoroscopy, operation, preoperative localization, and puncture channel times. These times were notably reduced during the first 20 surgeries performed by surgeons.[36] Fluoroscopy and initial puncture can be challenging due to various logical factors, but navigation helps define the trajectory. Accurate needle insertion is crucial for avoiding nerve and blood vessel damage. The navigation system assisted in predefining the trajectory, resulting in a 36.11% reduction in puncture channel time, a 17.01% reduction in operation time, and a 34.09% reduction in fluoroscopy times.

When interpreting the study findings, it is important to acknowledge potential biases that could affect the results. For example, the possibility of complex cases being reserved for

Table 4. Recommendations for Beginners in Endoscopic Spine Surgery.

Step	Description	Details and Recommendations
1	Anatomical study	Encourage cadaveric anatomy studies to enhance orientation and understanding of real anatomy during endoscopic procedures.
2	Surgical workshops/Courses on cadavers or simulators	It is necessary to become familiar with the equipment and maintain good ergonomics to prevent fatigue during initial surgeries.
3	Surgical observation programs	It is necessary to observe an experienced surgeon in their environment to understand the logistics of the operating room.
4	Integration	Integration into residency programs and participation in weekly case conferences.
5	Advocate for the inclusion of endoscopy in medical residency programs	Ensure early and effective learning of these techniques. Regularly attend weekly case conferences to discuss surgical indications and postoperative complications. This practice aids in making appropriate decisions and learning to prevent and manage complications effectively.
6	Case selection prudence	Select cases judiciously, starting with simpler scenarios and initially avoiding more complex ones. Complex cases often have more chronic symptomatology and complications such as vascular hyperplasia, adhesions, and dural tears.
7	Expert supervision	Ensure expert oversight during initial interventions to guarantee correct technique application and management of potential complications.
8	Proper patient selection and preoperative planning	Conduct thorough preoperative planning using detailed imaging like CT and MRI, particularly for calcified hernias.
9	Percutaneous epidural procedures	Engage in percutaneous epidural procedures such as selective nerve root blocks (SNRB), learning to localize the target level and insert the guide needle using fluoroscopy.
10	Precise needle handling	Handle the needle accurately to prevent inadvertent penetration into abdominal viscera, thus reducing the risk of infection.
11	Procedure initiation	In biportal surgery using an interlaminar approach, it is recommended for right-handed surgeons to start with left-sided approaches due to the anatomical orientation of the vertebral laminae. In uniportal surgery, it is recommended to begin with interlaminar approaches due to their greater familiarity and the possibility of conversion to open surgery if needed.
12	Progressive approach to disc herniations	Start with central and paracentral L5-S1 with interlaminar approach, followed by foraminal herniations in L4-L5 and L3-L4, and finally extraforaminal and central in higher lumbar levels.
13	Benefits of percutaneous lumbar endoscopic discectomy under local anesthesia	Consider this approach due to its lower morbidity compared to general anesthesia and for maintaining constant communication with the patient, reducing the risk of nerve damage. It is advisable to perform these procedures after gaining experience through several cases. If the patient experiences pain during local procedures, it can raise doubts and potentially lead to aborting the procedure.
14	Surgical field maintenance	Ensure a continuous water flow to maintain field sterility.
15	Hemorrhage control	Employ the push-rock method to manage bleeding from sharp bone or small epidural vessels. Use of serum adrenaline in specific cases.
16	Precautions with saline solution pressure	Avoid increasing saline solution pressure by manipulating the bag, to prevent intracranial pressure elevation and associated complications. Consider reducing the diastolic blood pressure to 90-100 mmHg to aid in bleeding control.
17	Ligamentum flavum removal	Use angled curettes instead of Kerrison rongeurs for effective removal; for contralateral decompression, create additional space by partial resection with a high-speed burr.
18	Minimizing excessive manipulation delicate manipulation and adhesiolysis	Execute careful manipulation and adhesiolysis to avert nerve injuries, particularly in revision cases. Reduce manipulation during the procedure to lower the risk of injuries and complications.
19	Dural repair	Utilize Gelfoam/Tachosil for temporary dural tears; contemplate dural suturing with a fine needle, but be aware of the risk of needle displacement into the epidural or intradural space. Conversion to an open procedure is advisable if displacement occurs.
20	Use of bipolar radiofrequency	Avoid high-intensity bipolar radiofrequency near neural structures to prevent neural damage.

(continued)

Table 4. (continued)

Step	Description	Details and Recommendations
21	Cautious handling of trephine and cannula and facet joint resection	Avoid complete penetration of the medial cortex of the superior articular process with the trephine and gently rotate the cannula clockwise to induce a controlled bone fracture. Exercise caution with excessive medial resection of the facet joint, ensuring correct endoscopic anatomical referencing.
22	Complete decompression techniques	Consider the removal of medial and superior portions of the pedicle if necessary, to achieve complete decompression in the region between the intervertebral disc and the lower pedicle.
23	Utilization of navigation systems	Employing navigation aids such as real-time imaging or robotic guidance can significantly decrease the learning curve and reduce various surgical times including fluoroscopy time, operation time, preoperative location time, and puncture-channel time. These times were notably reduced during the first 20 surgeries of novice surgeons, enhancing efficiency and safety.

open surgery may overestimate the learning curve and underestimate the duration. However, the study found no significant differences between experienced and novice surgeons in terms of preoperative VAS or ODI scores, symptom duration, or patient age, indicating that case complexity did not differ between the groups. It is also important to consider the obstacles identified in endoscopy, as a survey conducted in Thailand revealed that personal motivations and lack of support are common challenges.[10] Furthermore, surgical time can be a valuable measure of competence as it can impact efficacy and safety variables.[38] Therefore, it is important to consider that novice surgeons may take longer during surgery, which could contribute to the lack of differences in certain complications observed in some studies.

This study had some important limitations that should be considered when interpreting the results. First, efforts were made to standardize the follow-up times among the included studies; however, there were still variations in the duration of these periods. Additionally, the limited number of available studies for many analyzed variables made it challenging to perform subgroups and divisions to assess the influence of factors, such as case etiology, techniques used, and learning times. Also, our analysis did not categorize outcomes based on different etiologies nor did they consistently differentiate outcomes between uniportal and biportal. As such, variations in surgical time and complications related to the extent of decompression were not directly comparable. Recognizing this limitation is crucial, as it highlights the need for future research to systematically address these distinctions to enhance the comparability and applicability of the study findings. Another significant limitation was the presence of different definitions of the learning curve in various articles, with some studies using longer periods and others using shorter periods. Another limitation was the lack of differentiation between the interlaminar and transforaminal techniques within the uniportal approach, as well as the lack of distinction between the paraespinal and interlaminar methods in the biportal approach. However, it is essential for an endoscopic spine surgeon to be proficient in all these techniques to ensure comprehensive clinical competency. Furthermore, the heterogeneity in case etiologies may also have influenced the results, making a more precise and detailed comparison difficult.

Conclusions

According to the study results, it was determined that, on average, 32.5 cases are required to reach the learning curve in endoscopic spine surgery, with a minimum range of 18 cases and a maximum of 50 cases. The uniportal technique was found to require a lower number of cases to gain experience, followed by the biportal technique. Additionally, as surgeons gained more experience, improvements were seen in surgical outcomes, such as shorter surgery times, reduced fluoroscopy time, and better results in terms of leg and back pain both in the short and long term. It was also found that the group with less experience had a significantly higher incidence of complications than the more experienced group. These findings are highly relevant for spine surgeons performing endoscopic surgery as they provide valuable information about the number of cases needed to achieve an optimal learning curve in this technique. Knowing the approximate number of cases required to reach this learning curve can assist surgeons in planning their training and developing realistic expectations regarding their progress in the endoscopic spine technique.

Author Contributions

Conception and design: J.A.d.M.-M., J.C.-T.., C.B.-G., M.G.-M.; Analysis and interpretation of the data: J.A.d.M.-M., J.C.-T.., C.B.-G., M.G.-M.; Drafting of the article: J.A.d.M.-M., J.C.-T.., C.B.-G., M.G.-M.; Critical revision of the article for important intellectual content: J.A.d.M.-M., J.C.-T.., C.B.-G., M.G.-M.; Final approval of the article: J.A.d.M.-M., J.C.-T.., C.B.-G., M.G.-M.; Statistical expertise: J.A.d.M.-M. and M.G.-M.; Obtaining of funding: N/A.; Administrative, technical, or logistic support: N/A.; Collection and assembly of data: J.A.d.M.-M., J.C.-T.., C.B.-G., M.G.-M.

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ORCID iD

Manuel González-Murillo https://orcid.org/0000-0002-5205-1382

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