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Differential Agnostic Effect Size Analysis of Lumbar Stenosis Surgeries

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ABSTRACT

Study Design: A meta-analysis of 89 randomized prospective, prospective, and retrospective studies on spinal endoscopic surgery outcomes.

Objective: The study aimed to provide familiar Oswestry Disability Index (ODI), visual analog scale (VAS) back, and VAS leg effect size (ES) data following endoscopic decompression for sciatica-type back and leg pain due to lumbar herniated disc, foraminal, or lateral recess spinal stenosis.

Background: Higher-grade objective clinical outcome ES data are more suitable than lower-grade clinical evidence, including cross-sectional retrospective study outcomes or expert opinion to underpin the ongoing debate on whether or not to replace some of the traditional open and with other forms of minimally invasive spinal decompression surgeries such as the endoscopic technique.

Methods: A systematic search of PubMed, Embase, Web of Science, and the Cochrane Central Register of Controlled Trials from 1 January 2000 to 31 December 2019 identified 89 eligible studies on lumbar endoscopic decompression surgery enrolling 23,290 patient samples using the ODI and VAS for back and leg pain used for the ES calculation.

Results: There was an overall mean overall reduction of ODI of 46.25 (SD 6.10), VAS back decrease of 3.29 (SD 0.65), and VAS leg reduction of 5.77 (SD 0.66), respectively. Reference tables of familiar ODI, VAS back, and VAS leg show no significant impact of study design, follow-up, or patients' age on ES observed with these outcome instruments. There was no correlation of ES with long-term follow-up ($P = 0.091$). Spinal endoscopy produced an overall ODI ES of 0.92 extrapolated from 81 studies totaling 12,710 patient samples. Provided study comparisons to tubular retractor microdiscectomy and open laminectomy showed an ODI ES of 0.9 (2895 patients pooled from 16 studies) and 0.93 (1188 patients pooled from 5 studies). The corresponding VAS leg ES were 0.92 (12,631 endoscopy patients pooled from 81 studies), 0.92 (2348 microdiscectomy patients pooled from 15 studies), and 0.89 (1188 open laminectomy patients pooled from 5 studies).

Conclusion: Successful clinical outcomes can be achieved with various lumbar surgeries. ESs with endoscopic spinal surgery are on par with those found with open laminectomy and microsurgical decompression.

Clinical Relevance: This article is a meta-analysis on the benefit overlap between lumbar endoscopy, microsurgical decompression, laminectomy, and lumbar decompression fusion.

Level of Evidence: 2.

Endoscopic Minimally Invasive Surgery

Keywords: lumbar surgery, herniated disc, spinal stenosis, meta-analysis, minimally invasive surgery, endoscopy

INTRODUCTION

Endoscopic spinal surgery is on the rise, and in some countries has become the standard of care in the treatment of lumbar herniated disc and spinal stenosis in the foramen and lateral recess.[1] Within the last 3 years alone, there has been a surge of publications coming out of China,[2–54] South Korea,[42,55–78] and other Asian countries,[79–87] where spinal endoscopy has replaced microsurgical dissection techniques. Many of these articles focus on technological innovations with the procedure. Clinical benefits over traditional translaminar lumbar decompression techniques are often demonstrated in the context of a new instrument or a new technology, which is used to expand the clinical indications for endoscopic spinal surgery. While the transforaminal approach has been the "workhorse" endoscopic technique as pioneered by the senior author of this article some 30 years ago,[88–95] alternatives such as the interlaminar,[7,9,21,24,41,54,59,96,97] the full-endoscopic, and the uniportal biportal endoscopic (UBE)[61,67,98,99] techniques have recently been popularized to promote one method over another. At least on the surface, it may appear to the novice to endoscopic spinal surgery attempting to organize the available clinical information that some authors may be pushing biased agendas by attempting to exploit some perceived procedural advantages and disadvantages to make a case for their preferred spinal surgery technique. One example of this trend is the sheer number of procedural acronyms—YESS (Yeung endoscopic spine system),[12,26,90,95,100–104] TESSYS (transforaminal endoscopic spine system),[105–110] PELD (percutaneous endoscopic lumbar discectomy),[14,19,25,36,54,56,111] SED (selective endoscopic discectomy), BELD (biportal endoscopic lumbar decompression),[112] ULBD (unilateral laminotomy with bilateral decompression),[113] PBED (percutaneous biportal endoscopic decompression),[74] PTED (percutaneous transforaminal endoscopic discectomy),[114] UBE (unilateral biportal endoscopy),[61,67,98,99] BEIS (intervertebral foramen endoscopy),[115] TESSYS (transforaminal endoscopic spine system)-ISEE (Interlaminar endoscopic 270° spinal canal decompression),[116] so on—to list the most commonly used terminology. These acronyms are being proposed to improve the relevance of a new version of endoscopic and minimally invasive spine surgery that supposedly improves clinical outcomes. But does it, though, and which of these procedural variations of lumbar spinal stenosis surgery are clinically relevant? The Arbeitsgemeinschaft für Osteosynthesefragen-Spine has proposed an evidence-oriented classification system to meliorate this situation somewhat and to moderate the debate but has not presented any clinical evidence to back it up.[117]

The authors of this study attempted to grade the clinical evidence on lumbar spine surgeries directed at soft tissue and bony spinal stenosis including modern spinal endoscopy. Many of these studies including control arms consist of traditional translaminar microsurgical and open decompression. Therefore, the authors qualitatively graded and quantitatively analyzed the clinical evidence on the endoscopic literature including that of the respective control groups published thus far by performing a meta-analysis on commonly used numerical spinal surgery outcome instruments: the Oswestry Disability Index (ODI),[118–121] and the visual analog scale (VAS)[122] for back and leg pain. While many published meta-analyses attempted to demonstrate clinical superiority of the endoscopic spinal surgery outcomes compared to traditional translaminar microsurgical decompression techniques by selecting a few high-quality studies and without reporting the actual effect size (ES) numbers,[8,22,34,50,59,123–127] the authors of this article took a different approach to delineate the clinical relevance of procedural variations and technology advances in minimally invasive and endoscopic spinal surgery and the mode of studying them. Instead of performing a narrow focus meta-analysis based on a few prospective or randomized prospective, or well-controlled cross-sectional retrospective studies, this team of authors was interested in a broad investigation of the ESs associated with reported clinical outcome improvements with traditional translaminar and lumbar endoscopic spinal surgery by extracting and analyzing the ODI and VAS means, SDs, and number of patients in each study. Therefore, we performed additional subcategory, modifier, and wave analysis to cross-tabulate ES extractions by the length of follow-up, patients' age, the indication for surgery, the type of minimally invasive spinal surgery performed, the publication year, and the type of study design employed by the authors of the original studies. Ultimately, the authors intended to create a reference table of ES with the various minimally invasive spinal surgery to employ it in the comparative evaluation and discussion of their clinical merits.

MATERIALS AND METHODS

Search Strategy and Study Selection

The authors were interested in analyzing the ES data reported for commonly used numerical clinical outcome instruments including the ODI,[118–121] and the VAS[122] for back and leg pain with lumbar endoscopic decompression procedures for soft tissue and bony stenosis. Therefore, we performed a meta-analysis of clinical studies on endoscopic decompression for lumbar herniated disc and spinal stenosis employing preferred reporting items for systematic reviews and meta-analyses guidelines.[128–131] For this purpose, the authors searched the English literature on PubMed, Embase, Web of Science, and the Cochrane Database from 1 January 2000 to 31 December 2019 using "lumbar" and "herniated disc" or ''spinal stenosis'' and ''endoscopic'' and ''ODI'' and ''VAS'' as keywords. Three independent researchers (KUL, JFR, and ATY) contributed their literature searches and also reached consensus with the other coauthors if there were any discrepancies in the interpretation of the selected studies.

Inclusion Criteria and Data Extraction

The literature search was aimed at finding studies which included analysis of endoscopic spinal surgery outcomes reported on patients suffering from symptoms related to lumbar herniated disc, and foraminal or lateral recess stenosis utilizing ODI and VAS for back and leg pain. This literature search included straightforward cross-sectional retrospective, prospective single treatment group, or randomized prospective multitreatment arm study designs comparing endoscopic, with other minimally invasive spinal surgery techniques (MISST) including tubular retractor, and others. Retrieved studies were further stratified by the type of endoscopic MISST access to the neural elements including transforaminal, interlaminar, or combinations, or variations of these techniques. Case reports, review articles, letters to the editor, editorials, short-term reports, and nonclinical studies, such as biomechanical or cadaveric studies were excluded. Each study discovered during the extensive literature search performed by the authors was categorized as retrospective, prospective single treatment group, or randomized prospective multitreatment arm cohort studies. Their respective quality was assessed by the authors via consensus discussions to resolve any discrepancies in study quality assessment by evaluating the risk of bias (ROB) using the ROB assessment tool for controlled nonrandomized observational cohort studies, and the ROB tool for randomized controlled trials.[132]

Statistical Analysis

The purpose of our meta-analysis was to determine and compare the ES of the clinical improvement of patients treated with the various endoscopic spinal decompression surgery techniques for herniated disc, central, lateral recess, and foraminal stenosis on the basis of the reported numerical clinical outcome instruments. For this purpose, the authors extracted the reported data for ODI, VAS back, and VAS leg at baseline and postoperatively at final follow-up. Only studies which reported the mean, the SD, and the sample size preoperatively and postoperatively were included in this meta-analysis for the ES calculation using random ES models. The authors considered other ways of calculating the ES from reported *t* values or significance levels less accurate with the potential of underestimating the ES and did not employ them.

Clinical outcome data extracted from the articles included in this meta-analysis were means and SD of the VAS back, the VAS leg, and the ODI. The ES of postoperative improvements was calculated on the basis of the number of enrolled study patients available at last follow-up using Cohen *d* analysis. We used Prometa3 version 3.0 for the meta-analysis by creating a meta-analysis database of the included studies by recording the first study author and up to 2 additional coauthors, the year of publication, the study patients' mean age, and of the preoperative baseline and the postoperative value of the 3 numerical outcome variables at final available follow-up. Studies comparing multiple treatments were categorized by comparisons of "endoscopy" vs "microsurgical" decompression, laminectomy, and variations of these procedures with and without fusion. Additional moderators used in the analysis were the study design (retrospective, prospective, and randomized prospective), the indication for surgery (herniated disc radiculopathy, stenosis claudication, and discogenic pain), the type of MISST (endoscopy, open laminectomy, and tubular microdiscectomy), and, if employed, the type of endoscopic (transforaminal outside-in, transforaminal inside-out, interlaminar, combined outside-in and interlaminar, or biportal UBE endoscopy). The calculated ESs, lower limit (LL), upper limit (UL), the Higgins I^2 statistic of heterogeneity (I^2), variance (V), SE, number of patients, and the significance level (sig) of 95% CI were tabulated separately for ODI, VAS back, and VAS leg. The underlying average reduction of ODI, VAS back, and VAS leg was compared to the reported and calculated minimal clinically important difference (MCID) data—3.0 for VAS leg and VAS back and 15 for ODI.[83,133–137] Furthermore, the extracted mean ODI, VAS back, and VAS leg from each individual study were weighted by the inverse of the variance for each outcome instrument. The data heterogeneity was examined by Cochran Q test and the Higgins I^2 statistic with an I^2 threshold of greater than 50% being considered as sufficient. Funnel plots (SE vs ES) were visually assessed for evidence of publication bias and by calculating the P value (1-sided) for Egger intercept using the Prometa3 software, version 3.0 (Internovi, 2015). IBM SPSS statistics version 26.0 was used for area-plot analysis of ES vs SE to graphically display the extent of the overlap in postoperative surgical decompression benefit.

RESULTS

Initial Search Results

The initial screening literature search using the keywords "lumbar" and "herniated disc" or "spinal stenosis" and "endoscopic*" and "ODI" and "VAS" as subject headings identified 882 studies in PubMed, Embase, Web of Science, and the Cochrane Central Register of Controlled Trials. Among these 882 studies, duplicates, case reports, review articles, letters, technical notes, or patents as well as studies not reporting the average mean, SD of ODI and VAS scores, and number of patients or length of follow-up were excluded. The remaining 89 eligible studies were subjected to a full-text review. In attempt to compare short-term and long-term ES, study analysis was further stratified into short-term—53 studies with less than 2-year follow-up (Table 1)[1,4,5,7,9,11,13,18–20,23–28,36,38,40,42,43,45,51,56,66,68,74,78,111–114,116,138–156]—and long-term follow-up (36 studies) with a minimum of 2 years or longer follow-up (Table 2).[10,30,33,41,46,49,52,53,55,60,67,71,75,76,97,157–175] The details of the preferred reporting items for systematic reviews and meta-analyses study selection process are summarized in Figure 1.

Meta-Analysis Results

The ODI, VAS back, and VAS leg data obtained from the collective analysis of the 23,290 samples extracted from 89 articles with 112 study entries considering multiple treatment arms revealed an overall ES of 0.9 using a random effects model with an LL of 0.89 and UL of 0.91 and I^2 98.49. The weighted regression analysis for age vs overall ES showed no significant correlation between these 2 variables (P = 0.539). The weighted regression analysis for follow-up vs overall ES showed a significant correlation between these 2 variables (P = 0.014). The majority of the 89 studies only provided short postoperative follow-up times: under 12 months in 17 study entries, 1 year in 27 study entries, under 24 months in 23 study entries. Long-term follow-up was reported by 36 articles of which, 18 study entries had follow-up of 2 years, 17 study entries had follow-up data between 2 and 4 years, and another 10 study entries over 60 months with the longest 2 follow-up study entries running for 74.8 and 76.2 months. However, there was no statistically significant difference in ES on analysis of variance (ANOVA) Q testing between short-term and long-term follow-up studies (P = 0.091). A similar analysis of ES vs publication year using random effects model showed a trend toward increasing ES since 2010 although statistically not significant (P – 0.186) presumably representing clinical treatment improvements due to technology advancements. Publication bias analysis showed overall observed ES as 0.92 (ODI), 0.8 (VAS back), and 0.92 (VAS leg) with a significant improvement (P < 0.0001 for all 3 outcome instruments) on Egger linear regression with an intercept = −0.82 and t = −0.51 for ODI, an intercept = 1.62 and t = 0.74 for VAS back, and an intercept = 0.39 and t = 0.25 for VAS leg. Seventy-two of the 89 studies included in this meta-analysis were retrospective studies. Twelve studies were prospective, and another 5 studies were randomized prospective clinical trials both of which had multiple treatment arms. Twenty-four of the 36 studies included in the meta-analysis with longer than 2-year follow-up were retrospective studies and were estimated to have a high ROB. This was reflected in the asymmetric funnel plot with a significant number of studies falling outside the expected area of SE vs ES plot suggesting that the bias in the underlying studies put the authors' overall meta-analysis at moderate ROB.

Meta-Analysis by Modifiers

The impact of study design on ES was minimal and statistically not significantly different among retrospective, prospective, and randomized prospective trials (Table 3). The mean ODI analysis on 17,921 patients' samples showed ES of 0.92 for retrospective, ES of 0.92 for prospective, and ES of 0.91 for randomized prospective trials (P = 0.925). The mean VAS back analysis on 8002 patients' samples also did not show any statistically significant impact of study design on ES: ES of 0.8 for retrospective, ES of 0.6 for prospective, and ES of 0.81 for randomized prospective trials (P = 0.204). Similarly, the mean VAS leg analysis on 17,295 patients' samples also did not show any statistically significant impact of study design on ES: ES of 0.91 for retrospective, ES of 0.93 for prospective, and ES of 0.88 for randomized prospective trials (P = 0.575).

The indication for surgery was another modifier studied in our meta-analysis (Table 4). Extracted ODI means analysis showed a higher overall ES for endoscopic decompression of spinal stenosis-related claudication symptoms (ES = 0.95; 1638 patients pooled from 14 studies) than for herniated disc (ES = 0.92; 3520 patients pooled from 22 studies) or discogenic back pain (ES = 0.91; 216 patients pooled from 2 studies) at statistically insignificant level (P = 0.094). Moreover, extracted means analysis for VAS back (P = 0.074) and VAS leg (P = 0.74) did not produce any significant difference in overall ES for either of these 3 indications

Table 1. List of short-term (<2-year follow-up) lumbar decompression studies included into the effect size meta-analysis comparing endoscopic to other translaminar decompression surgeries with brief summary of study highlights.

#	Authors	Year	Title	Reference	Study Highlights
1.	Abudurexiti T, Qi L, et al[36]	2018	Microendoscopic discectomy vs percutaneous endoscopic surgery for lumbar disk herniation.	*J Int Med Res* 2018;46:3910–7.	Prospective study comparing PELD vs MED in the treatment of 216 patients with lumbar disc herniation
2.	Ahn JS, Lee HJ, et al[78]	2018	Extraforaminal approach of biportal endoscopic spinal surgery: a new endoscopic technique for transforaminal decompression and discectomy.	*J Neurosurg Spine* 2018;28:492–8.	Retrospective cohort study of 21 patients treated with biportal endoscopic spinal surgery as a new endoscopic technique for transforaminal decompression
3.	Ao S, Wu J, et al[19]	2019	Percutaneous endoscopic lumbar discectomy assisted by O-arm-based navigation improves the learning curve.	*Biomed Res Int* 2019;2019:6509409.	Prospective cohort study of 118 patients to assess the safety and efficacy of PELD assisted by O-arm-based navigation for treating LDH
4.	Cao S, Cui H, et al[138]	2019	"Tube in tube" interlaminar endoscopic decompression for the treatment of lumbar spinal stenosis: technique notes and preliminary clinical outcomes of case series.	*Medicine (Baltimore)* 2019;98:e17021.	Retrospective efficacy and safety study of 35 patients treated with tube-in-tube interlaminar endoscopic MED decompression in treating LSS
5.	Chen Z, Zhang L, et al[114]	2018	Percutaneous transforaminal endoscopic discectomy compared with microendoscopic discectomy for lumbar disc herniation: 1 year results of an ongoing randomized controlled trial.	*J Neurosurg Spine* 2018;28:300–10.	Randomized prospective controlled study of 153 patients to investigate whether percutaneous transforaminal endoscopic discectomy results in better clinical outcomes and less surgical trauma than MED
6.	Choi G, Lee SH, et al[139]	2006	Percutaneous endoscopic interlaminar discectomy for intracanalicular disc herniations at L5-S1 using a rigid working channel endoscope.	*Neurosurgery* 2006;58:ONS59-68; discussion ONS59-68.	Retrospective study of 65 patientson the procedure and clinical results of interlaminar L5-S1 level PELD and the relevant surgical anatomy
7.	Dabo X, Ziqiang C, et al[24]	2016	The clinical results of percutaneous endoscopic interlaminar discectomy (PEID) in th e treatment of calcified lumbar disc herniation: a case-control study.	*Pain Physician* 2016;19:69–76.	Retrospective case-control study of 30 patients treated with PELD for calcified and noncalcified lumbar disc herniations
8.	Eun SS, Chachan S, et al[140]	2018	Interlaminar percutaneous endoscopic lumbar discectomy: rotate and retract technique.	*World Neurosurg* 2018;118:188–92.	Retrospective study of 17 patients who underwent interlaminar PELD with the rotate and retract technique
9.	Eun SS, Eum JH, et al[112]	2017	Biportal endoscopic lumbar decompression for lumbar disk herniation and spinal canal stenosis: a technical note.	*J Neurol Surg A Cent Eur Neurosurg* 2017;78:390–6.	Retrospective study of 17 patients treated with biportal endoscopic lumbar decompression technique using 2 portals to treat difficult lumbar disc herniations and also lumbar spinal stenoses
10	Gadjradj, Pravesh S, et al[141]	2016	Clinical outcomes after percutaneous transforaminal endoscopic discectomy for lumbar disc herniation: a prospective case series.	*Neurosurg Focus*. 2016 Feb;40(2):E3.	Prospective study of 166 patients who underwent surgery for a total of 167 LDH
11.	He S, Sun Z, et al[26]	2018	Combining YESS and TESSYS techniques during percutaneous transforaminal endoscopic discectomy for multilevel lumbar disc herniation.	*Medicine (Baltimore)* 2018;97:e11240.	Retrospective study on 52 patients with multilevel LDH treated with combination of YESS and TESSYS
12.	Heo DH, Lee DC, et al[113]	2019	Comparative analysis of three types of minimally invasive decompressive surgery for lumbar central stenosis: biportal endoscopy, uniportal endoscopy, and microsurgery.	*Neurosurg Focus* 2019;46:E9.	Retrospective study on MED vs endoscopic unilateral laminotomy with bilateral decompression to treat lumbar canal stenosis
13.	Heo DH, Sharma S, et al[66]	2019	Endoscopic treatment of extraforaminal entrapment of L5 nerve root (far out syndrome) by unilateral biportal endoscopic approach: technical report and preliminary clinical results.	*Neurospine* 2019;16:130–7.	Retrospective consecutive of 16 patients with unilateral extraforaminal entrapment of the L5 nerve root (far out syndrome) treated with percutaneous biportal endoscopies
14.	Hsu HT, Chang SJ, et al[142]	2013	Learning curve of full-endoscopic lumbar discectomy.	*Eur Spine J* 2013;22:727–33.	Retrospective study of 57 patients who underwent full-endoscopic lumbar discectomy and 66 patients who underwent open microdiscectomy
15.	Hu A, Gu X, et al[5]	2018	Epidural vs intravenous steroids application following percutaneous endoscopic lumbar discectomy.	*Medicine (Baltimore)* 2018;97:e0654.	Retrospective study of LDH patients who had undergone transforaminal PELD comparing epidural steroid, intravenous steroid to control a group each containing 60 patients

Table 1. Continued.

#	Authors	Year	Title	Reference	Study Highlights
16.	Hu Z, Li X, et al[45]	2017	Significance of preoperative planning software for puncture and channel establishment in percutaneous endoscopic lumbar discectomy: a study of 40 cases.	*Int J Surg* 2017;41:97–103.	Retrospective study of 40 patients to compare the clinical efficacy of preoperative planning software in puncture and channel establishment of PELD
17.	Hua W, Tu J, et al[13]	2018	Full-endoscopic discectomy via the interlaminar approach for disc herniation at L4-L5 and L5-S1: an observational study.	*Medicine (Baltimore)* 2018;97:e0585.	Retrospective study of 80 patients to investigate the clinical outcomes of full-endoscopic discectomy via the interlaminar approach for LDH at L4-L5 under general anesthesia
18.	Hua W, Zhang Y, et al[7]	2018	Outcomes of discectomy by using full-endoscopic visualization technique via the interlaminar and transforaminal approaches in the treatment of L5-S1 disc herniation: an observational study.	*Medicine (Baltimore)* 2018;97:e13456.	Retrospective study of 60 patients treated with full-endoscopic visualization technique via the interlaminar approach vs the transforaminal approach for LDH under general anesthesia
19.	Hubbe U, Franco-Jimenez P, et al[143]	2006	Minimally invasive tubular microdiscectomy for recurrent lumbar disc herniation.	*J Neurosurg Spine* 2016;24:48–53.	Retrospective safety and efficacy of minimally invasive tubular microdiscectomy LDH
20.	Hwa Eum J, Hwa Heo D, et al[74]	2016	Percutaneous biportal endoscopic decompression for lumbar spinal stenosis: a technical note and preliminary clinical results.	*J Neurosurg Spine* 2016;24:602–7.	Retrospective study of 58 single-level lumbar stenosis patients who underwent unilateral laminotomy with bilateral foraminal decompression using a unilateral biportal endoscopic system
21.	Kapetanakis S, Giovannopoulou E, et al[144]	2016	Transforaminal percutaneous endoscopic discectomy in Parkinson disease: preliminary results and short review of the literature.	*Korean J Spine* 2016;13:144–50.	Retrospective case-control effectiveness study of transforaminal PELD in 10 Parkinson patients and 10 control patients
22.	Kim HS, Adsul N, et al[145]	2018	Full-endoscopic lumbar discectomy using the calcification floating technique for symptomatic partially calcified lumbar herniated nucleus pulposus.	*World Neurosurg* 2018;119:500–5.	Retrospective study of 31 patients who underwent full-endoscopic discectomy using free floating technique for partially calcified lumbar HNP
23.	Kim HS, Adsul N, et al[1]	2018	A mobile outside-in technique of transforaminal lumbar endoscopy for lumbar disc herniations.	*J Vis Exp* 2018.	Prospective study of 184 patients to describe the technical aspects of a novel mobile outside-in method in dealing with different types of disc prolapse
24.	Kim HS, Paudel B, et al[56]	2018	Percutaneous endoscopic lumbar discectomy for all types of lumbar disc herniations (LDH) including severely difficult and extremely difficult LDH cases.	*Pain Physician* 2018;21:E401-E8.	Retrospective consecutive case study of 98 patients who underwent PELD for severely difficult and extremely difficult
25.	Kim HS, Yudoyono F, et al[68]	2017	Analysis of clinical results of three different routes of percutaneous endoscopic transforaminal lumbar discectomy for lumbar herniated disk.	*World Neurosurg* 2017;103:442–8.	Retrospective study of 71 transforaminal PELD patients divided in the foraminal (group A), intervertebral (group B), and suprapedicular (group C) with 32, 46, and 33 patients, respectively
26.	Li LJ, Chang F, et al[146]	2018	Clinical effects of percutaneous endoscopic transforaminal decompression for the treatment of lumbar spinal stenosis.	*Zhongguo Gu Shang* 2018;31:617–20.	Retrospective study of 67 patients who underwent transforaminal PELD for lumbar spinal stenosis
27.	Li M, Yang H, et al[27]	2015	Full-endoscopic technique discectomy vs microendoscopic discectomy for the surgical treatment of lumbar disc herniation.	*Pain Physician* 2015;18:359–63.	Restrospective study of 85 patients treated with PELD vs MED for LDH
28.	Li XF, Jin LY, et al[147]	2019	Endoscopic ventral decompression for spinal stenosis with degenerative spondylolisthesis by partially removing posterosuperior margin underneath the slipping vertebral body: technical note and outcome evaluation.	*World Neurosurg* 2019;126:e517-e25.	Retrospective study of 25 patients to describe the percutaneous transforaminal endoscopic ventral decompression technique
29.	Liu W, Li Q, et al[4]	2019	Clinical efficacy of percutaneous transforaminal endoscopic discectomy in treating adolescent lumbar disc herniation.	*Medicine (Baltimore)* 2019;98:e14682.	Retrospective study of 43 adolescent patients diagnosed with single-segment LDH treated with transforaminal PELD
30.	Liu X, Yuan S, et al[111]	2018	Comparison of percutaneous endoscopic transforaminal discectomy, microendoscopic discectomy, and microdiscectomy for symptomatic lumbar disc herniation: minimum 2 year follow-up results.	*J Neurosurg Spine* 2018;28:317–25.	Retrospective study of 192 LDH patients at L3-L4 and L4-L5 divided into PELD (60 patients), MED (63 patients), and microdiscectomy (69 patients)

Table 1. Continued.

#	Authors	Year	Title	Reference	Study Highlights
31.	Liu Y, Cai P, et al[148]	2017	Effectiveness of percutaneous endoscopic spine surgery for treatment of lumbar spine disorders with intraspinal ossification.	*Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi* 2017;31:1326–33.	Retrospective study of 96 patients with LDH and LSS with intraspinal ossification were treated with PELD
32.	Madhavan K, Chieng LO, et al[149]	2016	Early experience with endoscopic foraminotomy in patients with moderate degenerative deformity.	*Neurosurg Focus* 2016;40:E6.	Retrospective study of retrospective analysis of 16 patients with coronal deformity of between 10° and 20° treated with PELD
33.	Pan Z, Ha Y, et al[42]	2016	Efficacy of transforaminal endoscopic spine system (TESSYS) technique in treating lumbar disc herniation.	*Med Sci Monit* 2016;22:530–9.	Retrospective study efficacy and safety study in 109 patients treated with percutaneous TESSYS and traditional fenestration discectomy
34.	Sang PM, Zhang M, et al[150]	2018	Treatment of migrated lumbar disc herniation with percutaneous endoscopic lumbar discectomy and target foraminoplasty.	*Zhongguo Gu Shang* 2018;31:302–5.	Retrospective study of 25 patients with migrated LDH were treated with PELD with target foraminoplasty
35.	Shi C, Kong W, et al[9]	2018	The early clinical outcomes of a percutaneous full-endoscopic interlaminar approach via a surrounding nerve root discectomy operative route for the treatment of ventral-type lumbar disc herniation.	*Biomed Res Int* 2018;2018:9157089.	Retrospective study of 22 patients undergoing full-endoscopic interlaminar discectomy for ventral LDH via both the shoulder and the axilla of the corresponding nerve root
36.	Shin SH, Bae JS, et al[151]	2018	Transforaminal endoscopic decompression for lumbar spinal stenosis: a novel surgical technique and clinical outcomes.	*World Neurosurg* 2018;114:e873-e82.	Retrospective study of 30 consecutive cases LCS treated with transforaminal endoscopic decompression
37.	Sun Y, Zhang W, et al[38]	2017	Comprehensive comparing percutaneous endoscopic lumbar discectomy with posterior lumbar internal fixation for treatment of adjacent segment lumbar disc prolapse with stable retrolisthesis: a retrospective case-control study.	*Medicine (Baltimore)* 2017;96:e7471.	Retrospective comparison study PELD (11 patients) and PLIF (13 patients) for treatment of adjacent segment lumbar disc prolapse with stable retrolisthesis after a previous fusion
38.	Tang S, Jin S, et al[25]	2018	Transforaminal percutaneous endoscopic lumbar decompression by using rigid bendable burr for lumbar lateral recess stenosis: technique and clinical outcome.	*Biomed Res Int* 2018;2018:2601232.	Retrospective comparative study PELD open decompression in LSS in 48 consecutive patients
39.	Tao, X. Z., Jing, L, et al[20]	2018	Therapeutic effect of transforaminal endoscopic spine system in the treatment of prolapse of lumbar intervertebral disc.	*Eur Rev Med Pharmacol Sci*. 2018 Jul;22(1 Suppl):103–110.	Randomized prospective trial of 462 LDH patients treated with PELD ($n = 231$) and open decompression in the control group ($n = 231$)
40.	Wang H, Zhou Y, et al[18]	2015	Risk factors for failure of single-level percutaneous endoscopic lumbar discectomy.	*J Neurosurg Spine* 2015;23:320–5.	Retrospective study to identify risk factors for failure of PELD for single-level LDH in 350 patients who underwent PELD
41.	Wang J, Zhou Y, et al[152]	2009	Percutaneous endoscopic lumbar discectomy for treatment of chronic discogenic low back pain.	*Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi* 2009;23:400–3.	Retrospective study of 52 PELD patients with discogenic chronic low back pain
42.	Wang SJ, Chen BH, et al[23]	2017	The effect of percutaneous endoscopic lumbar discectomy under different anesthesia on pain and immunity of patients with prolapse of lumbar intervertebral disc.	*Eur Rev Med Pharmacol Sci* 2017;21:2793–9.	Restrospective study of 82 PELD patients under different anesthesia on pain and immunity of patients with lumbar disc herniation
43.	Wang Y, Yan Y, et al[153]	2019	Outcomes of percutaneous endoscopic transarticular discectomy for huge central or paracentral lumbar disc herniation.	*Int Orthop* 2019;43:939–45.	Retrospective study on 16 patients undergoing percutaneous endoscopic transarticular discectomy for huge central/paracentral LDH
44.	Wen B, Zhang X, et al[43]	2016	Percutaneous endoscopic transforaminal lumbar spinal canal decompression for lumbar spinal stenosis.	*Medicine (Baltimore)* 2016;95:e5186.	Retrospective study of 64 patients with lumbar spinal stenosis who underwent percutaneous endoscopic lumbar spinal canal decompression
45.	Wu GN, Zhang SM, et al[154]	2017	Percataneous endoscopic lumbar discectomy for the treatment of lumbar intervertebral disc protrusion.	*Zhongguo Gu Shang* 2017;30:861–5.	Retrospective study of 46 PELD patients treated for LDH.
46.	Xin Z, Huang P, et al[51]	2019	Using a percutaneous spinal endoscopy unilateral posterior interlaminar approach to perform bilateral decompression for patients with lumbar lateral recess stenosis.	*Asian J Surg* 2019.	Retrospective study of 47 patients with bilateral symptomatic LCS treated with percutaneous spinal endoscopy via a unilateral posterior interlaminar approach with bilateral decompression

Table 1. Continued.

#	Authors	Year	Title	Reference	Study Highlights
47.	Xiong C, Li T, et al[116]	2009	Early outcomes of 270 degree spinal canal decompression by using TESSYS-ISEE technique in patients with lumbar spinal stenosis combined with disk herniation.	*Eur Spine J* 2019;28:78–86.	Retrospective study of 32 patients with LSS due to LDH with newly developed minimal invasive TESSYS-ISEE technique
48.	Xu B, Xu H, et al[11]	2017	Anatomic investigation of lumbar transforaminal fenestration approach and its clinical application in far lateral disc herniation.	*Medicine (Baltimore)* 2017;96:e7542.	Retrospective study of 30 patients with LDH underwent MED via the transforaminal fenestration approach
49.	Xu Z, Liu Y, et al[28]	2018	Percutaneous ndoscopic interlaminar discectomy for L5-S1 adolescent lumbar disc herniation.	*Turk Neurosurg* 2018;28:923–8.	Retrospective study of 23 adolescent patients who underwent percutaneous endoscopic interlaminar discectomy for L5-S1 LDH
50.	Yang D, Wu X, et al[155]	2018	A modified percutaneous endoscopic technique to remove extraforaminal disk herniation at the L5-S1 segment.	*World Neurosurg* 2018;119:e671-e8.	Retrospective study of 100 extraforaminal LDH patients. The geometric parameters of the transverse process, facet joint, and sacrum space based on imaging examination were measured
51.	Yang JC, Hai Y, et al[156]	2018	Percutaneous endoscopic transforaminal lumbar interbody fusion for lumbar spinal stenosis.	*Zhonghua Yi Xue Za Zhi* 2018;98:3711–5.	Retrospective study of percutaneous endoscopic transforaminal lumbar interbody fusion in 7 patients with L4-L5 single-segment lumbar spinal stenosis
52.	Ying J, Huang K, et al[40]	2016	The effect and feasibility study of transforaminal percutaneous endoscopic lumbar discectomy via superior border of inferior pedicle approach for down-migrated intracanal disc herniations.	*Medicine (Baltimore)* 2016;95:e2899.	Retrospective study of 45 PELD patients with down-migrated single-level LDH treated with upper border of inferior pedicle, foraminoplasty, or common transforaminal route
53.	Zhang J, Jin MR, et al[185]	2019	Clinical application of percutaneous transforaminal endoscope-assisted lumbar interbody fusion.	*Zhongguo Gu Shang* 2019;32:1138–43.	Retrospective safety and efficacy study on 25 patients percutaneous transforaminal endoscope-assisted lumbar interbody fusion

Abbreviations: HNP, Herniated Nucleus Pulposus; ISEE, Interlaminar Endoscopy; LCS, lateral canal stenosis; LDH, lumbar disc herniation; LSS, lumbar spinal stenosis; MED, minimally endoscopic discectomy; PELD, percutaneous endoscopic lumbar discectomy; TESSYS, transforaminal endoscopic spine system; YESS, Yeung endoscopic spine system.

(Table 4). Another question of interest to the authors was the impact of long-term vs short-term follow-up on the overall ES for the 3 clinical outcome instruments measuring benefit from the lumbar endoscopic spine surgery for indications investigated (Table 5). The highest overall ES numbers were calculated at 2-year follow-up for VAS leg (ES = 0.94; $P < 0.0001$; based on total 17,295 patient samples) and VAS back (ES = 0.9; $P < 0.0001$; based on total of 8002 patient samples pooled from 55 studies) at a statistically significant level. The overall ES based on the extracted ODI means from a total of 17,543 patients pooled from 108 study entries at 2-year follow-up and longer was ES = 0.92 without statistical significance ($P = 0.678$; Table 5).

Using the type of decompression as a modifier in calculating the overall ES in endoscopic spinal decompression surgeries allowed to compare postoperative improvements in ODI, VAS back, and VAS leg to those achieved with other types of decompression surgeries as they were used in multiarm comparison studies (Table 6). Spinal endoscopy produced an overall ODI ES of 0.92 extrapolated from 81 studies totaling 12,710 patient samples. Tubular retractor microdiscectomy produced smaller ODI ES (ES = 0.9; 2895 patient samples pooled from 16 studies) than open laminectomy (ES = 0.93; 1188 patient samples from 5 studies). The highest ODI ES was observed with endoscopically assisted minimally invasive fusions with percutaneous posterior supplemental pedicle screw instrumentation (ES = 0.95; 166 patient samples pooled from 4 studies; Table 4). Similar, VAS leg ESs were observed with endoscopy (ES = 0.92; 12,631 patient samples pooled from 80 studies) with spinal endoscopy, with small and statistically insignificant ($P = 0.592$) ES difference to the other MISST procedures listed in Table 6. The VAS back ESs were smaller without any statistically significant difference between spinal endoscopy and the other various MISSTs that were evaluated in the individual multitreatment arm comparison studies ($P = 0.4167$; 8002 patient samples from 55 studies; Table 6). The postoperative benefit overlap is graphically illustrated in Figure 2. The largest overall ES with the smallest SE was observed with laminectomy, tubular retractor microdiscectomy, and with endoscopically assisted MISST fusion and standalone endoscopic fusion surgery ($P = 0.022$). There was a wider scatter between

Table 2. List of long-term (>2-year follow-up) lumbar stenosis decompression studies included into the effect size meta-analysis comparing endoscopic to other translaminar decompression surgeries with brief summary of study highlights.

#	Authors	Year	Title	Reference	Study Highlights
1.	Ahn Y, Keum HJ, et al[157]	2019	Transforaminal endoscopic decompression for lumbar lateral recess stenosis: an advanced surgical technique and clinical outcomes.	*World Neurosurg* 2019;125:e916-e24.	Retrospective study of 45 consecutive patients who underwent transforaminal endoscopic decompression for LCS.
2.	Ahn Y, Lee HY, et al[158]	2011	Dural tears in percutaneous endoscopic lumbar discectomy.	*Eur Spine J* 2011;20:58–64.	Retrospective study of 816 consecutive PELD patients to assess frequency of dural tears.
3.	Ahn Y, Lee SG, et al[75]	2009	Transforaminal endoscopic lumbar discectomy vs open lumbar microdiscectomy: a comparative cohort study with a 5 year follow-up.	*Pain Physician* 2019;22:295–304.	Prospective study of 335 LDH patients treated with PELD or open lumbar microdiscectomy.
4.	Ahn Y, Lee U, et al[71]	2018	Five-year outcomes and predictive factors of transforaminal full-endoscopic lumbar discectomy.	*Medicine (Baltimore)* 2018;97:e13454.	Retrospective 5-y outcomes study of 204 transforaminal PELD patients to determine the factors predicting favorable outcome.
5.	Bai YB, Xu L, et al[159]	2012	Diagnosis and treatment of lumbar disc herniation by discography and percutaneous transforaminal endoscopic surgery.	*Zhonghua Yi Xue Za* Zhi 2012;92:3350–3.	Retrospective study of 119 patients with lumbar disc herniation who underwent discography and transforaminal endoscopic surgery under local anesthesia.
6.	Casal-Moro R, Castro-Menendez M, et al[160]	2011	Long-term outcome after microendoscopic diskectomy for lumbar disk herniation: a prospective clinical study with a 5 year follow-up.	*Neurosurgery* 2011;68:1568–75; discussion 75.	Prospective study of 120 LDH patients treated with MED using an 18-mm METRx tubular retractor.
7.	Choi G, Lee SH, et al[161]	2007	Percutaneous endoscopic discectomy for extraforaminal lumbar disc herniations: extraforaminal targeted fragmentectomy technique using working channel endoscope.	*Spine (Phila Pa 1976)* 2007;32:E93-9.	Retrospective analysis of 41 patients with soft lumbar extraforaminal disc herniation treated with PELD.
8.	Choi G, Modi HN, et al[162]	2013	Clinical results of XMR-assisted percutaneous transforaminal endoscopic lumbar discectomy.	*J Orthop Surg Res* 2013;8:14.	Prospective study of 89 LDH patients who had undergone PELD.
9.	Choi KC, Kim JS, et al[163]	2016	Percutaneous endoscopic lumbar discectomy as an alternative to open lumbar microdiscectomy for large lumbar disc herniation.	*Pain Physician* 2016;19:E291-300.	Retrospective study of 30 consecutive patients treated with transforaminal and interlaminar PELD for L5- S1 disc herniation.
10.	Choi KC, Park CK[76]	2016	Percutaneous endoscopic lumbar discectomy for L5-S1 disc herniation: consideration of the relation between the Iliac crest and L5-S1 disc.	*Pain Physician* 2016;19:E301-8.	Retrospective study of 100 consecutive L5-S1 PELD patients with and without foraminoplasty.
11.	Chung J, Kong C, et al[164]	2019	Percutaneous endoscopic lumbar foraminoplasty for lumbar foraminal stenosis of elderly patients with unilateral radiculopathy: radiographic changes in magnetic resonance images.	*J Neurol Surg A Cent Eur Neurosurg* 2019;80:302–11.	Retrospective study of 24 patients aged >65 y underwent PELD to treat unilateral radiculopathy caused by LCS.
12.	Dey PC, Nanda SN[60]	2019	Functional outcome after endoscopic lumbar discectomy by Destandau's technique: a prospective study of 614 patients.	*Asian Spine J* 2019;13:786–92.	Prospective study of 614 LDH patients treated with PELD.
13.	Eun SS, Lee SH, et al[165]	2018	Transforaminal percutaneous endoscopic lumbar diskectomy for down-migrated disk herniations: lever-up, rotate, and tilt technique.	*J Neurol Surg A Cent Eur Neurosurg* 2018;79:163–8.	Retrospective review of 18 LDH patients who underwent PELD.
14.	Gibson JNA, Subramanian AS, et al[166]	2017	A randomised controlled trial of transforaminal endoscopic discectomy vs microdiscectomy.	*Eur Spine J* 2017;26:847–56.	Randomized prospective study of 143 single-level LDH patients: 70 received TED under conscious sedation and 70 MED under general anesthesia.
15.	Hong X, Shi R, et al[167]	2018	Lumbar disc herniation treated by microendoscopic discectomy: prognostic predictors of long-term postoperative outcome.	*Orthopade* 2018;47:993–1002.	Retrospective study of 664 LDH patients who suffered from sciatica and underwent primary MED.
16.	Kim JE, Choi DJ[55]	2018	Clinical and radiological outcomes of unilateral biportal endoscopic decompression by 30 degrees arthroscopy in lumbar spinal stenosis: minimum 2 year follow-up.	*Clin Orthop Surg* 2018;10:328–36.	Retrospective study of 55 LSS patients treated with PELD.
17.	Kim JE, Choi DJ[67]	2018	Unilateral biportal endoscopic decompression by 30 degrees endoscopy in lumbar spinal stenosis: technical note and preliminary report.	*J Orthop* 2018;15:366–71.	Retrospective study of 105 patients receiving 30° endoscopy through biportals or triportals.
18.	Komp M, Hahn P, et al[97]	2015	Bilateral spinal decompression of lumbar central stenosis with the full-endoscopic interlaminar vs microsurgical laminotomy technique: a prospective, randomized, controlled study	*Pain Physician*. 2015 Jan-Feb;18(1):61–70.	Randomized prospective study of 135 patients comparing FEID with a conventional microsurgical laminotomy technique.
19.	Kong W, Chen T, et al[41]	2019	Treatment of L5-S1 intervertebral disc herniation with posterior percutaneous full-endoscopic discectomy by grafting tubes at various positions via an interlaminar approach.	*BMC Surg* 2019;19:124.	Retrospective study on 98 patients with L5-S1 LDH were treated with PELD.
20.	Lee SH, Kang HS, et al[168]	2010	Foraminoplastic ventral epidural approach for removal of extruded herniated fragment at the L5-S1 level.	*Neurol Med Chir (Tokyo)* 2010;50:1074–8.	Retrospective review was performed of 25 consecutive LDH patients treated with PELD with foraminoplasty.
21.	Lewandrowski KU, Ostergren M, et al[169]	2018	Intradiscal expandable balloon distraction during transforaminal decompression for lumbar foraminal and lateral recess stenosis.	*Surg Innov* 2018;25:165–73.	Retrospective study of 52 patients with symptomatic LCS treated with PELD.
22.	Li H, Jiang C, et al[52]	2018	Comparison of MED and PELD in the treatment of adolescent lumbar disc herniation: a 5 year retrospective follow-up.	*World Neurosurg* 2018;112:e255-e60.	Retrospective efficacy and safety study MED and PELD in the treatment of 30 ALDH patients.
23.	Li ZZ, Hou SX, et al[30]	2017	Modified percutaneous lumbar foraminoplasty and percutaneous endoscopic lumbar discectomy: instrument design, technique notes, and 5 years follow-up.	*Pain Physician* 2017;20:E85-E98.	Prospective cohort study of 148 patients with uncontained LDH was treated with modified percutaneous lumbar foraminoplasty PELD.
24.	Lubbers, T. Abuamona, R., et al[170]	2012	Percutaneous endoscopic treatment of foraminal and extraforaminal disc herniation at the L5-S1 level.	*Acta Neurochir (Wien)*. 2012 Oct;154(10):1789–95.	Prospective study of 22 PELD patients with lateral and far lateral LDH at the L5-S1.
25.	Pan F, Shen B, et al[49]	2016	Transforaminal endoscopic system technique for discogenic low back pain: a prospective cohort study.	*Int J Surg* 2016;35:134–8.	Retrospective study 77 consecutive patients treated with PELD for discogenic low back pain.
26.	Shawky Abdelgawaad A, Babic D, et al[171]	2018	Extraforaminal microscopic-assisted percutaneous nucleotomy for foraminal and extraforaminal lumbar disc herniations.	*Spine J* 2018;18:620–5.	Prospective cohort study of 76 patients with foraminal or extraforaminal LDH treated with tubular percutaneous extraforaminal microscopic-assisted nucleotomy.
27.	Soliman HM[172]	2013	Irrigation endoscopic discectomy: a novel percutaneous approach for lumbar disc prolapse.	*Eur Spine J* 2013;22:1037–44.	Prospective of 43 patients with uncontained LDH underwent surgery biportal with irrigation endoscopic discectomy.

Table 2. Continued.

#	Authors	Year	Title	Reference	Study Highlights
28.	Song H, Hu W, et al[46]	2017	Percutaneous endoscopic interlaminar discectomy of L5-S1 disc herniation: a comparison between intermittent endoscopy technique and full endoscopy technique.	*J Orthop Surg Res* 2017;12:162.	Retrospective study of 126 patients intermittent endoscopy technique and full endoscopy technique of endoscopic interlaminar lumbar discectomy at the L5-S1.
29.	Teli M, Lovi A, et al[173]	2010	Higher risk of dural tears and recurrent herniation with lumbar microendoscopic discectomy.	*Eur Spine J* 2010;19:443–50.	Randomized controlled trial of 240 patients was randomized to microendoscopic (group 1), micro (group 2) or open (group 3) discectomy with minimum 2-y follow-up.
30.	Tu Z, Wang B, et al[53]	2018	Early experience of full-endoscopic interlaminar discectomy for adolescent lumbar disc herniation with sciatic scoliosis.	*Pain Physician* 2018;21:E63-E70.	Retrospective case series of patients aged < 20 y with single-level ALDH with and without scoliosis treated with FEID; average follow-up 39.0 mo.
31.	Wang Y, Zhang W, et al[10]	2018	Transforaminal endoscopic discectomy for treatment of central disc herniation: surgical techniques and clinical outcome.	*Pain Physician* 2018;21:E113-E23.	Retrospective 2-y follow-up study of 69 consecutive patients treated with transforaminal PELD central disc herniation.
32.	Wang YP, Zhang W, et al[33]	2016	Suprapedicular foraminal endoscopic approach to lumbar lateral recess decompression surgery to treat degenerative lumbar spinal stenosis.	*Med Sci Monit* 2016;22:4604–11.	Retrospective study of 52 patients with lumbar spinal stenosis underwent transforaminal endoscopic surgery.
33.	Xu B, Xu H, et al[174]	2018	Bilateral decompression and intervertebral fusion via unilateral fenestration for complex lumbar spinal stenosis with a mobile microendoscopic technique.	*Medicine (Baltimore)* 2018;97:e9715.	Retrospective study on 61 patients with complex lumbar spinal stenosis (lumbar canal stenosis combined with degenerative spondylolisthesis, instability, and scoliosis) treated with Destandau-type mobile microendoscopic discectomy
34.	Youn MS, Shin JK, et al[64]	2018	Endoscopic posterior decompression under local anesthesia for degenerative lumbar spinal stenosis.	*J Neurosurg Spine* 2018;29:661–6.	Retrospective study of 50 patients (28 women and 22 men) treated for LDH with endoscopic posterior decompression under local anesthesia followed up to 24 mo postoperatively.
35.	Zhang B, Kong Q, et al[175]	2019	Short-term effectiveness of percutaneous endoscopic transforaminal bilateral decompression for severe central lumbar spinal stenosis.	*Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi* 2019;33:1399–405.	Retrospective study on effectiveness and safety of bilateral transforaminal bilateral PELD decompression for severe central lumbar spinal stenosis in 44 patients.
36.	Zhang Y, Chong F, et al[17]	2019	Comparison of endoscope-assisted and microscope-assisted tubular surgery for lumbar laminectomies and discectomies: minimum 2 year follow-up results.	*Biomed Res Int* 2019;2019:5321580.	Retrospective study of 307 withLumbar spinal stenosis or LDH treated with endoscope- or microscope-assisted tubular laminectomy or discectomy.

Abbreviations: ALDH, adolescent lumbar disc herniation; FEID, full-endoscopic interlaminar discectomy; LCS, lateral canal stenosis; LDH, lumbar disc herniation; LSS, lumbar spinal stenosis; MED, minimally endoscopic discectomy; METRx, minimal exposure tubular retractor; PELD, percutaneous endoscopic lumbar discectomy; TED, transforaminal endoscopic discectomy.

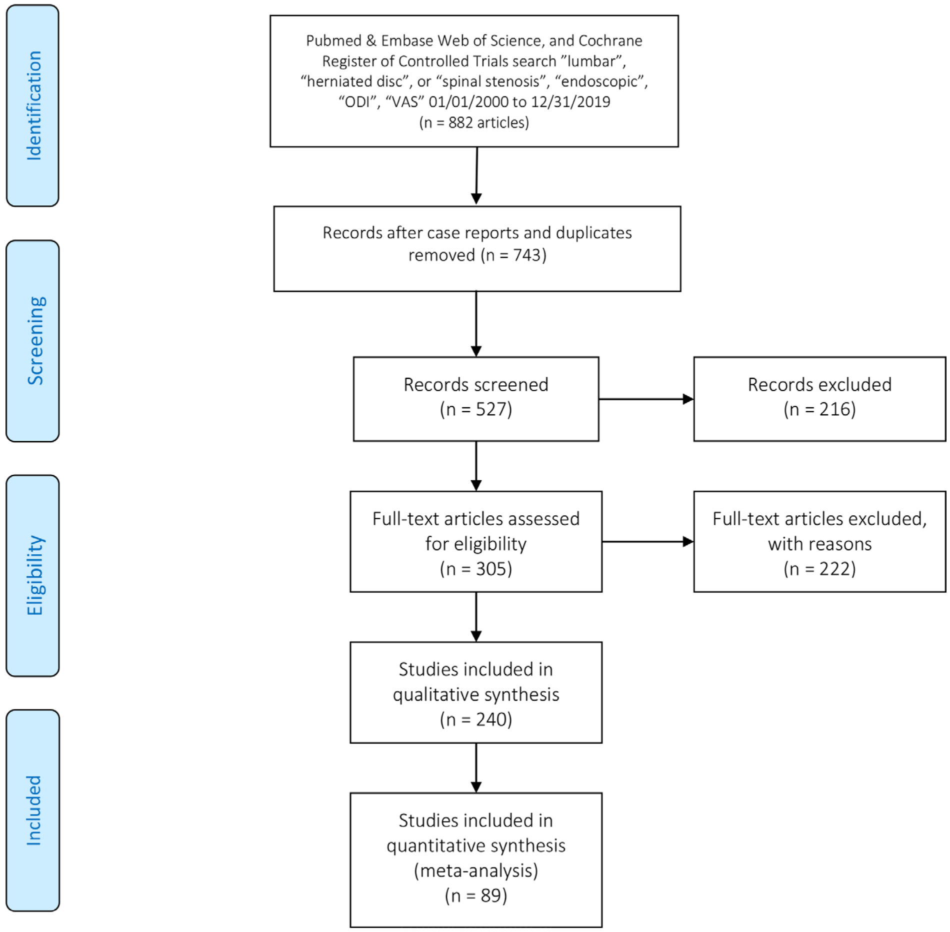

Figure 1. Preferred reporting items for systematic reviews and meta-analyses flow chart of selected lumbar spinal stenosis studies found in PubMed, Embase, Web of Science, and in the Cochrane Central Register of Controlled Trials using the keywords "lumbar" and "herniated disc" or "spinal stenosis" and "endoscopic" and "ODI" and "VAS" as subject headings analyzed to compare effect sizes of endoscopic to traditional translaminar decompression with and without fusion. ODI, Oswestry Disability Index; VAS, visual analog scale.

SE and ES combinations with spinal endoscopy as a whole likely graphically representing variations in surgeon skill level, indication for surgery, and patient selection criteria (Figure 2).

The ES comparison using the type of endoscopy as a modifier in the meta-analysis on 13,184 patient samples pooled from 81 studies showed statistically significant differences ($P < 0.0001$) between transforaminal

Table 3. Analysis of effect size, heterogeneity, and ANOVA testing of difference by study type.

	Study Design	Number of Studies Included in this Analysis	Effect Size	Lower Limit	Upper Limit	Higgins I^2 Statistic of Heterogeneity	Variance	Standard Error	Number of Patients
Oswestry Disability Index	Prospective study	6	0.9217	0.8644	0.9789	0.0000	0.0009	0.0292	2106
	Randomized prospective study	11	0.9100	0.8398	0.9802	0.0000	0.0013	0.0358	1891
	Retrospective study	83	0.9234	0.9095	0.9373	0.0000	0.0001	0.0071	12,464
	ANOVA Q test random effects with separate estimates of T^2					Sig = 0.925	Total patient samples		16,461
VAS back	Prospective study	3	0.5951	0.3093	0.8809	0.0000	0.0213	0.1458	534
	Randomized prospective study	39	0.8009	0.7412	0.8606	0.0000	0.0009	0.0305	6056
	Retrospective study	5	0.8059	0.7236	0.8882	0.0000	0.0018	0.0420	670
	ANOVA Q test random effects with separate estimates of T^2					Sig = 0.204	Total patient samples		7260
VAS leg	Prospective study	7	0.9318	0.8774	0.9862	0.0000	0.0008	0.0278	2258
	Randomized prospective study	7	0.8834	0.8066	0.9603	0.0000	0.0015	0.0392	1594
	Retrospective study	82	0.9134	0.8980	0.9288	0.0000	0.0001	0.0079	11,701
	ANOVA Q test random effects with separate estimates of T^2					Sig = 0.575	Total patient samples		15,553

Abbreviations: ANOVA, analysis of variance; Sig, significance level of 95% CI; VAS, visual analog scale.

Table 4. Analysis of effect size, heterogeneity, and ANOVA testing of difference by surgery indication.

	Indication for Surgery	Number of Studies Included in This Analysis	Effect Size	Lower Limit	Upper Limit	Higgins I^2 Statistic of Heterogeneity	Variance	Standard Error	Number of Patients
Oswestry Disability Index	Discogenic pain	2	0.9112	0.8866	0.9359	0.0000	0.0002	0.0126	216
	HNP radiculopathy	22	0.9179	0.8888	0.9471	0.0000	0.0002	0.0149	3520
	Stenosis claudication	14	0.9531	0.9290	0.9772	0.0000	0.0002	0.0123	1638
	ANOVA Q test random effects with separate estimates of T^2					Sig = 0.094	Total patient samples		5374
VAS back	Stenosis claudication	5	0.8745	0.7792	0.9698	0.0000	0.0024	0.0486	388
	HNP radiculopathy	10	0.7086	0.5522	0.8650	0.0000	0.0064	0.0798	1108
	ANOVA Q test random effects with separate estimates of T^2					Sig = 0.074	Total patient samples		1496
VAS leg	Stenosis claudication	13	0.9113	0.8673	0.9553	0.0000	0.0005	0.0225	1024
	HNP radiculopathy	23	0.8942	0.8612	0.9273	0.0000	0.0003	0.0169	3667
	Discogenic pain	3	0.8828	0.8204	0.9452	0.0000	0.0010	0.0318	320
	ANOVA Q test random effects with separate estimates of T^2					Sig = 0.74	Total patient samples		5011

Abbreviations: ANOVA, analysis of variance; HNP, herniated nucleus pulposus; Sig, significance level of 95% CI; VAS, visual analog scale.

outside-in (ODI ES = 0. 9), transforaminal inside-out (ODI ES = 0.9), interlaminar (ODI ES = 0.96), and the combination of the transforaminal outside-in and interlaminar (ODI ES = 0.98), and UBE (ODI ES = 0.93; Table 7). Similar ES differences were calculated for the VAS leg on a total of 13,105 patients pooled from 85 studies at statistical significance level ($P < 0.00001$) comparing outcomes between transforaminal outside-in (VAS leg ES = 0.91), transforaminal inside-out (VAS leg ES = 0.89), interlaminar (VAS leg ES = 0.93), and the combination of the transforaminal outside-in and interlaminar (VAS leg ES = 0.97), and UBE (VAS leg ES = 0.93; Table 7). Such differences were not statistically significant for the VAS back outcome means obtained on a total of 5134 patients pooled from 37 studies (Table 7). The statistically significant postoperative benefit overlap is graphically illustrated in Figure 3 ($P = 0.001$). The largest ESs with the smallest SEs were observed with the combined outside-in and interlaminar technique, the transforaminal inside-out, and UBE technique. The widest scatter was seen with the transforaminal outside-in technique.

Forest Plot Analysis of Long-Term Studies

Since the ES analysis suggested a significant difference when studied by follow-up, the authors performed a visual forest plot analysis of the ESs for the extracted means of ODI, VAS back, and VAS leg. There were 46 long-term study entries which reported ODI with a minimum of 2 years or longer. The overall ES for ODI was 0.92 with an LL of 0.9, and a UL of 0.94 calculated from the total of 9420 patient samples (Figure 4). In comparison, there were 26 studies which reported VAS back with a minimum of 2 years or longer follow-up. The overall ES for VAS back was 0.71 with an LL of 0.61, and a UL of 0.81 calculated from the total of 4926 patient samples (Figure 5). Another 44 studies reported VAS leg with a minimum of 2 years or longer follow-up. The overall ES for VAS leg was 0.71 with a lower 95% CI limit of 0.61 and a UL of 0.81 calculated from the total of 4926 patient samples (Figure 6).

Individual Studies Results and MCID

The meta-analysis on the 36 long-term studies showed the following mean preoperative baseline

Table 5. Analysis of effect size, heterogeneity, and ANOVA testing of difference by length of follow-up.

	Length of Follow-Up	Number of Studies Included in This Analysis	Effect Size	Lower Limit	Upper Limit	Higgins I^2 Statistic of Heterogeneity	Variance	Standard Error	Number of Patients
Oswestry Disability Index	More than 2 y	45	0.9243	0.9044	0.9442	0.0000	0.0001	0.0101	9304
	Up to 2 y	46	0.9240	0.8996	0.9484	0.0000	0.0002	0.0125	5283
	Up to 12 mo	15	0.9074	0.8775	0.9372	0.0000	0.0002	0.0152	2664
	Up to 6 mo	2	0.9104	0.8862	0.9345	0.0000	0.0002	0.0123	292
	ANOVA Q test random effects with separate estimates of T^2					Sig = 0.678	Total patient samples		17,543
VAS back	More than 2 y	25	0.7075	0.6043	0.8106	0.0000	0.0028	0.0526	4948
	Up to 2 y	21	0.9023	0.8723	0.9323	0.0000	0.0002	0.0153	1978
	Up to 12 mo	6	0.7007	0.5910	0.8104	0.0000	0.0031	0.0560	872
	ANOVA Q est random effects with separate estimates of T^2					Sig <0.0001	Total patient samples		7798
VAS leg	More than 2 y	43	0.8920	0.8651	0.9190	0.0000	0.0002	0.0138	8690
	Up to 2 y	46	0.9441	0.9299	0.9582	0.0000	0.0001	0.0072	5237
	Up to 12 mo	16	0.8915	0.8465	0.9365	0.0000	0.0005	0.0230	2768
	Up to 6 mo	2	0.8366	0.8088	0.8643	0.0000	0.0002	0.0142	292
	ANOVA Q test random effects with separate estimates of T^2					Sig <0.0001	Total patient samples		16,987

Abbreviations: ANOVA, analysis of variance; Sig, significance level of 95% CI; VAS, visual analog scale.

Table 6. Analysis of effect size, heterogeneity, and ANOVA testing of difference by surgery type.

	Type of Surgery	Number of Studies Included in This Analysis	Effect Size	Lower Limit	Upper Limit	Higgins I^2 Statistic of Heterogeneity	Variance	Standard Error	Number of Patients
Oswestry Disability Index	Endoscopic-assisted MIS fusion	4	0.9496	0.9087	0.9905	0.0000	0.0004	0.0209	166
	Open laminectomy	5	0.9294	0.8793	0.9795	0.0000	0.0007	0.0255	1188
	Endoscopy	81	0.9178	0.9013	0.9343	0.0000	0.0001	0.0084	12,710
	Tubular microdiscectomy	16	0.8968	0.8543	0.9394	0.0000	0.0005	0.0217	2895
	Standalone endo fusion	1	0.8337	0.7336	0.8984	0.0000	0.0017	0.0410	36
	ANOVA Q test random effects with separate estimates of T^2				Sig = 0.049		Total patient samples		16,995
VAS back	Endoscopic-assisted MIS fusion	2	0.9325	0.8087	1.0563	0.0000	0.0040	0.0632	28
	Tubular microdiscectomy	11	0.8186	0.6960	0.9413	0.0000	0.0039	0.0626	1962
	Open laminectomy	4	0.7918	0.6583	0.9253	0.0000	0.0046	0.0681	726
	Endoscopy	34	0.7732	0.7122	0.8342	0.0000	0.0010	0.0311	5028
	Standalone endo fusion	1	0.7320	0.5740	0.8374	0.0000	0.0044	0.0662	36
	ANOVA Q test random effects with separate estimates of T^2				Sig = 0.607		Total patient samples		7780
VAS LEG	Endoscopic-assisted MIS fusion	4	0.9313	0.8945	0.9682	0.0000	0.0004	0.0188	166
	Tubular microdiscectomy	15	0.9172	0.8770	0.9574	0.0000	0.0004	0.0205	2348
	Endoscopy	80	0.9158	0.9002	0.9315	0.0000	0.0001	0.0080	12,631
	Open laminectomy	5	0.8929	0.7910	0.9949	0.0000	0.0027	0.0520	1188
	Standalone endo fusion	1	0.8796	0.8070	0.9261	0.0000	0.0009	0.0295	36
	ANOVA Q test random effects with separate estimates of T^2				Sig = 0.592		Total patient samples		16,369

Abbreviations: ANOVA, analysis of variance; MIS, minimally invasive surgery; Sig, significance level of 95% CI; VAS, visual analog scale.

numbers: ODI 59.34 (SD 12.67), VAS back 4.90 (SD 1.89), and VAS leg 7.22 (SD 1.90), respectively. The overall improvements after endoscopic surgery were: ODI reduction of 46.25 (SD 6.10), VAS back reduction of 3.29 (SD 0.65), and VAS leg reduction of 5.77 (SD 0.66), respectively. These ODI reductions are the equivalent of 3 times the MCID for endoscopy.[176] The VAS leg reduction was 2 times as high as the reported MCID,[176] and the VAS back reduction was on the order of the reported MCID.[83,177] The mean percent change of ODI, VAS back, and VAS leg at minimum 2-year follow-up or longer after the endoscopic decompression was 77.94% (SD 10.28%), 67.14% (SD 13.26%), and 79.71% (SD 9.14%), respectively.

DISCUSSION

The authors of this meta-analysis took a broad approach to extract ES data from original studies on the various types of minimally invasive spinal stenosis surgeries to afford the reader the ability to understand their clinical benefit concerning indication for

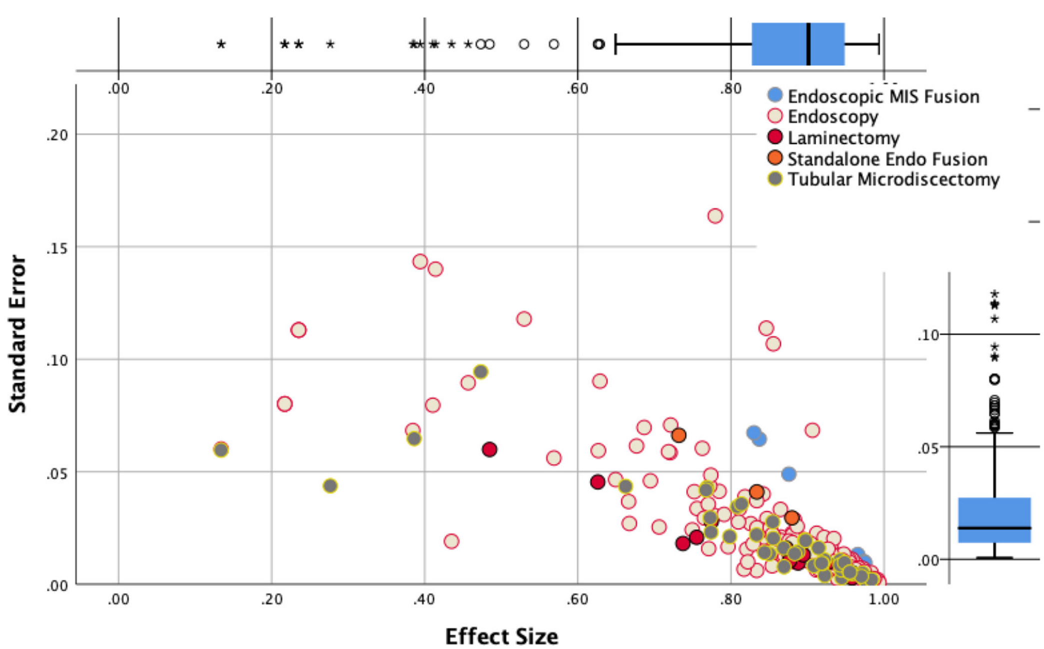

Figure 2. Meta-analysis regression plot of effect size (ES) vs standard error stratified for the type of decompression surgery using random effects model showed substantial overlap in the plotted relationship between these procedures and, hence, clinical benefit with all lumbar decompression methods some of which were with fusion including endoscopy with statistical significance in spite of the underlying risk of moderate publication bias: endoscopic-assisted minimally invasive surgery fusion - 3 studies, ES = 0.94, endoscopy - 84 studies, ES = 0.9, open laminectomy - 6 studies, ES = 0.89, and tubular microdiscectomy - 21 studies, ES = 0.89, $P = 0.022$.

Table 7. Analysis of effect size, heterogeneity, and ANOVA testing of difference by type of endoscopy.

	Type of Endoscopy	Number of Studies Included in This Analysis	Effect Size	Lower Limit	Upper Limit	Higgins I^2 Statistic of Heterogeneity	Variance	Standard Error	Number of Patients
Oswestry Disability Index	Combined outside-in and Interlaminar	1	0.9805	0.9749	0.9848	0.0000	0.0000	0.0025	124
	Interlaminar approach	20	0.9567	0.9403	0.9732	0.0000	0.0001	0.0084	2940
	Biportal UBE endoscopy	9	0.9299	0.8954	0.9645	0.0000	0.0003	0.0176	960
	Transforaminal outside-in	51	0.9044	0.8803	0.9285	0.0000	0.0002	0.0123	8198
	Transforaminal inside-out	5	0.8967	0.8468	0.9467	0.0000	0.0007	0.0255	962
	ANOVA Q test random effects with separate estimates of T^2				Sig < 0.0001		Total patient samples		13,184
VAS back	Biportal UBE endoscopy	4	0.8943	0.8470	0.9416	0.0000	0.0006	0.0241	336
	Interlaminar approach	10	0.8336	0.7687	0.8984	0.0000	0.0011	0.0331	794
	Transforaminal outside-in	22	0.7775	0.6964	0.8586	0.0000	0.0017	0.0414	3990
	Transforaminal inside-out	1	0.8300	0.6435	0.9235	3.9883	0.0045	0.0673	14
	ANOVA Q test random effects with separate estimates of T^2				Sig = 0.093		Total patient samples		5134
VAS leg	Combined outside-in and interlaminar	1	0.9660	0.9562	0.9736	0.0000	0.0000	0.0044	124
	Interlaminar approach	20	0.9331	0.9106	0.9556	0.0000	0.0001	0.0115	2914
	Biportal UBE endoscopy	10	0.9271	0.9008	0.9534	0.0000	0.0002	0.0134	1002
	Transforaminal outside-in	48	0.9112	0.8880	0.9345	0.0000	0.0001	0.0119	7954
	Transforaminal inside-out	6	0.8912	0.8544	0.9281	0.0000	0.0004	0.0188	1111
	ANOVA Q test random effects with separate estimates of T^2				Sig <0.00001		Total patient samples		13,105

Abbreviations: ANOVA, analysis of variance; Sig, significance level of 95% CI; UBE, uniportal biportal endoscopy; VAS, visual analog scale.

surgery and burden to the patient in an across-the-board normalized comparison. Highlighting differences in outcomes between endoscopic and other forms of minimally invasive (MISST) and traditional open spinal surgery techniques by reporting the ES has several advantages to reporting statistical significance in group comparison tests. The ES calculation emphasizes the size of the difference between the various treatment groups rather than confounding it with sample size.[178] Although the ES determination is straightforward—for example, it can be calculated by subtracting the means of the control group from the means of the experimental group and divide it by the SD— ES is rarely used in the discussion of clinical outcomes between various treatments.[179] However, it can be highly useful as a measure of overlap between the various lumbar stenosis surgeries. It is a form of data interpretation the authors employed in this study to illustrate the clinical benefit

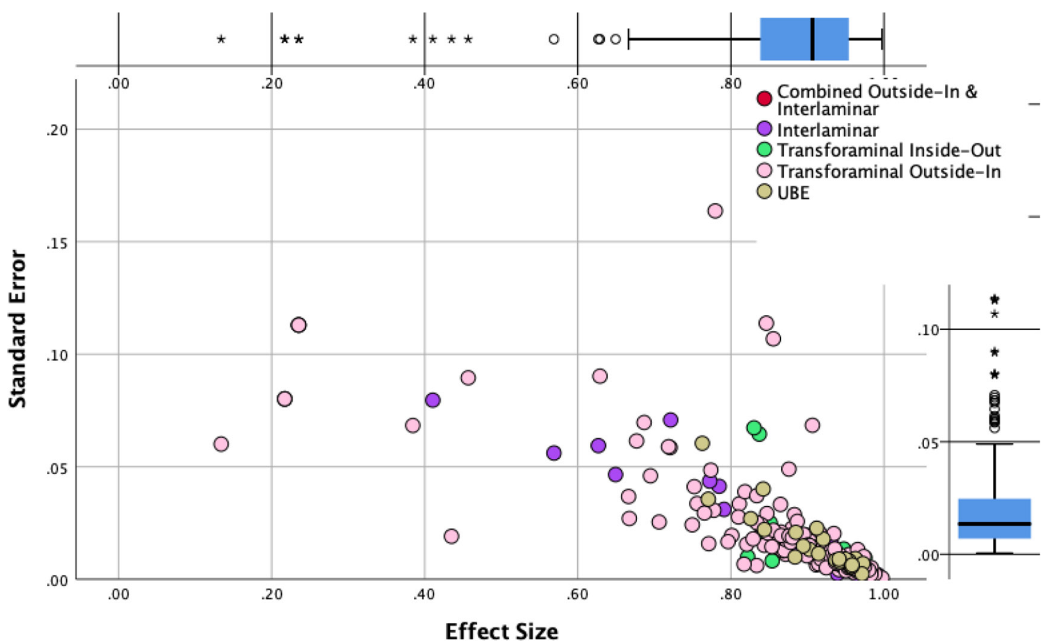

Figure 3. Meta-analysis area plot of effect size (ES) vs standard error using random effects model showed substantial overlap in the plotted relationship between these 2 variables and, hence, clinical benefit with all endoscopic lumbar decompression methods in spite of the underlying risk of moderate publication bias: transforaminal outside-in with combined interlaminar approach - 1 study, ES = 0.97, uniportal biportal endoscopy (UBE) - 6 studies, ES = 0.92, interlaminar approach - 23 studies, ES = 0.93, transforaminal inside-out approach - 2 studies, ES = 0.89, and transforaminal outside-in approach - 54 studies, ES = 0.89, with statistically significant ES differences between these procedures (P < 0.001).

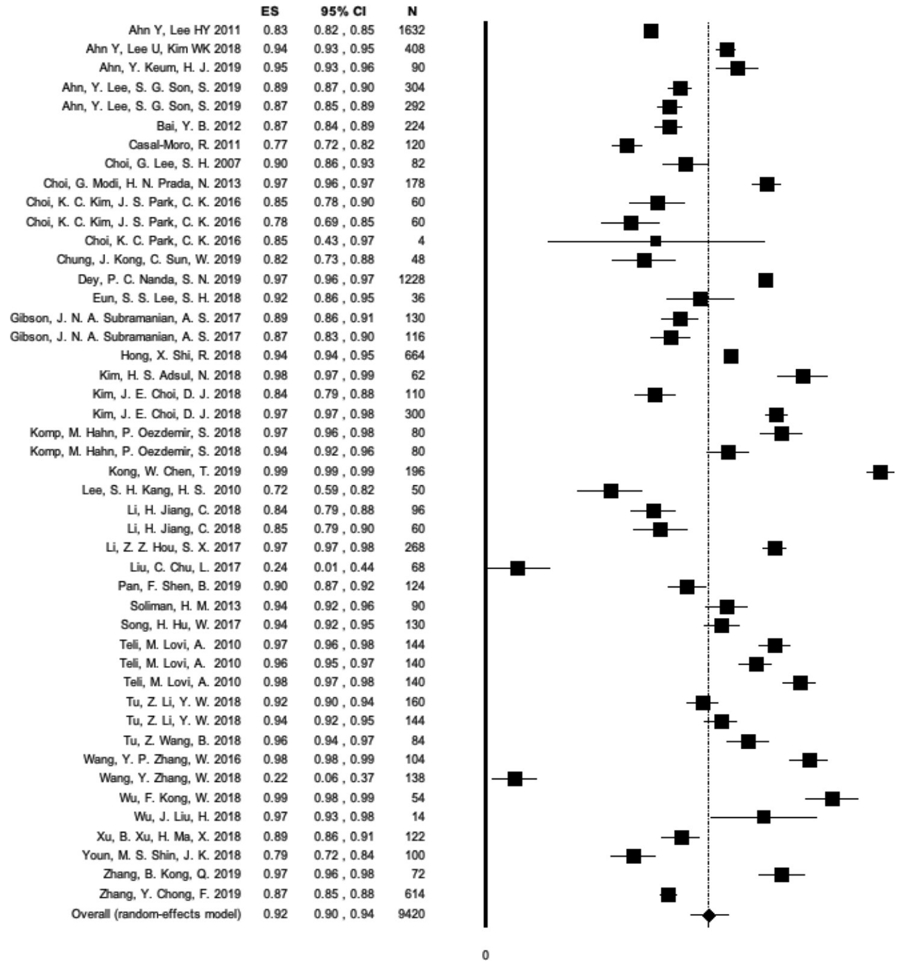

Figure 4. Forest plot of effect sizes (ESs), 95% CI, and the number of patients enrolled in each individual endoscopic spinal surgery study (*N*) calculated for the 46 study groups which reported Oswestry Disability Index with a minimum of 2 y or longer follow-up listed in alphabetical order according to the first author's name. The number of individual study patients is represented by the size of the symbol. The overall ES was 0.92 with a lower 95% CI limit of 0.9, and an upper limit of 0.94 calculated from the total of 9420 patient samples enrolled in these studies.

of the various open, minimally invasive, and endoscopic lumbar spinal stenosis surgeries to patients and all other stakeholders involved in the delivery of modern spine care.

We chose the meta-analysis approach to calculating the ESs since it overcomes the common problem of not knowing the SD in the population from which the different treatment groups came from by estimating it through pooling data from the treatment groups of various studies. The authors also expected, based on their collective clinical experience, substantial overlap in terms of clinical benefit of the different endoscopic surgeries. Ultimately, this overlap of clinical benefit was confirmed by the area plots of ES vs SE (Figures 2 and 3). The ES determination was employed by the authors to handle this well-known clinical situation best since this overlap could be conceptualized as the probability analysis by the surgeon to accurately choose the most effective of the various lumbar stenosis surgeries for each patient regardless of whether endoscopic, MISST, or traditional open surgery based on the type of painful pathoanatomy, the clinical context of the patient's relevant symptoms at the time when the spine care is delivered, and the surgeon's bias toward a preferred technique based on his or her training, experience, and skill level.[180] The impact of skill level was most likely apparent with the transforaminal outside-in technique where the widest spread of ES vs SE was seen (Figure 3). In other words, when attempting to compare clinical outcomes with the various endoscopic and other MISST techniques one is entering a gray zone where many confounding factors impacting clinical outcomes may play out but where identifying the best performing treatment for a certain clinical indication may still be possible at a high probability in spite of substantial overlap in clinical outcomes. While it is obvious that the reported ESs ranging from 0.71 to 0.97 derived from preoperative and postoperative disability

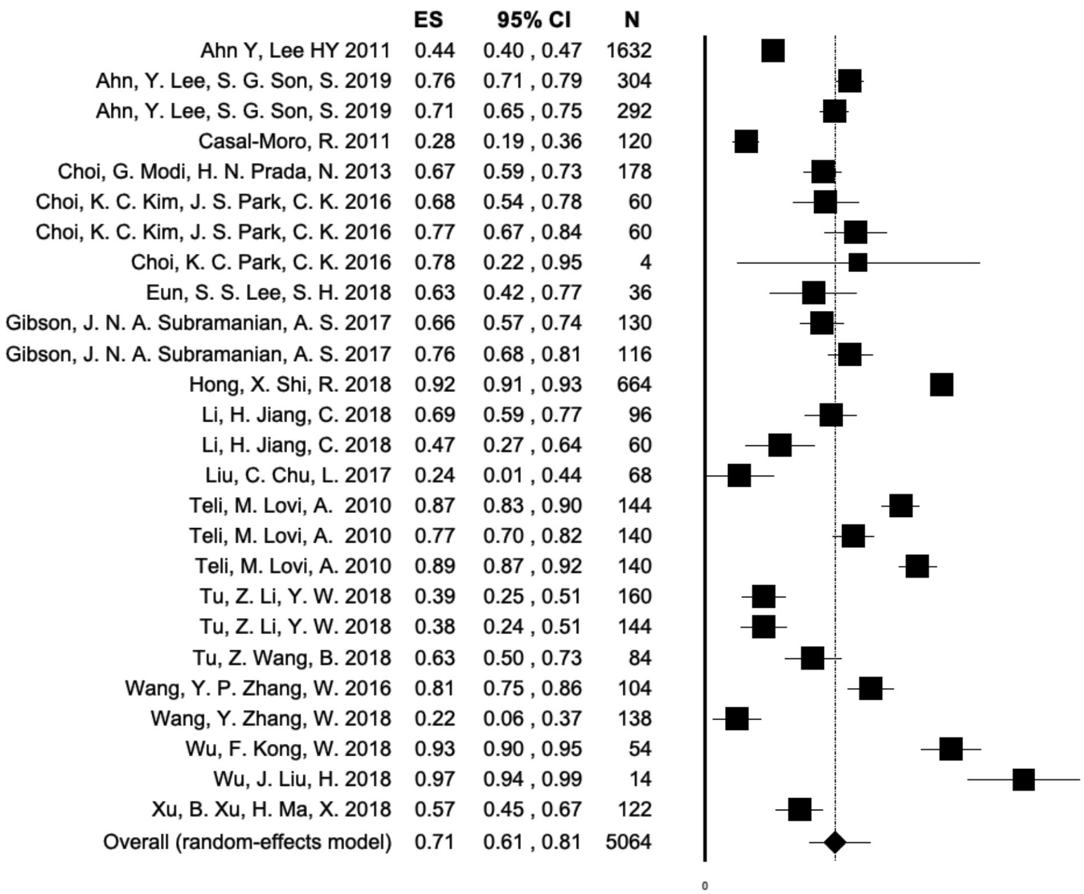

Figure 5. Forest plot of effect sizes (ESs), 95% CI, and the number of patients enrolled in each individual endoscopic spinal surgery study (*N*) calculated for the 26 study groups which reported visual analog scale back with a minimum of 2 y or longer follow-up listed in alphabetical order according to the first author's name. The number of individual study patients is represented by the size of the symbol. The overall ES was 0.71 with a lower 95% CI limit of 0.61, and an upper limit of 0.81 calculated from the total of 4926 patient samples enrolled in these studies.

data (ODI, VAS back, and VAS leg) extrapolated by the authors from a total of 89 studies were large,[181] which represented multiple of the reported MCID,[83,177] and without dispute justify the use of the endoscopic and other forms of MISST to treat symptoms related to herniated disc and spinal stenosis in the lateral recess and the foramen, a familiar data set of ESs with these procedures—to the authors' best knowledge—has not been published. Filling this knowledge gap with the many types of endoscopic spinal surgeries, as exemplified by the long list of acronyms noted in the introduction, was the primary motivation of this team of authors to employ this broad rather than a narrow focus meta-analysis approach.

Employing the inclusion and exclusion criteria stated in the method section, the authors' meta-analysis was based on studies, most of which were published within the last 3 years, but rarely older than 10 years, thus, likely representing the recent technology advancements facilitating the outcomes of increasing ES—without statistical significance—reported herein. As a result, ESs were calculated based on extracted ODI, VAS back, and VAS leg data extrapolated from a vast number of 23,290 patient samples pooled from 89 studies (Tables 1 and 2). Explicitly, our meta-analysis confirmed that the majority of patients treated with endoscopic and other forms of MISST lumbar stenosis decompressions were between the ages of 30 and 70 years without ES being impacted by that at a statistically significant level by age. Neither did the study design translate into any statistically significant impact on ES (Table 3). In other words, patients' outcomes are more likely to be impacted by addressing the relevant painful clinical pathology adequately rather than by the way they are studied. Typically, longer follow-up is valued as a prerequisite of meaningful outcome study. However, as illustrated by our meta-analysis, ESs were the largest when extrapolated for VAS back and VAS leg up until a 2-year follow-up in most studies at a statistically significant level (Table 5). Longer follow-up to as much as 6 years and longer did not necessarily translate into larger ESs ($P = 0.091$); in other words, the natural progression of the disease process may play out with diminishing ESs

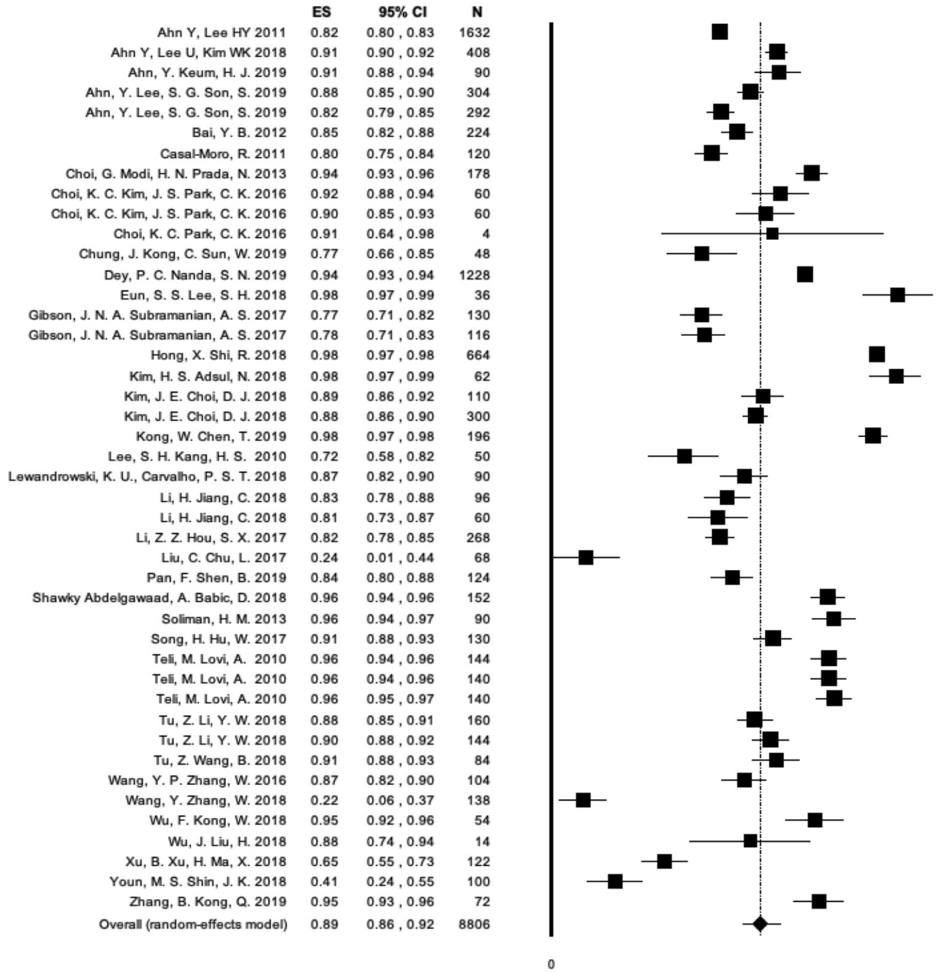

Figure 6. Forest plot of effect sizes (ESs), 95% CI, and the number of patients enrolled in each individual endoscopic spinal surgery study (*N*) calculated for the 44 study groups which reported visual analog scale leg with a minimum of 2 y or longer follow-up listed in alphabetical order according to the first author's name. The number of individual study patients is represented by the size of the symbol. The overall ES was 0.89 with a lower 95% CI limit of 0.86, and an upper limit of 0.92 calculated from the total of 8806 patients enrolled in these studies.

over time, and perhaps Kaplan Meier durability analyses are more suitable to determine the long-term effects of the contemporary lumbar stenosis surgeries by way of a utilization analysis of additional treatments if any at what point after that.[182] Patients with incomplete pain relief and ongoing disability continue to utilize medical services. In the opinion of public health policymakers, the absence of any additional utilization following the lumbar stenosis index surgery is the ultimate proof of superiority by making good on the promise of better value spine care purchasing for the increasing number of aging patients who need it.

When breaking down the ES by a surgical indication as to the modifier, a mixed picture emerged. The ODI ES spinal stenosis-related neurogenic claudication was higher than VAS back and VAS leg at a statistically significant level (Table 4), emphasizing the more functional context of his 10-item outcome tool. The statistical overlap between the VAS leg ESs for the 3 clinical indications studied—stenosis claudication, HNP radiculopathy, and discogenic pain were quite large, suggesting that endoscopic spinal surgery is effective in relieving sciatica-type leg and back pain due to either 1 of these 3 conditions. Using the type of MISST and endoscopic surgery as modifiers was possible, because some of the studies included in this meta-analysis had treatment arms comparing these techniques. There was significant overlap between ESs observed with open laminectomy or tubular retractor microsurgical dissection with similar VAS back, and VAS leg ES data to endoscopy, there were statistically significant differences ($P = 0.049$) when employing the ODI as an outcome tool with ESs for endoscopy being higher (0.92) than for microsurgical dissection (0.89; Table 6). The open laminectomy (ES = 0.93) and endoscopically assisted interbody spinal fusion followed by percutaneous posterior supplemental pedicle screw fixation (ES = 0.95) had a higher overall ODI ES numbers presumably because of a more comprehensive decompression and perhaps elimination of instability (Table 6). The largest ODI (8198 patients), VAS back (3990 patients), and VAS leg (7954 patients) data set were observed with the transforaminal outside-in approach (Table 7). The highest ODI and VAS leg ESs were found with statistical significance with the interlaminar approach, which was the second most commonly performed endoscopic approach, followed by the UBE uniportal biportal technique ($P < 0.0001$). Besides the endoscopic lumbar fusion studies included in this meta-analysis, 2 additional noteworthy uniportal endoscopic fusion articles in patients with low-grade scoliosis,[183] and patients with symptomatic foraminal stenosis secondary to severe collapsed disc space[184] were published within the last year after the cut-off date of this meta-analysis. Based on VAS and ODI outcome reporting, these pivotal studies would not have met the inclusion criteria of our meta-analysis, even if they were published before 31 December 2019, since ES could either not be calculated, or allocated.

As discussed at the outset of this article, the authors were not interested in pushing one endoscopic approach or MISST over another. We were only interested in reporting a familiar set of ODI, VAS back, and VAS leg ESs in the form of reference tables (Table 3 through 7) to aid in the ongoing discussion on how to most effectively transition modern spine care to more reliable and less costly procedures by replacing some of the traditional open with endoscopic and other types of MISST spinal surgery in routine practice. The authors expected the publication bias found in our meta-analysis as one of the main limitations. Seventy-two of the 89 studies included in this meta-analysis were retrospective studies. Twelve studies were prospective, and another 5 studies were randomized prospective clinical trials both of which had multiple treatment arms. Twenty-four of the 36 studies included in the meta-analysis with longer than 2-year follow-up were retrospective. They were estimated to have a high ROB supported by the asymmetric funnel plot, and the spread of ES data in the individual ODI, VAS back, and VAS leg forest plots (Figures 4–6) suggesting that the authors' meta-analysis was at an overall moderate ROB. To diminish the effect of publication bias the authors employed random ES models for the calculations. While there may be many additional unknown limitations to this type of meta-analysis because of variation in patient's expectations, surgeons' skill level, or the organizational process and procedural aspects of the surgery either carried out in an outpatient ambulatory surgery center or in a hospital setting, and many other factors that may be responsible for the heterogeneity observed in some of the subgroups as evidenced by some of the outliers, the difference found in the ODI, VAS back, and VAS leg ESs is reflective of real-life clinical scenarios where spine care is delivered under a great variety of patient- and system-related circumstances. The surgeon skill factor is likely the most relevant confounder in this whole analysis and may be responsible for the wide overlap in successful clinical outcomes regardless of the type of surgery employed. However, statistically significant differences do exist between the type of endoscopic and other types of MISST surgery and should be further investigated to better define and validate preoperative predictors of favorable clinical outcomes with their use. At this juncture, though, the authors accomplished their task of reporting a familiar ODI, VAS back, and VAS leg ES data set (Tables 3–7) for common minimally invasive and endoscopic spinal surgeries, and how they compare to traditional open spinal surgery in the treatment of symptoms related to herniated disc, foraminal, and lateral recess stenosis.

CONCLUSIONS

Despite these limitations, and considering that the authors did not attempt a formal comparison to other MISSTs or traditional open surgical decompression, one argument is to be made from the authors' meta-analysis: the 3 types of ES data sets with the various endoscopic spinal surgeries are on par with those observed with open laminectomy, microsurgical dissection, and those seen with MISST fusion surgeries which often come with a higher perioperative burden to the patient and are more costly due to the use of implants, higher complication and reoperation rates and unplanned aftercare, longer postoperative recovery and return to work. The surgeon skill level is the most significant confounding factor. The ongoing debate on the merits of endoscopic spine surgery will likely continue. With this meta-analysis, the authors provided the statistical numbers required to have this debate in an objective manner where one wonders about the continued need for aggressive open surgeries for the indications investigated herein if the reported differences in ES numbers for clinical improvements are marginal.

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