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High heterogeneity and no significant differences in clinical outcomes of endoscopic foraminotomy vs fusion for lumbar foraminal stenosis: a meta-analysis

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- *Objective:* This study aimed to systematically review the literature for comparative and non-comparative studies reporting on clinical outcomes of patients with lumbar foraminal stenosis treated by either endoscopic foraminotomy or fusion.
- *Methods:* In adherence with Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines, a literature search was done on January 17, 2022, using Medline and Embase. Clinical studies were eligible if they reported outcomes following fusion or endoscopic foraminotomy, in patients with primary lumbar foraminal stenosis. Two independent reviewers screened titles, abstracts, and full-texts to determine eligibility; performed data extraction; and assessed the quality of eligible studies according to the Joanna Briggs Institute (JBI) checklist.
- *Results:* The search returned 827 records; 266 were duplicates, 538 were excluded after title/abstract/full-text screening, and 23 were eligible, with 16 case series reporting on endoscopic foraminotomy, 7 case series reporting on fusion, and no comparative studies. The JBI checklist indicated that 21 studies scored ≥4 points. When comparing endoscopic foraminotomy to fusion, pooled data revealed reduced operative time (69 vs 119 min, $P < 0.01$) but similar Oswestry disability index (19 vs 20, $P = 0.67$), lower back pain (2 vs 2, $P = 0.11$), leg pain (2 vs 2, $P = 0.15$), complication rates (10% vs 5%, $P = 0.22$), and reoperation rates (5% vs 0%, $P = 0.16$). The proportions of patients with good/excellent MacNab criteria were similar for endoscopic foraminotomy and fusion (82–91% vs 85–91%).
- *Conclusions:* There were high heterogeneity and no significant differences in clinical outcomes, complication rates, and reoperation rates between endoscopic foraminotomy and fusion for the treatment of lumbar foraminal stenosis; although endoscopic foraminotomy has reduced operative time.

Keywords

- endoscopic foraminotomy
- fusion
- lumbar foraminal stenosis
- clinical outcomes
- reoperation rates
- complication rates

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Introduction

Endoscopic surgery is gaining popularity for spinal procedures, with a number of systematic reviews demonstrating satisfactory outcomes and considerable benefits of endoscopic lumbar discectomy (1), as well as endoscopic cervical discectomy and decompression (2, 3). Endoscopy is also used to treat lumbar foraminal stenosis, although the best treatment for this indication remains unclear, and fusion remains commonly used.

A recent meta-analysis by Giordan *et al.* (4) synthesized the literature reporting outcomes of endoscopic lumbar foraminotomy and reported satisfactory results after pooling of complications, revisions, and clinical improvements. Giordan *et al.* included 14 case series and did not identify any studies that directly compared the outcomes of endoscopic foraminotomy vs fusion for lumbar foraminal stenosis, and the outcomes pooled were limited to binary events such as complications and revisions. It therefore remains unclear whether endoscopic

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foraminotomy has equivalent or superior outcomes compared to fusion, and whether the additional costs and complexity are justified.

At the authors' clinic, foraminal stenosis has been routinely treated by fusion. Two years ago, the authors started performing endoscopic surgery to treat a variety of indications, including foraminal stenosis; we are therefore interested in understanding if there are differences in outcomes between these two surgeries. The purpose of this meta-analysis was to systematically review the literature for comparative and non-comparative studies reporting on the clinical outcomes of patients with lumbar foraminal stenosis treated by either endoscopic foraminotomy or fusion. The hypothesis was that endoscopic foraminotomy and fusion produce equivalent postoperative Oswestry disability index (ODI), postoperative lower back or leg pain, and MacNab criteria.

Materials and methods

This systematic review was performed according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) criteria and registered with PROSPERO prior to commencement of the study (CRD42022302028).

Search strategy

An electronic literature search was conducted on January 17, 2022, using Medline (PubMed) and Embase. The search strategy was based on the following key terms: lumbar foraminal stenosis, fusion, and endoscopic foraminotomy (Supplemental file, see section on supplementary materials given at the end of this article).

Selection criteria

Duplicate articles were removed and then titles and abstracts were screened independently by two readers (MVK, SRP) to determine their relevance in accordance with the following eligibility criteria:

Inclusion criteria:

- comparative and non-comparative studies that report outcomes of interest following fusion, endoscopic foraminotomy, or combined endoscopic foraminotomy and discectomy, in patients with primary lumbar foraminal stenosis (with or without lateral recess stenosis, disc herniation, disc degeneration, spondylolisthesis, or scoliosis) and
- studies that report at least one of the following outcomes of interest: postoperative ODI, postoperative lower back or leg pain on visual analog scale (VAS) or numerical rating scale (NRS), and/or MacNab criteria.

Exclusion criteria:

- studies that report on patients who have additional concomitant conditions other than lateral recess stenosis, disc herniation, disc degeneration, spondylolisthesis, or scoliosis,
- studies that report on patients with secondary lumbar foraminal stenosis following fusion surgery,
- studies on animals and computer simulations,
- studies published in languages other than English, due to a lack of confidence of the researchers in analysis in other languages;
- studies published more than 15 years ago, due to advancements in surgical techniques and medical devices, and
- narrative or systematic reviews, meta-analyses, editorials, and expert opinions.

Full-text versions of the articles were retrieved if they were found to be relevant, or if the title and abstract did not provide sufficient information to establish final eligibility, and these were screened independently by two readers (MVK, SRP). Any disagreement between readers was solved by review and consensus.

Data extraction and quality assessment

The following characteristics were extracted from the included studies independently by two readers (MVK, SRP): lead author, year of publication, journal, study design, ethical approval, conflicts of interest, time period during which surgeries occurred, country, main indication for surgery, other indications, type of surgery, cohort size, age, gender distribution, intraoperative parameters, follow-up time, clinical outcomes, complication rate, and reoperation rate. Extracted data were compared between the two readers, and if discrepancies were found, consensus was achieved through review and discussion. Where two or more studies were based on the same patient population, the longest follow-up and/or most complete data were presented, and shorter follow-up and/or incomplete data were disregarded. When relevant data were missing from the included articles, the authors were each contacted up to three times by email, LinkedIn, and/or Research Gate, to request missing data.

The methodological quality of the studies was assessed according to the Joanna Briggs Institute (JBI) clinical appraisal tools checklist for case series (5) and cohort studies (6). The cohort study checklist was modified by removing question 6 'were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)?' as it was not applicable for any of the included studies. Thus, a score of 10 points on the JBI checklist indicated high quality/low risk of

bias, while a score of 0 points indicated poor quality/high risk of bias. Any discrepancies in appraisal were resolved through discussion and consensus between the two readers.

Statistical analysis

When available in the original articles, outcomes were tabulated: continuous outcomes were reported as means, S.D., and ranges, while categorical outcomes were reported as proportions. Operative time, postoperative ODI, postoperative pain on VAS/NRS, complication rates, and reoperation rates were the only outcomes consistently reported across studies, for which forest plots were created on pooled data. Since outcome measures can depend on follow-up, they were presented separately for short- (mean follow-up <2 years) and mid- (mean follow-up 2–6 years) term findings. Heterogeneity was evaluated by visual inspection of forest plots, and using the I^2 statistic and its connected χ^2 test, to provide a measure of the degree of inconsistency across studies (7). Pooled estimates of raw means and their 95% CI were calculated using a random-effects model framework. Pooled estimates of proportions and their 95% CIs were calculated via Freeman–Tukey double arcsine transformation using inverse-variance weighting within a random-effects model framework. In cases where the range was available, but the S.D. was not, the latter was calculated according to Hozo *et al.* (8) *P*-values <0.05 were considered statistically significant. Statistical analyses were performed using R version 4.1.3 (R Foundation for Statistical Computing, Vienna, Austria) using the meta package.

Results

Literature search

The electronic literature search identified 827 references, of which 266 were duplicates (Fig. 1). The titles and abstracts of the remaining 561 references were screened, and 506 were excluded because they did not meet the inclusion criteria. The remaining 55 articles underwent full-text screening, of which a further 28 articles were excluded because 17 (9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25) were on patients with foraminal stenosis and an excluded indication, 4 (26, 27, 28, 29) were on open decompression, 3 (30, 31, 32) reported no outcomes of interest, 2 (33, 34) were letters to editors or surgical technique notes, 1 (35) was on foraminal stenosis secondary to fusion surgery, and 1 (36) was on a combination of 2 or more procedures. A

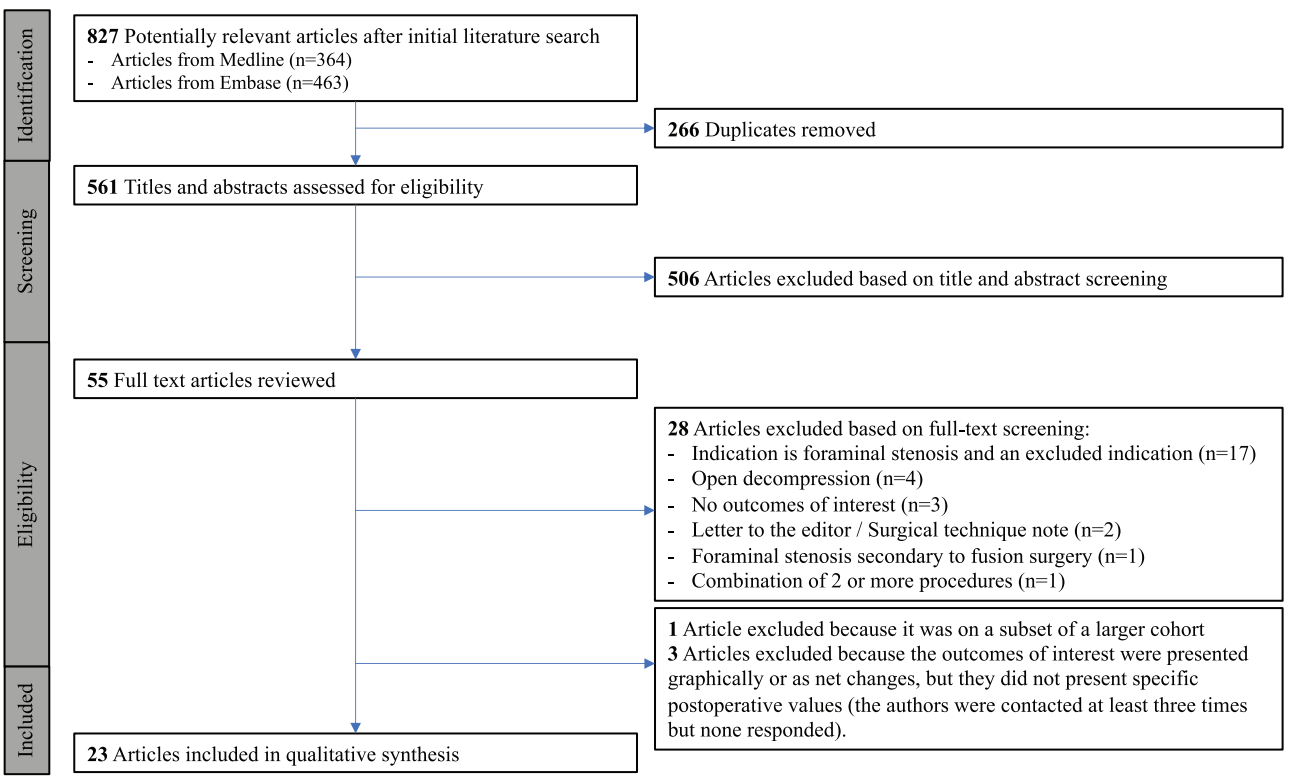

Figure 1
Flowchart of the study selection procedure.

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

Reference	Study design	Ethical approval	COI	Time period	Country	Main indication	Other indication	Specific surgery
Endoscopic foraminotomy								
Short term								
Kim *et al.* (52)	Retrospective	Yes	none	January 2018–January 2020	Korea	Coexisting foraminal, extraforaminal, and lateral recess stenosis	Spondylolisthesis, ASD	Interlaminar contralateral endoscopic lumbar foraminotomy
Shi *et al.* (56)	Retrospective	Yes	None	January 2018–June 2019	China	Foraminal stenosis		Endoscopic lumbar foraminoplasty and decompression, with and without the use of a preoperative software
Song *et al.* (59)	Retrospective	Yes	None	January 2019–June 2019	China	Foraminal stenosis		Full-endoscopic foraminotomy
Yang *et al.* (61)	Retrospective	Yes	None	October 2014–December 2017	Taiwan	Foraminal or extraforaminal stenosis		Full-endoscopic transforaminal decompression
Yoo *et al.* (63)	Retrospective	Yes	Yes	January 2017–December 2017	Korea	Foraminal stenosis	Spondylolisthesis	Percutaneous lumbar foraminoplasty
Akbary *et al.* (44)	Technical note	No	None	March 2017–December 2017	Korea	Foraminal stenosis and lateral recess stenosis at the level below		Biportal endoscopic decompression using a contralateral approach
Chung *et al.* (47)	Surgical technique	Yes		January 2015–December 2016	Korea	Foraminal stensosis	Degenerative scoliosis, spondylolisthesis	Percutaneous endoscopic lumbar foraminoplasty
Ishibashi *et al.* (49)	Retrospective	Yes	None	November 2016–December 2017	Japan	Foraminal stenosis		Percutaneous endoscopic translaminar approach
Kim & Choi (50)	Technical note	No	None		Korea	Foraminal stenosis		Far lateral approach of biportal arthroscopic spinal surgery using 30° arthroscopy
Kim*et al.* (51)	Retrospective	Yes	None		Korea	Foraminal stenosis	ASD, spondylolisthesis, herniated disc	Unilateral biportal endoscopic far-lateral
Madhavan *et al.* (53)	Retrospective	Yes			USA	Foraminal stenosis and coronal deformity >10°		Decompression endoscopic foraminotomy
Mid term								
Murata *et al.* (54)	Retrospective	Yes	Yes	January 2013–December 2017	Japan	Foraminal stenosis	Spondylosis, degenerative scoliosis, herniated discs	Microendoscopic foraminal decompression using an extraforaminal approach
Yeung *et al.* (62)	Retrospective	Yes	Yes	2012–2015	USA	Foraminal stenosis		Transforaminal endoscopic surgery
Youn *et al.* (38)	Retrospective	Yes	None	January 2012–December 2015	Korea	Foraminal stenosis		Endoscopic partial facetectomy, with and without discectomy
Ahn *et al.* (42)	Retrospective	Yes	None	September 2011–December 2012	Korea	Foraminal stenosis		Percutaneous endoscopic lumbar foraminotomy through a foraminal approach
Ahn *et al.*(43)	Prospective	No	None	January 2009–September 2011	Korea	Foraminal stenosis	Herniated disc	Percutaneous endoscopic lumbar foraminotomy
Fusion								
Short term								
Alimi *et al.* (45)	Retrospective	Yes	None	2007–2013	USA	Foraminal stenosis	Degenerative scoliosis, ASD, spondylolisthesis, lateral listhesis	XLIF
Yamada *et al.* (60)	Prospective	No	None	From 2006	Japan	Foraminal stenosis		Total facetectomy on the symptomatic side and TLIF
Mid term								
Cofano *et al.* (48)	Retrospective	Yes	None	January 2016–October 2019	Italy	Foraminal stensosis	Spondylolisthesis < 25%, DDD	ALIF, with and without posterior instrumentation
Shin *et al.* (58)	Retrospective	No	None	March 2007–July 2010	Korea	Foraminal stenosis and spondylolisthesis		ALIF with percutaneous pedicle screw fixation

(Continued)

Table 1 Continued.

Reference	Study design	Ethical approval	COI	Time period	Country	Main indication	Other indication	Specific surgery
Shim *et al.* (57)	Retrospective	No	None	November 2002–January 2008	Korea	Foraminal stenosis and isthmic spondylolisthesis		ALIF with instrumented posterolateral fusion, or ALIF with percutaneous pedicle screw fixation
Cho *et al.* (46)	Retrospective			December 2004–December 2007	Korea	Foraminal stenosis	DDD, spondylolisthesis, herniated disc	ALIF
Park *et al.* (55)	Retrospective			January 2004–September 2007	Korea	Foraminal and lateral recess stenosis		Stand-alone PLIF

ALIF, anterior lumbar interbody fusion; ASD, adjacent segment disease; COI, conflicts of interest; DDD, degenerative disc disease; PLIF, posterior lumbar interbody fusion; TLIF, transforaminal lumbar interbody fusion; XLIF, extreme lumbar interbody fusion.

further four articles were excluded because one (37) was on a subset of a larger cohort (38), and three (39, 40, 41) presented the outcomes of interest graphically or as net changes but did not present specific postoperative values (the authors were contacted at least three times but none responded).

A total of 23 articles (38, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63) were eligible for data extraction, all of which reported on clinical outcomes of patients with lumbar foraminal stenosis treated by either endoscopic foraminotomy or fusion.

Characteristics of the included studies

Of the 23 included studies, 16 (38, 42, 43, 44, 47, 49, 50, 51, 52, 53, 54, 56, 59, 61, 62, 63) reported outcomes of endoscopic foraminotomy and 7 (45, 46, 48, 55, 57, 58, 60) reported outcomes of fusion, but none compared endoscopic foraminotomy vs fusion (Table 1). Studies on endoscopic foraminotomy reported on procedures performed between 2009 and 2020 in Asia (n =14) and America (n=2), while studies on fusion reported on procedures performed between 2002 and 2019 in Asia (n=5), America (n=1), and Europe (n=1). For studies on endoscopic foraminotomy, the main indication for surgery was isolated foraminal stenosis (n=12), foraminal or extraforaminal stenosis (n=1), coexisting foraminal, extraforaminal and lateral recess stenosis (n=1), foraminal stenosis with lateral recess stenosis at the level below the foraminal stenosis (n=1), and foraminal stenosis with coronal deformity >10° (n=1). For studies on fusion, the main indication for surgery was isolated foraminal stenosis (n=4), foraminal stenosis with spondylolisthesis (n=2), and coexisting foraminal and lateral recess stenosis (n =1).

Studies on endoscopic foraminotomy included the following surgical techniques: uniportal outside-in extraforaminal approach (n=9), both outside-in and inside-out uniportal extraforaminal approaches (n=1), uniportal translaminar approach (n=2), biportal extraforaminal approach (n=2), biportal decompression of exiting and traversing nerve roots through an interlaminar window (n=1), and not specified (n=1). Studies on fusion included the following surgical techniques: anterior lumbar interbody fusion (ALIF) (n=4), posterior lumbar interbody fusion (PLIF) (n=1), transforaminal lumbar interbody fusion (TLIF) (n=1), and extreme lumbar interbody fusion (XLIF) (n=1).

Quality assessment using the JBI 10-point checklist indicated that 16 studies (38, 42, 43, 44, 45, 46, 47, 48, 49, 52, 54, 57, 58, 59, 61, 63) scored ≥7 points, 5 studies (51, 55, 56, 60, 62) scored between 4 and 6 points, while 2 studies (50, 53) scored ≤3 points (Table 2).

Operative time

Operative time was reported in 12 studies (42, 43, 44, 47, 49, 50, 51, 52, 56, 59, 61, 62) on endoscopic foraminotomy and 3 studies (55, 57, 58) on fusion. The pooled data revealed significantly shorter operative time for endoscopic foraminotomy compared to fusion (69 min vs 119 min, $P < 0.01$) (Table 3, Fig. 2).

MacNab criteria

MacNab criteria were reported in ten studies (42, 43, 50, 51, 52, 54, 56, 59, 61, 62) on endoscopic foraminotomy and one study (57) on fusion (Table 4). In the short term, the proportions of patients with good or excellent MacNab criteria were 81–100% for endoscopic foraminotomy (not reported for fusion). In the mid term, the proportions of patients with good or excellent MacNab criteria were similar for endoscopic foraminotomy and fusion (82–91% vs 85–91%).

Oswestry disability index

Postoperative ODI was reported in 12 studies (38, 42, 43, 44, 47, 51, 52, 53, 56, 59, 61, 63) on endoscopic foraminotomy and 5 studies (45, 46, 48, 55, 58) on fusion (Table 4). In the short term, the pooled data revealed an ODI of 18 for endoscopic foraminotomy (not reported for fusion). In the mid term, the pooled data revealed similar ODI for endoscopic foraminotomy and fusion (19 vs 20, $P = 0.67$) (Fig. 3).

Lower back pain

Six studies (42, 43, 51, 53, 54, 61) on endoscopic foraminotomy and six studies (45, 46, 48, 57, 58, 60) on fusion reported postoperative lower back pain on VAS/NRS (Table 4). There were no significant differences in lower back pain in the short term (2 vs 3, $P = 0.13$) or in the mid term (2 vs 2, $P = 0.11$) (Fig. 4).

Table 2 Quality assessment using the Joanna Briggs Institute (JBI) critical appraisal tools.

References	Assessment questions*									
	1	2	3	4	5	6	7	8	9	10
Case series										
Cofano *et al.* (48)	Yes	Unclear	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Kim *et al.* (51)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Song *et al.* (59)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yang *et al.* (61)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Murata *et al.* (54)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yoo *et al.* (63)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Youn *et al.* (38)	Yes	Unclear	Unclear	Yes	Yes	Yes	Yes	No	Yes	Yes
Akbary *et al.* (44)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Chung *et al.* (47)	Yes	Unclear	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ishibashi *et al.* (49)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Kim & Choi (50)	No	Unclear	Unclear	Yes	Unclear	No	No	No	Yes	No
Kim *et al.* (51)	Yes	Unclear	Unclear	Unclear	Unclear	Yes	Yes	Yes	Yes	Yes
Ahn *et al.* (42)	Yes	Unclear	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Madhavan *et al.* (53)	No	Unclear	Unclear	Unclear	Unclear	Yes	No	Yes	No	Yes
Alimi *et al.* (45)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ahn *et al.* (43)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Shin *et al.* (58)	Yes	Unclear	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cho *et al.* (46)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Park *et al.* (55)	Yes	Yes	Yes	Unclear	Unclear	Yes	Yes	No	Yes	No
Cohort studies										
Shi *et al.* (56)	Yes	No	Yes	Yes	No	Yes	No	Yes	NA	Yes
Yeung *et al.* (62)	No	No	Yes	Yes	No	Yes	Yes	Yes	NA	Yes
Yamada *et al.* (60)	No	No	Yes	Yes	No	Yes	No	Yes	NA	Yes
Shim *et al.* (57)	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Unclear	Yes

*The questions for the Case series was as follows:
1: Were there clear criteria for inclusion in the case series?; 2: Was the condition measured in a standard, reliable way for all participants included in the case series?; 3: Were valid methods used for identification of the condition for all participants included in the case series?; 4: Did the case series have consecutive inclusion of participants?; 5: Did the case series have complete inclusion of participants?; 6: Was there clear reporting of the demographics of the participants in the study?; 7: Was there clear reporting of clinical information of the participants?; 8: Were the outcomes or follow up results of cases clearly reported?; 9: Was there clear reporting of the presenting site(s)/clinic(s) demographic information?; 10: Was statistical analysis appropriate?
For the Cohort studies, it was:
1: Were the two groups similar and recruited from the same population?; 2: Were the exposures measured similarly to assign people to both exposed and unexposed groups?; 3: Was the exposure measured in a valid and reliable way?; 4: Were confounding factors identified?; 5: Were strategies to deal with confounding factors stated?; 6: Were the outcomes measured in a valid and reliable way?; 7: Was the follow up time reported and sufficient to be long enough for outcomes to occur?; 8: Was follow up complete, and if not, were the reasons to loss to follow up described and explored?; 9: Were strategies to address incomplete follow up utilized?; 10: Was appropriate statistical analysis used?

Table 3 Characteristics of the individuals participating in the studies included in the meta-analysis.

Reference	Cohort size	Levels, *n*	Levels studied	Age (years)		Males, *n* (%)	Operative time (minutes)	
				Mean ± S.D.	Range		Mean ± S.D.	Range
Endoscopic foraminotomy								
Short term								
Kim *et al.* (52)	48	48	L5–S1	68 ± 10	41–87	21 (44%)	74 ± 6	56–97
Shi *et al.* (56) – Group 1	22	22	L4–L5, L5–S1	62 ± 9		11 (50%)	75 ± 13	
Shi *et al.* (56) – Group 2	21	21	L4–L5, L5–S1	64 ± 8		12 (57%)	68 ± 12	
Song *et al.* (59)	21	21	L5–S1	66 ± 10	52–85	10 (48%)	64 ± 26	33–114
Yang *et al.* (61)	22	22	L5–S1	65	50–77	4 (18%)	96 ± 24	43–126
Yoo *et al.* (63)	24	25	L4–L5, L5–S1	68	58–74	15 (63%)		
Akbary *et al.* (44)	30	30	L2–L3, L3–L4, L4–L5, L5–S1	61	38–80	15 (50%)	103 ± 44	45–180
Chung *et al.* (47)	24	27	L2–L3, L3–L4, L4–L5, L5–S1	75	65–82	5 (21%)	69	34–110
Ishibashi *et al.* (49)	10	10	L5–S1	62	47–80	7 (70%)	78	51–110
Kim & Choi (50)	12	12	L5–S1				55	45–70
Kim *et al.* (51)	31	35	L2–L3, L3–L4, L4–L5, L5–S1	71 ± 9	51–89	14 (45%)	49 ± 14	
Madhavan *et al.* (53)	16	20	L1–L2, L2–L3, L3–L4, L4–L5, L5–S1	70 ± 16	61–86	7 (44%)		
Mid term								
Murata *et al.* (54)	78	78	L5–S1	69 ± 21	33–88	47 (60%)		
Yeung *et al.* (62)	176	1 & 2 levels	L2–L3, L3–L4, L4–L5, L5–S1	61 ± 14	19–84	108 (61%)	60 ± 22	23–114
Youn *et al.* (38)	51	56	L2–L3, L3–L4, L4–L5, L5–S1	67	48–82	24 (47%)		
Ahn *et al.* (42)	35	38	L3–L4, L4–L5, L5–S1	59	20–81	19 (54%)	59	20–135
Ahn *et al.*(43)	33	36	L2–L3, L3–L4, L4–L5, L5–S1	64	27–81	15 (45%)	56 ± 19	35–120
Fusion								
Short term								
Alimi *et al.* (45)	23	23	L2–L3, L3–L4, L4–L5	66 ± 2		13 (57%)		
Yamada *et al.* (60)	38	38	L5–S1	69 ± 16		21 (55%)		
Mid term								
Cofano *et al.* (48)	34	34	L5–S1	53 ± 12		15 (44%)		
Shin *et al.* (58) – Group 1	24	24	L4–L5, L5–S1	59	41–78	10 (42%)	272	
Shin *et al.* (58) – Group 2	16	16	L4–L5, L5–S1	52	36–73	8 (50%)	246	
Shim *et al.* (57) – Group 1	23	23	L5–S1	68 ± 2	65–73	9 (39%)	137 ± 5	
Shim *et al.* (57) – Group 2	26	26	L5–S1	69	66–75	11 (42%)	83 ± 4	
Cho *et al.* (46)	28	28	L5–S1	58	32–68	14 (50%)		
Park *et al.* (55)	34	34	L5–S1	58	37–76	9 (26%)	137	122–197

Leg pain

Ten studies (42, 43, 44, 47, 50, 51, 53, 54, 56, 61) on endoscopic foraminotomy and seven studies (45, 46, 48, 55, 57, 58, 60) on fusion reported postoperative leg pain on VAS/NRS (Table 4). In the short term, leg pain was lower for endoscopic foraminotomy (1 vs 2, $P < 0.01$), while in the mid term, there were no differences (2 vs 2, $P = 0.15$) (Fig. 5).

Complication rate

Fourteen studies (38, 43, 44, 47, 49, 50, 51, 52, 53, 54, 56, 59, 62, 63) on endoscopic foraminotomy and five studies (46, 48, 55, 57, 58) on fusion reported complication rates (Table 4). In the short term, the pooled complication rate was 2% for endoscopic foraminotomy (not reported for fusion). In the mid term, there were no significant differences in complication rates (10% vs 5%, $P = 0.22$) (Fig. 6). The complication rate reported by Kim *et al.* (52) was 23% ($n = 11$), considerably higher than that reported by other short-term studies on endoscopic foraminotomy, and consisted of two cases of segmental instability, two cases of incidental durotomy, one case of hematoma, and six cases of postoperative dysesthesia.

Reoperation rate

Thirteen studies (38, 43, 47, 49, 51, 52, 53, 54, 56, 59, 61, 62, 63) on endoscopic foraminotomy and five studies (46, 48, 55, 57, 58) on fusion reported reoperation rates (Table 4). In the short term, the pooled reoperation rate was 2% for endoscopic foraminotomy (not reported for fusion). In the mid term, there were no significant differences in reoperation rates (5% vs 0%, $P = 0.16$) (Fig. 7). The reoperation rate reported by Yeung *et al.* (62) was 21% ($n = 37$), considerably higher than that reported by other studies on endoscopic foraminotomy. It

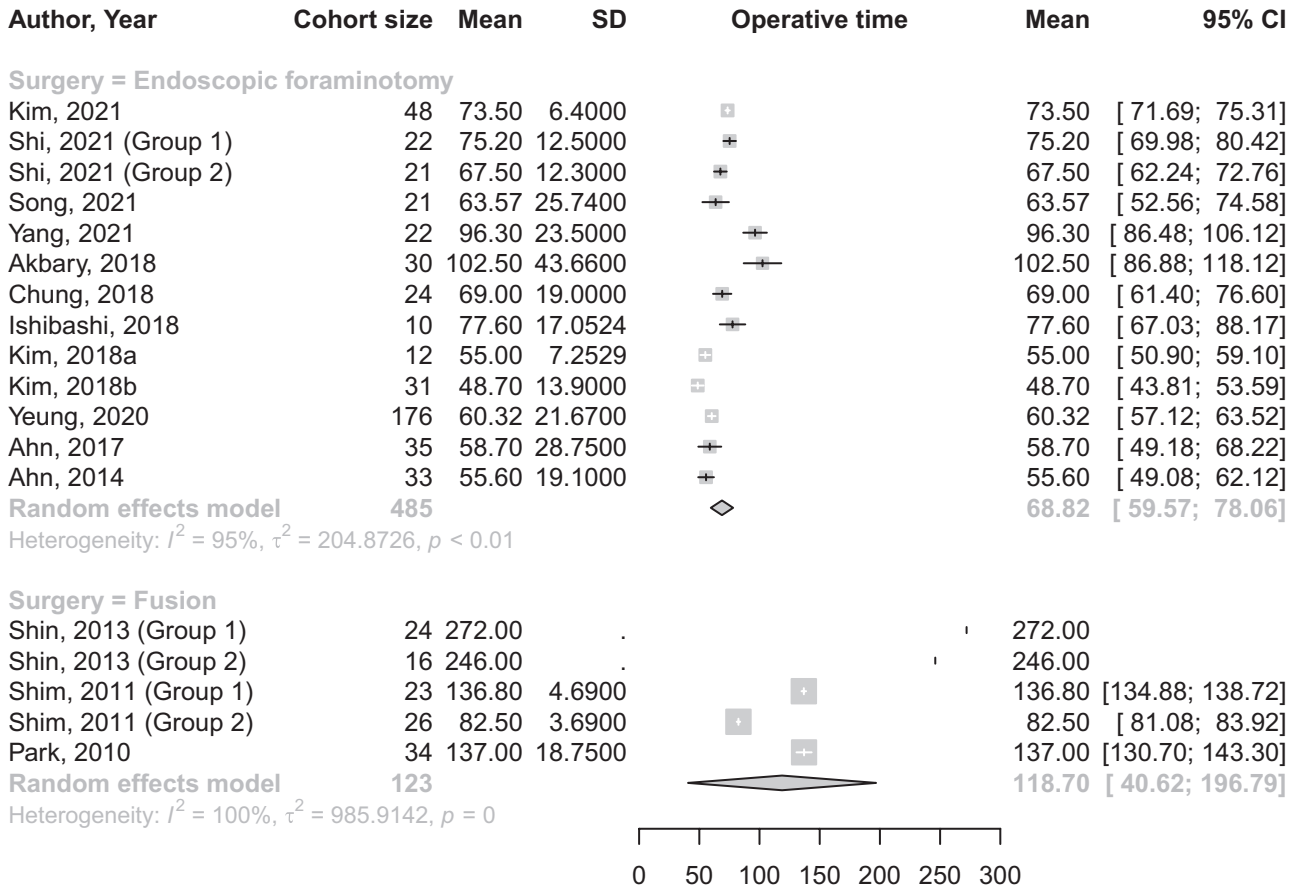

Figure 2
Forest plot presenting operative time stratified by surgery, endoscopic foraminotomy vs fusion.

is important to note that Yeung *et al.* studied two different surgical approaches, with the inside-out technique producing considerably higher reoperation rates than the modified outside-in technique (8% vs 36%), this may be because the inside-out technique places the cannula inside the disc, which can cause iatrogenic damage. Sensitivity analysis without including the study by Yeung *et al.* showed no differences in mid-term reoperation rates between endoscopic foraminotomy and fusion (1% vs 0%, $P = 0.56$).

General outcomes

Five studies (42, 43, 44, 49, 59) on endoscopic foraminotomy and three studies (55, 57, 58) on fusion reported hospital stay; however, these data were not very meaningful as they depended on hospital and country policies (Supplementary Material Appendix 1, see section on supplementary materials given at the end of this article). One study (44) on endoscopic foraminotomy and three studies (55, 57, 58) on fusion reported blood loss. Two studies (49, 54) on endoscopic foraminotomy and one study (60) on fusion reported Japanese Orthopedic Association scores. Six studies (38, 49, 52, 59, 62, 63) on endoscopic foraminotomy and no studies on fusion reported pain on VAS/NRS, without specifying the location of pain. Two studies (38, 53) on endoscopic foraminotomy and no studies on fusion reported SF-36. No studies reported the cost of surgery.

Discussion

The most important finding of this meta-analysis is that there were high heterogeneity and no significant differences in clinical outcomes, complication rates, and reoperation rates between endoscopic foraminotomy and fusion for the treatment of lumbar foraminal stenosis. The two surgical techniques result in comparable MacNab criteria, ODI, lower back pain, and leg pain, thus confirming the hypothesis; but endoscopic foraminotomy

Table 4 Clinical scores, complications, and reoperations from the studies included in the meta-analysis. Data are presented as mean ± SD. (range) or as *n* (%).

Reference	Follow-up (months)	Oswestry disability index		Back pain VAS/NRS		Leg pain VAS/NRS		McNab criteria				Complications	Re-op
		Pre-op	Post-Op	Pre-Op	Post-op	Pre-Op	Post-op	Excellent	Good	Fair	Poor		
Endoscopic foraminotomy													
Short term													
Kim *et al.* (52)	11 ± 5 (6–24)	72±10 (56–84)	26 ±6 (14–52)					11 (23%)	35 (73%)	2 (4%)	0	11 (23%)	2 (4%)
Shi *et al.* (56) – Group 1	12	55 ± 15	13 ± 9			6 ± 1	1 ± 1	9 (41%)	10 (45%)	2 (9%)	1 (5%)	0 (0%)	0 (0%)
Shi *et al.* (56) – Group 2	12	56 ± 15	13 ± 6			7±1	1±1	11 (52%)	8 (38%)	2 (10%)	0 (0%)	0 (0%)	0 (0%)
Song *et al.* (59)	13 ± 1 (12–16)	65 ± 5	22 ± 5					12 (57%)	7 (33%)	1 (5%)	1 (5%)	1 (5%)	1 (5%)
Yang *et al.* (61)	23 (12–45)	62 (50–83)	16 (0 –83)	6 ± 2	2 ± 2	7 ± 1	1 ± 1	10 (45%)	9 (41%)	3 (14%)	0 (0%)		2 (9%)
Yoo *et al.* (63)	3	35 30–43)	27 (24 –35)									0 (0%)	0 (0%)
Akbary *et al.* (44)	6 ± 4 (1 –10)	68 ± 10 (50–88)	16 ± 7 (10–20)			8 ± 1	2 ± 1					0 (0%)	
Chung *et al.* (47)	12– 24	33 ±9	10 ± 7			8 ± 2	3 ± 3					1 (4%)	1 (4%)
Ishibashi *et al.* (49)	13 (6 –19)											0 (0%)	0 (0%)
Kim & Choi (50)						8	2	12 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	
Kim*et al.* (51)	15 ± 2	67 ± 7	17 ± 1	5 ± 1	2 ± 1	8 ± 1	1 ± 1	13 (42%)	12 (39%)	4 (13%)	2 (6%)	0 (0%)	1 (3%)
Madhavan *et al.* (53)	8 ± 5 (2 –14)	33 ± 14	22 ± 10	7 ± 4	4 ± 3	6 ± 4	2 ± 4					2 (13%)	0 (0%)
Mid- term													
Murata *et al.* (54)	24			5 ± 3	2 ± 2	7± 2	2 ± 2	62 (80%)	9 (12%)	4 (5%)	3 (4%)	5 (6%)	0 (0%)
Yeung *et al.* (62)	69 ± 6 (60–83)							93 (53%)	63 (36%)	17 (10%)	3 (2%)	24 (14%)	37(21%)
Youn *et al.* (38)	24	48 ± 6	19									5 (10%)	2 (4%)
Ahn *et al.* (42)	24	66 ± 17	19 ± 16	5 ± 1	2 ± 1	8 ± 1	2 ± 2	14 (40%)	18 (51%)	2 (6%)	1 (3%)		
Ahn *et al.*(43)	24	66 ± 17	19 ± 17	5 ± 2	2 ± 2	8 ± 1	2 ± 2	13 (39%)	14 (42%)	4 (12%)	2 (6%)	2 (6%)	1 (3%)
Fusion													
Short term													
Alimi *et al.* (45)	11 ± 4	48 ± 4	25 ± 4	7 ± 1	3 ± 1	7 ± 1	2 ± 1						
Yamada *et al.* (60)	12			5 ± 2	3 ± 2	7 ± 3	2 ± 1						
Mid-term													
Cofano *et al.* (48)	26 ± 11 (12–48)	48 ± 18	21 ± 13	7 ± 2	3 ± 3	7 ± 2	2 ± 2					1 (3%)	1 (3%)
Shin *et al.* (58) – Group 1	34 (14–54)	60 ± 12	16 ± 10	7 ± 1	2 ± 1	7 ± 1	2 ± 1					0 (0%)	0 (0%)
Shin *et al.* (58) – Group 2	33 (16–50)	70 ± 15	16 ± 18	5 ± 1	2 ± 1	8 ± 1	2 ± 1					1 (6%)	0 (0%)
Shim *et al.* (57) – Group 1	30 (24–47)			6	1.3*	8	1	13 (57%)	8 (35%)	2 (9%)	0 (0%)	3 (13%)	0 (0%)
Shim *et al.* (57) – Group 2	30 (24–47)			6	2.3*	8	1	12 (46%)	10 (38%)	3 (12%)	1 (4%)	1 (4%)	0 (0%)
Cho *et al.* (46)	27 ± 5 (24–40)	54 ± 19	28 ± 13	6 ± 2	2 ± 2	6 ± 3	2 ± 2					1 (4%)	0 (0%)
Park *et al.* (55)	48 (24–70)	28	14			9	2					5 (15%)	0 (0%)

NRS, numeric rating scale; Pre-op, preoperative; Post-op, postoperative; Re-op, reoperations; VAS, visual analog scale.

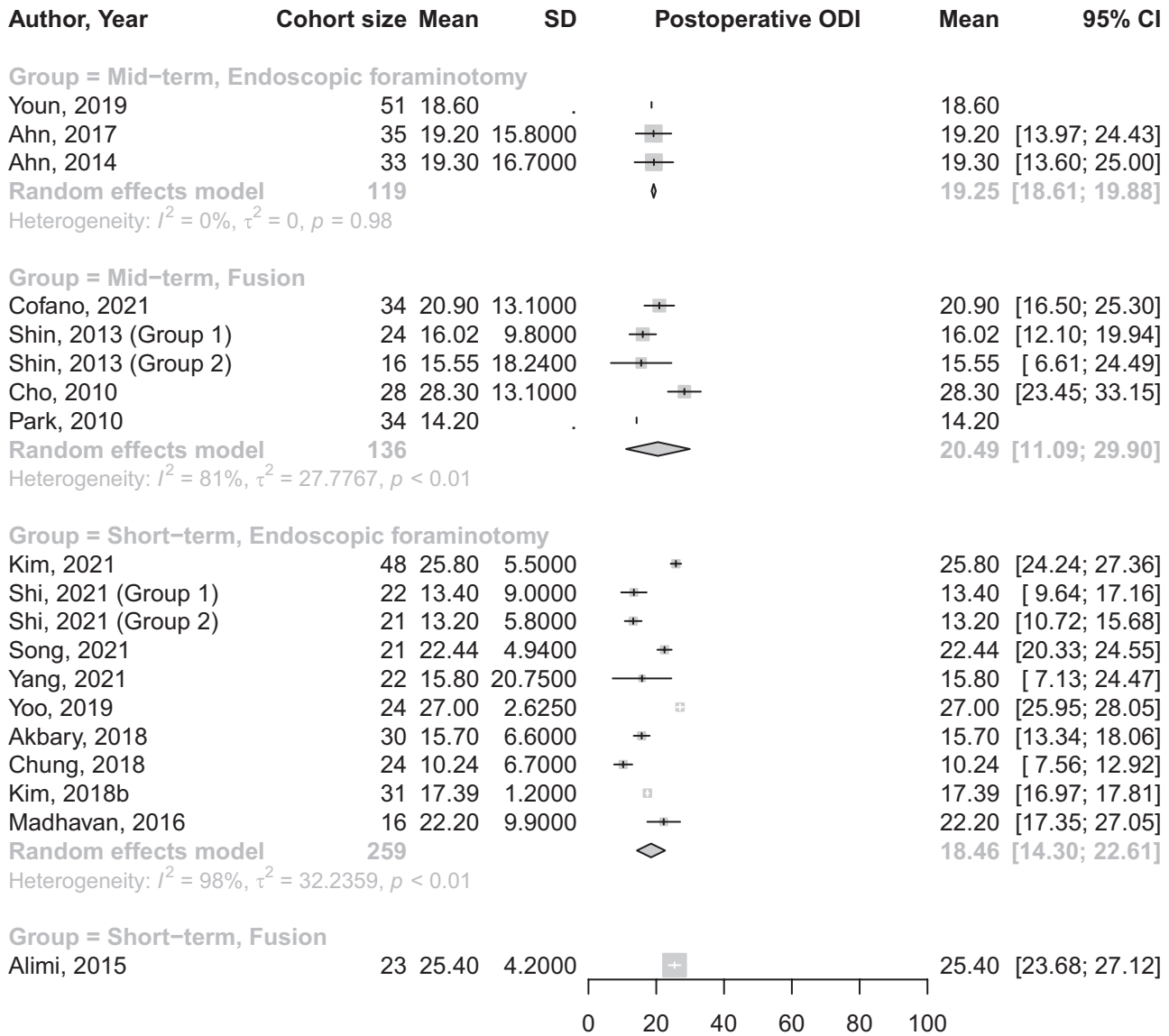

Figure 3
Forest plot presenting postoperative Oswestry disability index (ODI) stratified by surgery, endoscopic foraminotomy vs fusion.

has reduced operative time. Therefore, the authors of the present meta-analysis believe that endoscopic foraminotomy could become the treatment of choice for lumbar foraminal stenosis.

There is only one previous meta-analysis (4) that has summarized the outcomes of endoscopic foraminotomy for lumbar foraminal stenosis. It included 14 non-comparative studies with patients having either primary or secondary (developed after previous spinal surgery) lumbar foraminal stenosis and reported only on MacNab criteria, ODI, leg pain, and adverse events. That meta-analysis (4) found no significant differences in clinical outcomes and adverse events when comparing patients with primary vs secondary lumbar foraminal stenosis and concluded that endoscopic foraminotomy 'is a useful and safe method to achieve decompression in foraminal stenosis. This technique is mainly indicated in the elderly or patients not eligible for major surgery'. The authors of the present study believe that endoscopic foraminotomy is a useful and safe method that can be used to treat the general population, not only elderly patients or patients not eligible for major surgery.

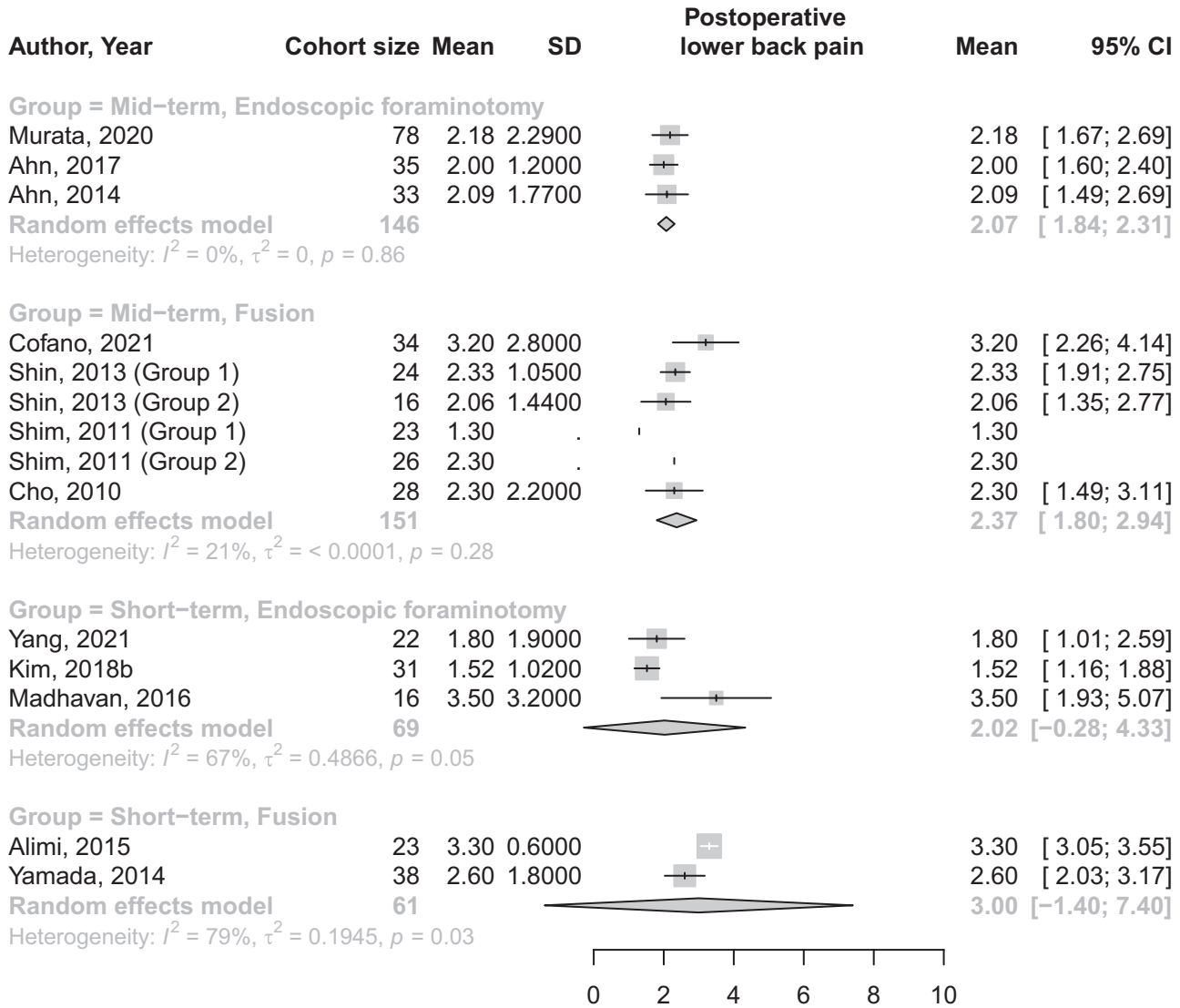

Figure 4

Forest plot presenting postoperative lower back pain on visual analog scale (VAS) or numeric rating scale (NRS) stratified by surgery, endoscopic foraminotomy vs fusion.

The present meta-analysis has shown that the short- and mid-term clinical outcomes of endoscopic foraminotomy and fusion are comparable, although endoscopic foraminotomy results in reduced operative time. Nonetheless, this review was not able to assess long-term complication and reoperation rates, because none of the included studies reported long-term data. It is important to note that fusion has specific long-term risks, including pseudarthrosis, adjacent segment disease, hardware-related complications, and metallic wear related complications, while patients treated with endoscopic foraminotomy may require fusion surgery in the long-term (64, 65). Furthermore, the cost of fusion surgery has increased over recent years, with 50% of the global cost being due to implants (66). Moreover, in many countries, endoscopic foraminotomy is an outpatient surgery, which can lead to a substantial reduction in cost (4, 67).

The present meta-analysis has a number of limitations. First, no included studies directly compared endoscopic foraminotomy vs fusion; therefore, it is difficult to ascertain that patients treated by fusion could have been treated by endoscopic foraminotomy and vice versa. Heterogeneity in patient indication was minimized by

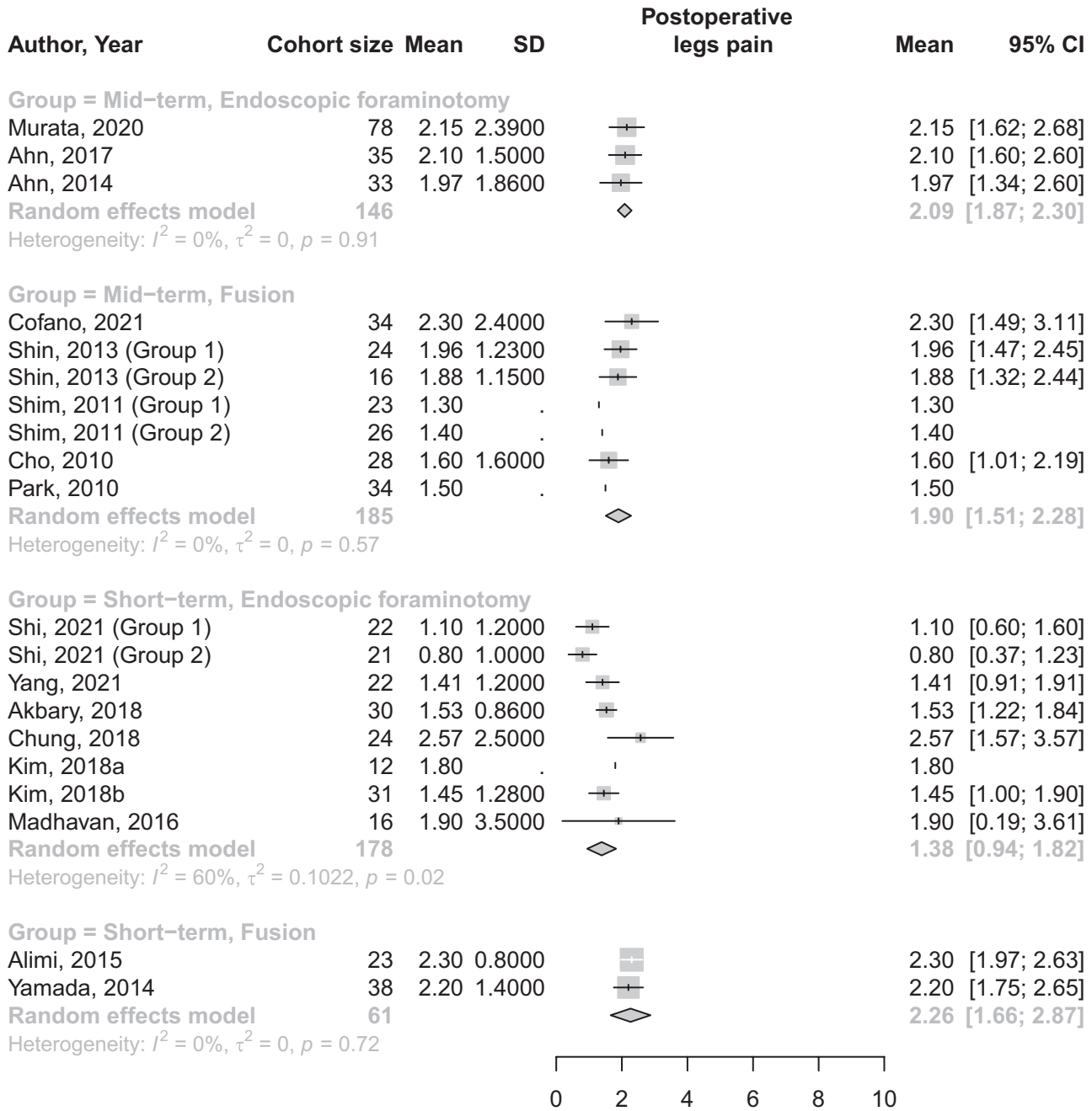

Figure 5

Forest plot presenting postoperative leg pain on visual analog scale (VAS) or numeric rating scale (NRS) stratified by surgery, endoscopic foraminotomy vs fusion.

including only patients with primary lumbar foraminal stenosis (with or without lateral recess stenosis, disc herniation, disc degeneration, spondylolisthesis, or scoliosis) but excluding patients with other concomitant conditions. Second, included studies had different approaches of endoscopic foraminotomy (uniportal, biportal, outside-in, and inside-out) and fusion (ALIF, PLIF, TLIF and XLIF), which may have created heterogeneity across studies. Third, included studies on fusion had an overall longer follow-up time than the studies

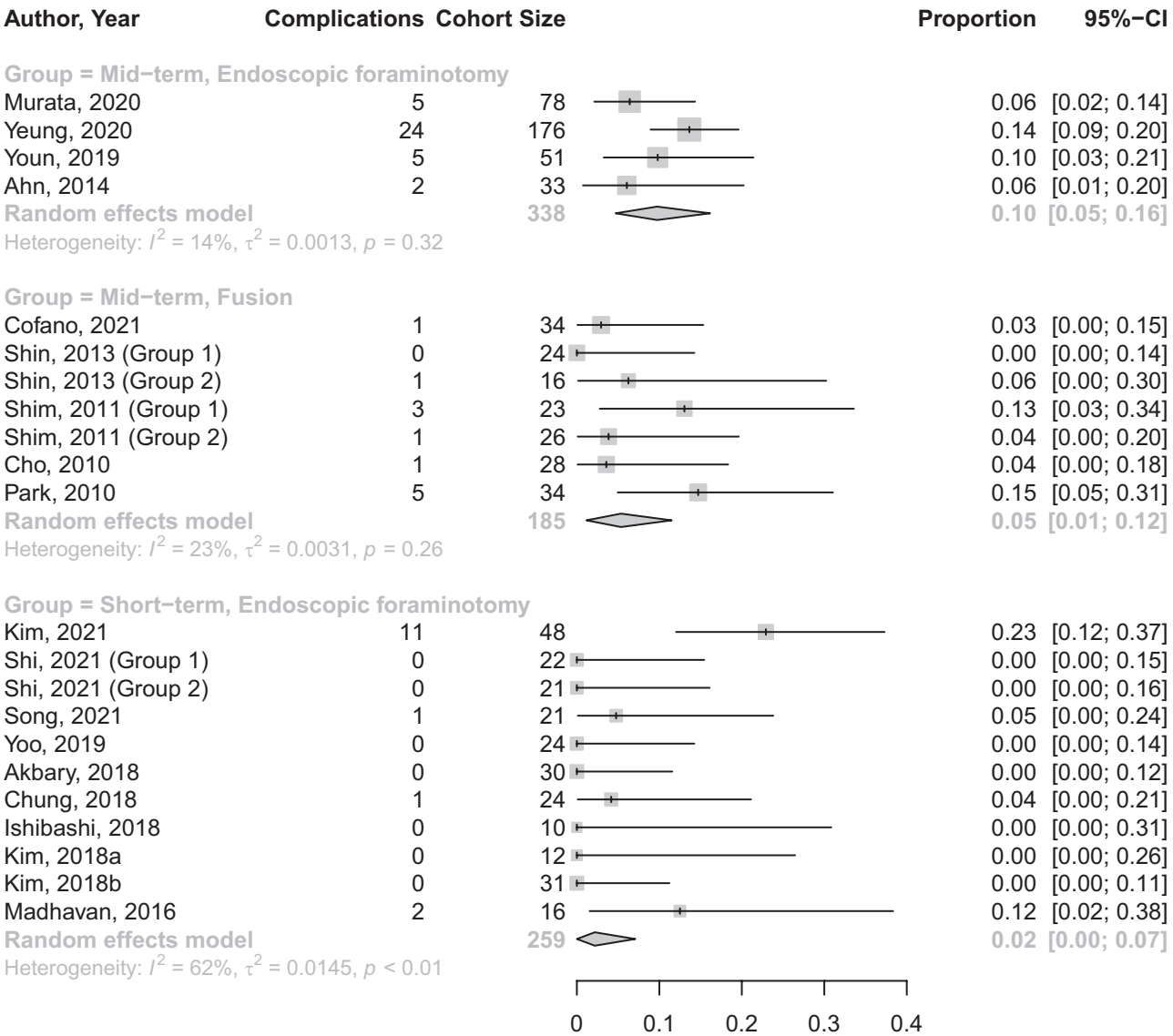

Figure 6
Forest plot presenting complication rates stratified by surgery, endoscopic foraminotomy vs fusion.

on endoscopic foraminotomy. The effect of this was reduced by separating the studies into those with short-term and mid-term outcomes. None of the included studies reported long-term outcomes, and thus, it is not possible to conclude if differences in complication and reoperation rates will exist in the long-term. Fourth, certain studies with relevant outcomes could not be included in the meta-analysis, because the necessary data were not reported. The authors of the present meta-analysis contacted the authors of the relevant clinical studies at least three times, but received no response. Fifth, two of the included studies scored three points or less on the JBI 10-point checklist, indicating poor quality/high risk of bias.

Conclusions

This meta-analysis found high heterogeneity and no significant differences in clinical outcomes, complication rates, and reoperation rates between endoscopic foraminotomy and fusion for the treatment of lumbar foraminal stenosis; although endoscopic foraminotomy resulted in reduced operative time. Therefore, endoscopic

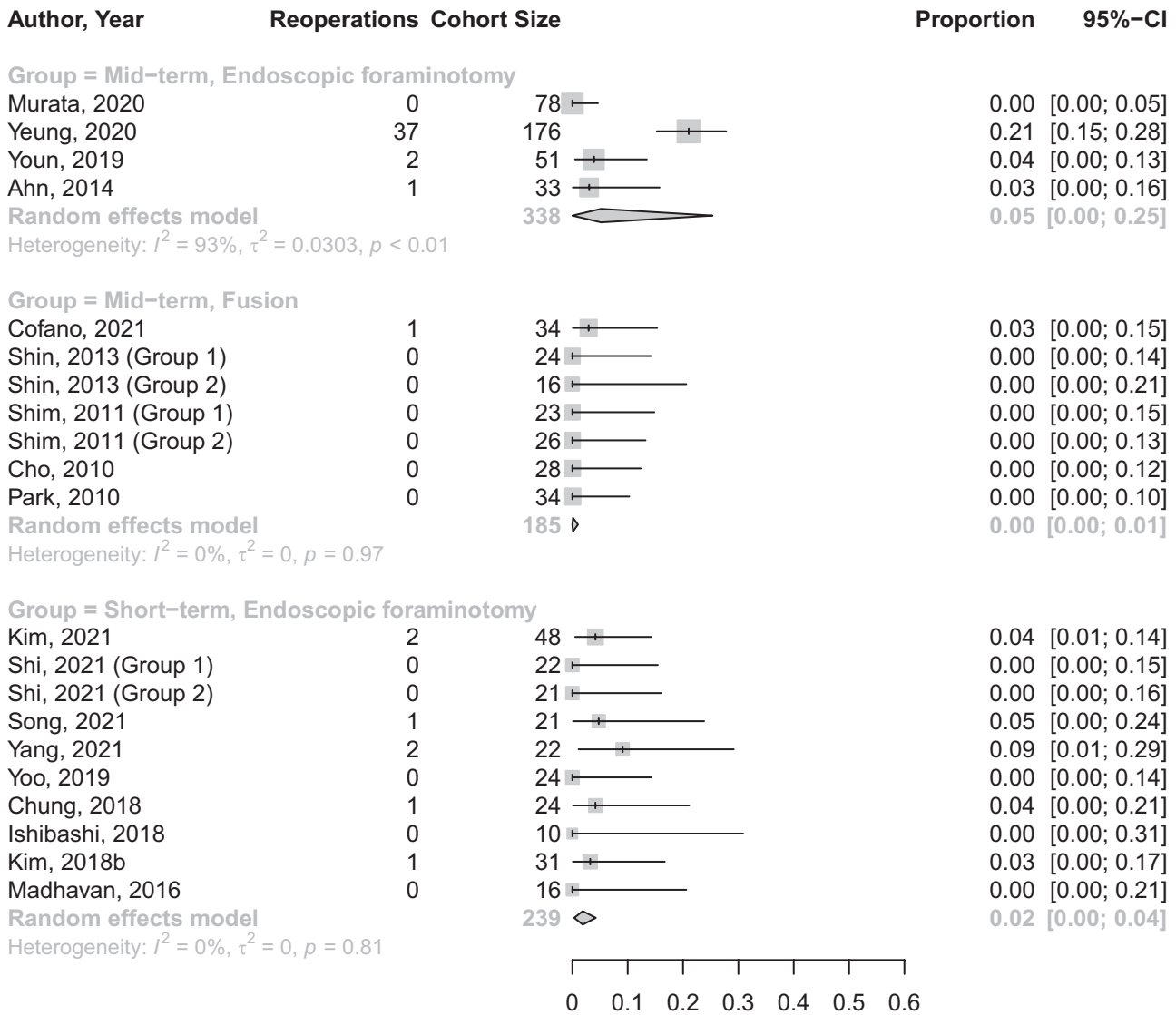

Figure 7
Forest plot presenting reoperation rates stratified by surgery, endoscopic foraminotomy vs fusion.

foraminotomy could become the treatment of choice for lumbar foraminal stenosis.

Supplementary materials
This is linked to the online version of the paper at https://doi.org/10.1530/EOR-22-0093.

ICMJE conflict of interest statement
MVK – no conflicts of interest; SRP – no conflicts of interest; MS – no conflicts of interest; HA – consultancy fees and royalties from Clariance; VF – consultancy fees and royalties from Clariance and Medicrea; MSz – consultancy fees and royalties from Clariance, and consultancy fees from Zimmer.

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