Systematic Review

Full-Endoscopic Procedures Versus Traditional Discectomy Surgery for Discectomy: A Systematic Review and Meta-analysis of Current Global Clinical Trials

Xiao-Chuan Li, MD, Cheng-Fan Zhong, MD, Gui-Bin Deng, MD, Rong-Wei Liang, MD, and Chun-Ming Huang, MD

From: Department of Orthopedics Surgery, Gaozhou People's Hospital, No 89, Xi-Guan Road, Guangdong 525200, China

Address Correspondence:
Chun-Ming Huang, MD
Department of Orthopedics Surgery
Gaozhou People's Hospital
No 89, Xi-Guan Road,
Guangdong 525200, China
E-mail:
155328540 2@qq.com

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Background: Traditional discectomy surgery (TDS) provides good or excellent results in clinical surgical discectomy but may induce neural adhesion, spinal structural damage, instability, and other complications. The potential advantages of full-endoscopic (FE) procedures over standard TDS include less blood loss, less postoperative pain, shorter hospitalization, and an earlier return to work. However, more evidence is needed to support this new technology in clinical applications.

Objective: The aim of this systematic review and meta-analysis was to compare the safety and efficacy of FE and TDS.

Study Design: Comprehensive systematic review and meta-analysis of the literature.

Methods: Electronic databases, including PubMed, EMBASE, SinoMed, and Cochrane Library, were searched to identify clinical therapeutic trials comparing FE to TDS for discectomy.

Results: Six trials comprising 730 patients were included, and the overall quality of the literature was moderate, including 4 Grade I levels of evidence (4 randomized controlled trials, [RCTs]) and 2 Grade II levels (2 non-RCTs). The pooled data revealed no difference in reoperation rates between FE and TDS (P = 0.94), but the complication rate was significantly lower in the FE group (3.86%) than in the TDS group (11.4%). Perioperative parameters (operation time, blood loss, hospitalization time, and return to work days) were significantly lower in the FE group ($P < 0.05$ for all groups using either score). Postoperative pain and neurology score assessments were conducted at 4 different time points at 3 months, 6 months, 12 months, and 24 months. Significant differences were detected in the following: lumbar North American Spine Society (NASS) pain at 6 months ($P = 0.008$); cervical NASS neurology at 6 months ($P = 0.03$); visual analog scale (VAS) score in leg at 3 months ($P < 0.001$); VAS score in arm at 24 months ($P = 0.002$); VAS score in neck at 3 months, 6 months, and 12 months after therapy ($P = 0.003$, $P = 0.004$, $P = 0.01$); and VAS score in neck at 3 months and 6 months ($P = 0.01$, $P = 0.004$). Moreover, the pooled data revealed no statistically significant differences in improvements in the Oswestry disability index (ODI), instability (X-ray), and Hilibrand criteria ($P > 0.05$ for all groups).

Limitations: Only 6 studies were included, 4 of which had the same authors. Between-study heterogeneity due to differences in socioeconomic factors, nutrition, and matching criteria is difficult to avoid.

Conclusions: Based on this meta-analysis of 24 months of clinical results, we conclude that the FE procedure is as effective as TDS but has the additional benefits of lower complication rates and superior perioperative parameters. In addition, patients may experience less pain with FE techniques due to a smaller incision and less operative injury. However, large-volume, well-designed RCTs with extensive follow-up are needed to confirm and update the findings of this analysis.

Key words: Full-endoscopic, minimally invasive, discectomy, meta-analysis

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Neck and back pain are the most common disorders in orthopedic clinics and are mainly due to disc degeneration. These disorders not only lead to heavy social and familial financial burdens but also impact the mental health of patients (1-4). According to recent research statistics (2), in the United States, economic losses caused by neck pain exceed 100 billion US dollars annually. Conventional open surgical techniques provide good or excellent results in patients whose symptoms fail to improve with conservative management (5,6), but these techniques may induce neural adhesion, spinal structural damage, instability, and other complications (7-11).

Minimally invasive surgery, though different from conventional open surgery, should be nearly or exactly as effective as conventional open techniques (12). Several recent systematic reviews have compared minimally invasive discectomy, but these studies were limited to tubular or microendoscopic surgery or other surgical procedures (9,12-19). Full-endoscopic (FE) discectomy (20,21) is a new type of minimally invasive spinal surgery designed to reduce surgical trauma, accelerate postoperative recovery, and maintain the integrity of the normal anatomy of the spine. However, it may be associated with increased risks of neurological injury, incidental durotomy, and reoperation (22-24). In addition, a learning curve is required before surgeons can use this technique effectively and reliably (25-27). Therefore, the use of this technique should be guided by high-quality evidence (28). However, there is still no quantitative evidence about whether FE achieves better or worse outcomes than traditional discectomy surgery (TDS).

Thus, a meta-analysis is needed to examine the improvement in clinical outcomes, perioperative parameters, and complications for FE discectomy versus TDS. The aim of this study was to compare the efficacy and safety of FE discectomy and TDS.

Methods

We followed the protocol outlined in the Cochrane Handbook for Systematic Reviews of Interventions (29). The study was designed and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement (30,31).

Search Strategy

The PubMed, EMBASE, MEDLINE, SinoMed, and Cochrane Library databases were searched on January 31, 2015, without restriction to regions, publication types, or language. Information retrieval was specific to human studies. The search strategy is shown in Fig. 1, and the related articles function was also used to broaden the search. The computer search was supplemented with manual searches of the reference lists of all retrieved studies and review articles.

Eligibility Criteria

Two reviewers independently extracted relevant information from each eligible study. Information about the characteristics of the study participants, details of the interventions used, and comparisons as well as relevant outcomes were recorded. Clinical studies in the form of randomized controlled trials (RCTs) or non-randomized controlled trials (non-RCTs) in any phase were included. The exclusion criteria were as follows: comparative single-arm or no sham trials, case series, case reports, review articles, editorials, letters, surveys, economic studies, articles on laparoscopic spinal fusion, and unrelated publications. Finally, the outcomes were cross-checked independently, and any inconsistencies in results were discussed. The exhaustive searches are detailed in Table 1.

Methodological Evaluation and Data Analysis

The quality of each included study was evaluated by the Cochrane Handbook for Systematic Reviews of Interventions (version 5.1.0). RCTs were evaluated using the Cochrane Collaboration tool for assessing the risk of bias (29), and non-RCTs were assessed using the modified Newcastle-Ottawa scale (32,33), which consists of 3 factors: patient selection, comparability of the study groups, and assessment of outcome. A score of 0 – 9 (allocated as stars) was allocated to each study. Studies achieving 6 or more stars were considered high quality. All meta-analyses were performed using Review Manager 5.2.0 (Cochrane Collaboration, UK). The weighted mean difference (WMD) and risk ratio (RR) were used to compare continuous and dichotomous variables, respectively. All results are reported with 95% confidence intervals (CIs). Statistical heterogeneity between studies was assessed using the chi-square test. Values of $I2 > 50\%$ or $P < 0.10$ indicated heterogeneity between different trials. When the standard deviation (SD) could not be obtained, to obtain more credible results, we evaluated the SD as half the mean (M) in 4 trials (34-37).

Quality Assessment

The quality of the evidence was assessed according to the guidelines of the Grading of Recommendations,

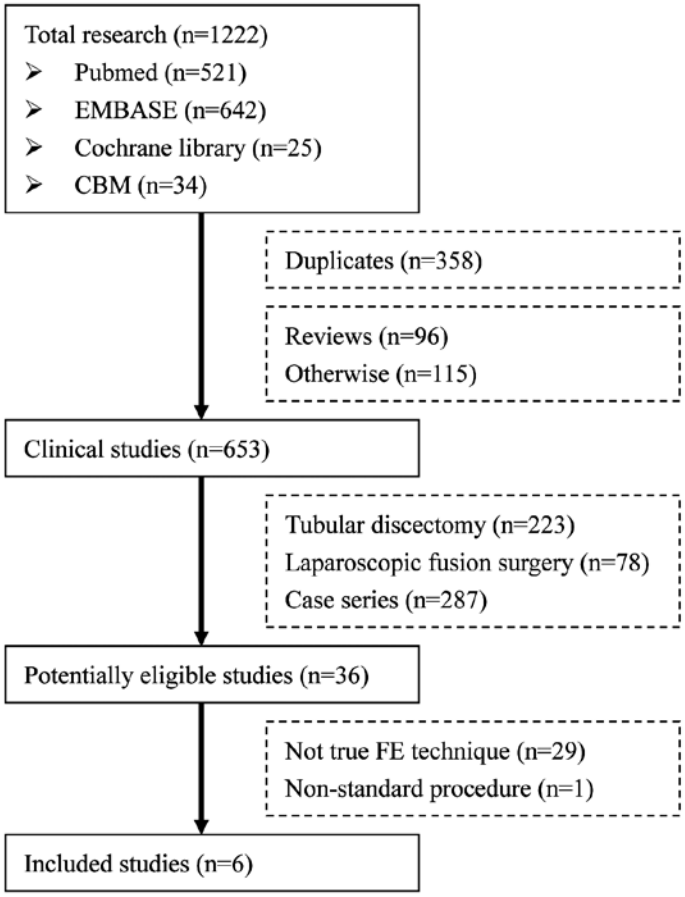

Fig. 1. *Flow diagram sketches the current systematic review and meta-analysis identified, screened, included and excluded.*

Assessment, Development, and Evaluation (GRADE) working group (38-40). The evidence grades are divided into the following categories: (1) high, which indicates that further research is very unlikely to change confidence in the effect estimate; (2) moderate, which indicates that further research is likely to significantly alter confidence in the effect estimate and may change the estimate; (3) low, which indicates that further research is very likely to significantly change confidence in the effect estimate and to change the estimate; and (4) very low, which indicates that any effect estimate is uncertain.

Data Synthesis

A meta-analysis and comparison were conducted if 2 or more included studies involved clinical and statistical homogeneous results. When not possible due to the small number of studies or heterogeneity, a qualitative descriptive analysis was performed.

Results

The PubMed, EMBASE, SinoMed, and Cochrane Library databases were searched (Fig. 1). Six studies including 730 cases fulfilled the predefined inclusion criteria (34-37,41,42). Examination of the references cited in these studies and review articles did not yield any further studies for evaluation.

Characteristics of Eligible Studies

The detailed information of the 6 trials (4 RCTs and 2 non-RCTs) included in the meta-analysis are summarized in Table 1. There were 2 trials (35,37) of cervical discectomy and 4 studies of lumbar discectomy (34,36,41,42). In the FE treatment group, 3 trials used a

Table 1. *Characteristics of the 6 included studies.*

Characteristic	Lee 2009 (41)		Ruetten 2008 (37)		Ruetten 2008 (36)		Ruetten 2009 (34)		Ruetten 2009 (35)		Wang 2011 (42)	
Study design/ Level of evidence	Non-RCT/2b		RCT/1b		RCT/1b		RCT/1b		RCT/1b		Non-RCT/2b	
Surgical site	Lumbar		Cervical		Lumbar		Lumbar (recurrent)		Cervical		Lumbar (recurrent)	
Follow-up duration	34 months		24 months		24 months		24 months		24 months		20 months	
Participants (m:f)	54 patients (38:16)		200 patients (68:132)		200 patients (84:116)		100 patients (56:44)		120 patients (43:77)		56 patients (33:23)	
Age:	45 (26–67) years		43 (27–62) years		43 (20–68) years		39 (23–59) years		(30–61) years		FE: (36±8) days TDS: (35±9) days	
Duration:	>28days		94 (5–240) days		82 (1–480) days		69 (1–390) days		(4–128) days		FE: (69±26) days TDS: (66±24) days	
Conservative treatment time	mean: 6w		mean: 10w (171/200)		mean: 9w (162/200)		mean: 9w (79/100)		NA		NA	
Intervention/ Comparison	FE=25; TDS=29 (NA)		FE=100; TDS=100 (WOLF)		FE=100; TDS=100 (WOLF)		FE=50; TDS=50 (WOLF)		FE=60; TDS=60 (WOLF)		FE=28; TDS=28 (WOLF)	
	L4-5: 25	L4-5: 29	C4-5: 7 C5-6: 20 C6-7: 55 C7-T1: 14	C4-5: 11 C5-6: 22 C6-7: 61 C7-T1: 10	L5-S1: 38 L4-5: 33 L3-4: 20 L2-3: 7 L1-2: 2	L5-S1: 39 L4-5: 31 L3-4: 25 L2-3: 5 L1-2: 0	L5-S1: 17 L4-5: 24 L3-4: 6 L2-3: 3	L5-S1: 21 L4-5: 18 L3-4: 10 L2-3: 1	C3-4: 2 C4-5: 9 C5-6: 29 C6-7: 20 C7-T1: 2	C3-4: 1 C4-5: 9 C5-6: 26 C6-7: 21 C7-T1: 3	L5-S1: 22 L4-5: 6	L5-S1: 15 L4-5: 13
Outcomes	VAS scores, ODI improvements, Perioperative parameters, MRI/CT and X-rays, Complications		VAS scores, NASS scores, Perioperative parameters, Hilibrand criteria, Complications		VAS scores, ODI improvements, NASS scores, Perioperative parameters, Complications		VAS scores, ODI improvements, NASS scores, Perioperative parameters, Complications		VAS scores, NASS scores, Perioperative parameters, Hilibrand criteria, MRI/CT and X-rays, Complications		VAS scores, Perioperative parameters, Complications	

Note: RCT: Randomized controlled trial; FE: Full-endoscopic group; TDS: Traditional discectomy group; VAS: Visual analogue scale; ODI: Oswestry disability index; NASS: North American Spine Society Instrument; w: weeks; m:male; f: female; NA: Not available.

foraminotomy approach (35,41,42), 2 used an interlaminar or transforaminal pathway (34,36), and one used a transdiscal method (35). In the TDS procedure, 4 trials used microsurgical sequestrectomy (34,36,41,42) and 2 used microsurgical Anterior Cervical Discectomy and Fusion (ACDF) polyetheretherketone (PEEK) cage, no plate) (35,37).

Methodological Quality of Included Studies

Four RCTs (34-37) provided a moderate level of evidence due to a lack of allocation concealment (Table 2), and 2 non-RCTs (41,42) were estimated to be of high quality according to the modified Newcastle-Ottawa scale (Table 3). Overall, the total risk of bias of the included studies is considered moderate.

Quality of Evidence

The quality of the evidence was evaluated and shown in Table 4 (43,44). All RCTs were downgraded by one level following the GRADE guidelines (38-40) due to limitations in risk of bias. The RCTs (34-37) were graded as moderate quality. The quality of the non-RCTs (41,42) was not upgraded and denoted as low due to a lack of allocation concealment and the blinding of participants and personnel. Therefore, 2 non-RCTs were considered to provide low-quality evidence.

Table 2. *Bias of risk in randomized controlled trials*

	Ruetten 2008 (Cervical) (37)	Ruetten 2008 (Lumbar) (36)	Ruetten 2009 (Cervical) (35)	Ruetten 2009 (Lumbar) (34)
Random sequence generation	Unclear risk	Unclear risk	Low risk	Unclear risk
Allocation concealment	High risk	High risk	High risk	High risk
Blinding of participants and personnel	High risk	High risk	High risk	High risk
Blinding of outcome assessment	Low risk	Low risk	Low risk	Low risk
Incomplete outcome data	Low risk	Low risk	Low risk	Low risk
Selective reporting	Low risk	Low risk	Low risk	Low risk
Other bias	Low risk	Low risk	Low risk	Low risk

Table 3. *Modified Newcastle-Ottawa Scale (NOS) scores for non-RCT studies*

Study	Selection	Comparability	Outcomes	Quality score
Lee 2009 (Lumbar) (41)	2	3	2	7
Wang 2011 (Lumbar) (42)	2	3	2	7

Table 4. *Grading of clinical studies following GRADE guidelines.*

References	Study design	Risk of bias	Indirectness	Imprecision	Publication bias	Large effect	Plausible residual confounding	Total	Quality of evidence
Lee et al 2009 (41)	Non-RCT	-2	0	0	0	0	0	-2	low
Ruetten et al 2008 (36)	RCT	-1	0	0	0	0	0	-1	moderate
Ruetten et al 2008 (37)	RCT	-1	0	0	0	0	0	-1	moderate
Ruetten et al 2009 (34)	RCT	-1	0	0	0	0	0	-1	moderate
Ruetten et al 2009 (35)	RCT	-1	0	0	0	0	0	-1	moderate
Wang et al 2011 (42)	Non-RCT	-2	0	0	0	0	0	-2	low

RCT: Randomized controlled trial

Complications

All included studies reported the outcome of complications with low heterogeneity (Fig. 2). There were 14/363 complications in the FE group and 42/367 complications in the TDS group, and the pooled data indicated a significant difference favoring the FE group (RR: 0.35; 95% CI, 0.19 – 0.63; $P < 0.001$, Fig. 2). Analyses of the cervical and lumbar subgroups also revealed a lower incidence of complications in both groups (Cervical subgroup: RR: 0.43; 95% CI: 0.15 – 1.20, $P = 0.11$; Lumbar subgroup: RR: 0.31; 95% CI: 0.15 – 0.65, $P = 0.002$; Fig. 2).

Reoperation

The incidence of reoperation was reported in 5 studies, and the heterogeneity was low (Fig. 3). In the FE group, 25/335 cases required a second operation, compared to 25/339 cases in the TDS group. The incidence of reoperation did not differ significantly between the groups (RR: 1.02; 95% CI, 0.59 – 1.75; $P = 0.94$, Fig. 3). In the subgroup analysis, there were no significant differences between the FE group and TDS group (Cervical subgroup: RR: 1.43; 95% CI: 0.56 – 3.66, $P = 0.46$; Lumbar subgroup: RR: 0.86; 95% CI: 0.45 – 1.67, $P = 0.66$; Fig. 3).

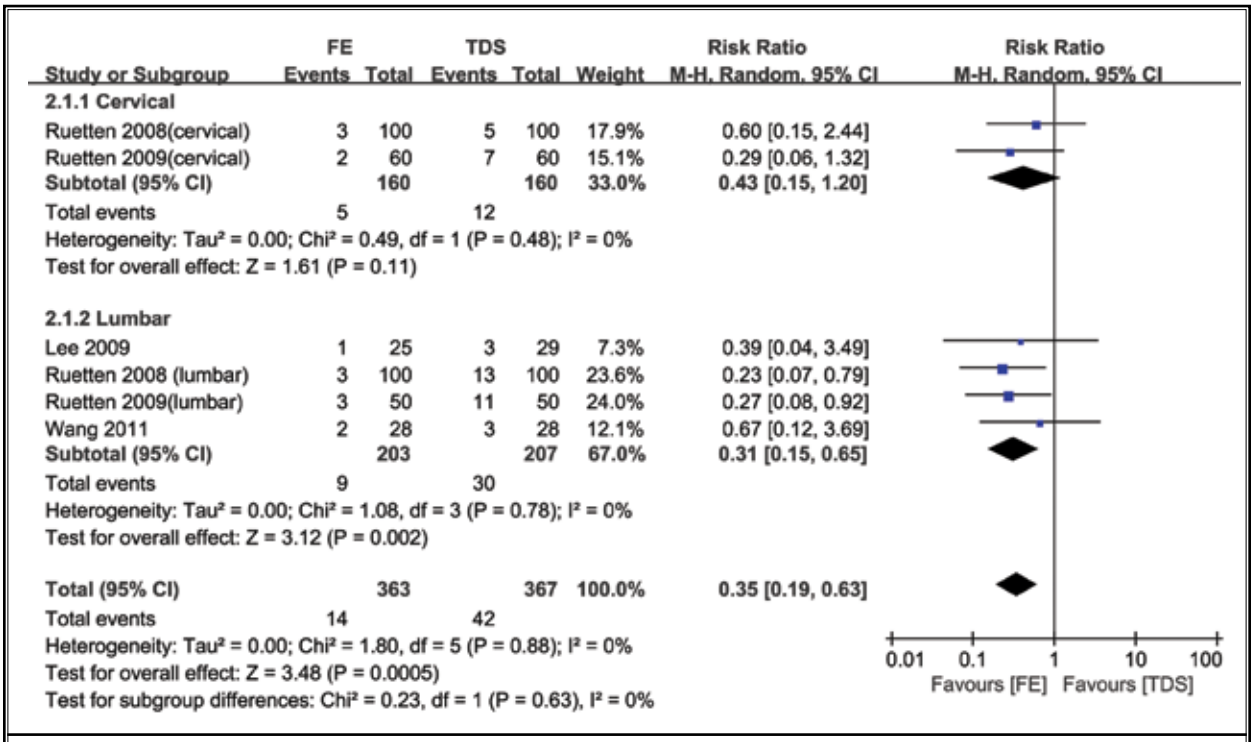

Fig. 2. Forest plot and meta-analysis of complications.

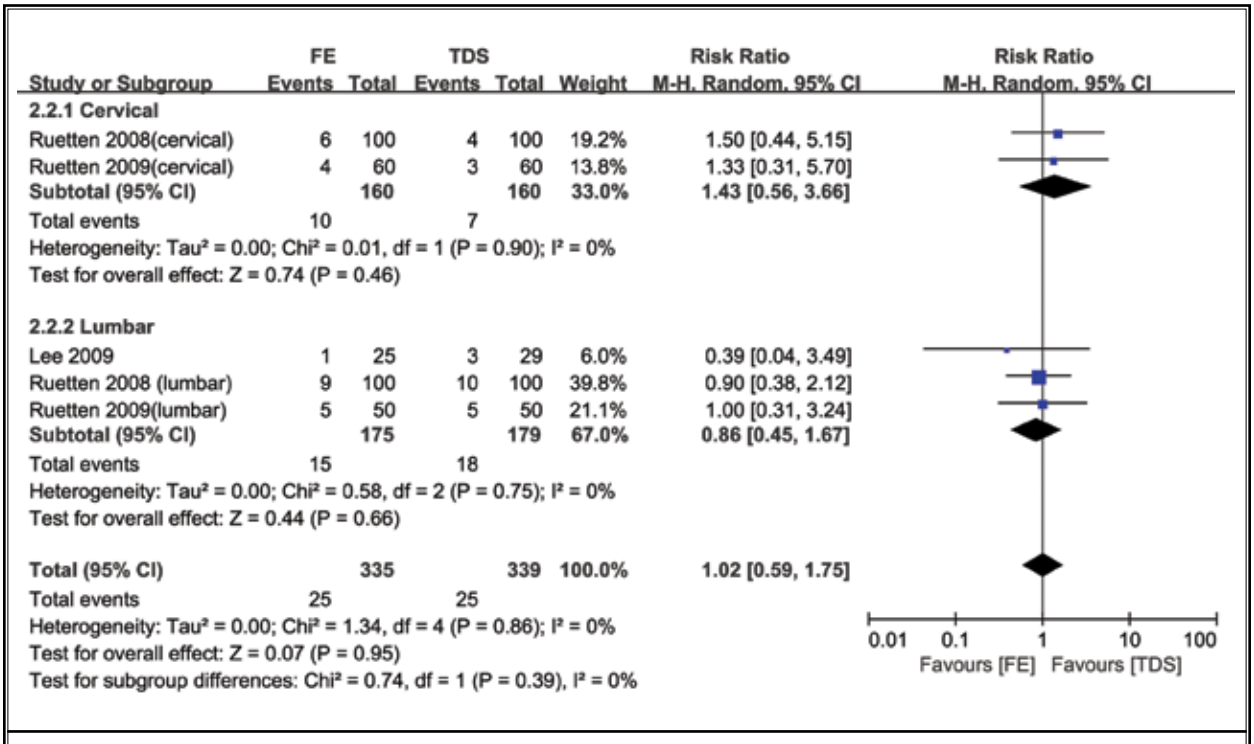

Fig. 3. *Forest plot and meta-analysis of reoperation rate.*

Perioperative Parameters

All 6 studies reported operation time. The pooled analysis revealed a shorter operation time in both the cervical and lumbar groups (Cervical WMD: -35.34; 95% CI: -45.12 – -25.56; $P < 0.001$; Lumbar WMD: -18.48; 95% CI: -33.48 – -3.47; $P < 0.001$; Table 4, Fig. 4). Five studies reported perioperative blood loss, and pooling the data revealed a statistically significant difference favoring the FE group (Cervical WMD: -5.00; 95% CI: -5.87 – -4.13; $P < 0.001$; Lumbar WMD: -43.48; 95% CI: -54.70 – -32.25; $P < 0.001$; Table 4, Fig. 4). The hospital stay was published in 3 studies, and the pooled data indicated shorter hospital stays in the FE group (Cervical WMD: -9.33; 95% CI: -20.11 – 1.44; $P = 0.09$; Lumbar WMD: -12.16; 95% CI: -17.24 – -7.09; $P < 0.001$; Table 4, Fig. 4). Three trials provided the days until return to work, and the results revealed a shorter time in the FE group (Cervical WMD: -15.00; 95% CI: -18.87 – -11.13; $P < 0.001$; Lumbar WMD: -24.00; 95% CI: -28.58 – -19.42; $P < 0.001$; Table 4, Fig. 4).

Clinical Outcomes

Clinical Outcomes

According to the complete depiction of the radicular pain status after 2 years, the clinical outcomes were divided into the following 3 types: no pain, occasional pain, and no improvement. The first 2 results were considered effective clinical outcomes. Pooled analysis of 3 studies including 500 patients revealed no significant differences between the groups (Cervical subgroup: RR: 1.01; 95% CI: 0.92 – 1.12, $P = 0.82$; Lumbar subgroup: RR: 1.05; 95% CI: 1.00 – 1.10, $P = 0.05$; Fig. 5, Table 6).

Results of Different Meta-analysis Outcomes of NASS and VAS Scores

Data were pooled from 4 studies of 620 patients, and the primary results of the overall meta-analyses of the NASS and visual analog scale (VAS) scores are presented in Fig. 6 and Table 5.

The NASS pain score changed in the cervical (0.08, 0.20, -0.13, -0.10, Fig. 6, Table 5) and lumbar groups (0.03, -0.16, 0.13, -0.13, Fig. 6, Table 5), but this change was only significant 6 months after therapy in the cervical group ($P = 0.02$, Fig. 6, Table 5).

The NASS neurology score did not significantly change after therapy at any follow-up time points except at 3 months in the lumbar group (P = 0.008, Fig. 6, Table 5).

The arm VAS score was reduced at 3 months, 6 months, and 24 months (-0.91, -0.93, -1.53, Fig. 6, Table 5) but increased at 12 months (1.91, Fig. 6, Table 5). However, only change in the VAS score at 24 months was statistically significant ($P = 0.002$, Fig. 6, Table 5). The leg VAS score was reduced at all follow-up time points, but none of these changes were significant (Fig. 6, Table 5).

The VAS scores in the neck (-2.86, -2.50, -2.00, -0.09, Fig. 6, Table 5) and back (-2.20, -2.63, -0.83, -1.98, Fig. 6, Table 5) were both reduced after therapy at 3 months, 6 months, 12 months, and 24 months, and this reduction was significant in the cervical group at 3 months, 6 months, and 12 months ($P = 0.003$, $P = 0.006$, $P = 0.01$, Fig. 6, Table 5) and in the lumbar group at 3 months and 6 months ($P = 0.01$, $P = 0.004$, Fig 6, Table 5).

Results of Different Meta-analyses of Hilibrand Criteria and Oswestry Disability Index Improvement

Two trials reported Hilibrand criteria in cervical operations. The pooled analysis revealed no significant difference between the FE and TDS groups at 3 months, 6 months, 12 months, and 24 months (RR: 1.02, RR: 1.01, RR: 1.04, RR: 1.02, Fig. 7, Table 6). Oswestry Disability Index (ODI) improvement was increased at 3 months, 12 months, and 24 months after therapy (0.06, 0.37, 1.60, Fig. 7, Table 6) but was reduced at 6 months (-1.51, Fig. 7, Table 6). None of these changes were statistically significant at any follow-up time point.

Others

Only one study reported postoperative lumbar vertebral instability, and the results revealed no significant difference between the groups (OR: 0.37; 95% CI: 0.01 – 9.65, P = 0.55, Table 6). Twelve patients in cervical operations exhibited progression of pre-existing adjacent disc degeneration (9 × TDS = 18.8%; 3 × FE = 5.9%, not significant).

Discussion

The FE technique was first used in the clinic more than 8 years ago (45,46). Although there have been many publications on endoscopic spine surgery, few controlled studies are available comparing the modern FE procedure to TDS (21). In addition, few review articles about this topic were identified because most of the relevant studies in this field have only recently been published (21).

This systematic review and meta-analysis presents an integrated overview comparing recent studies on

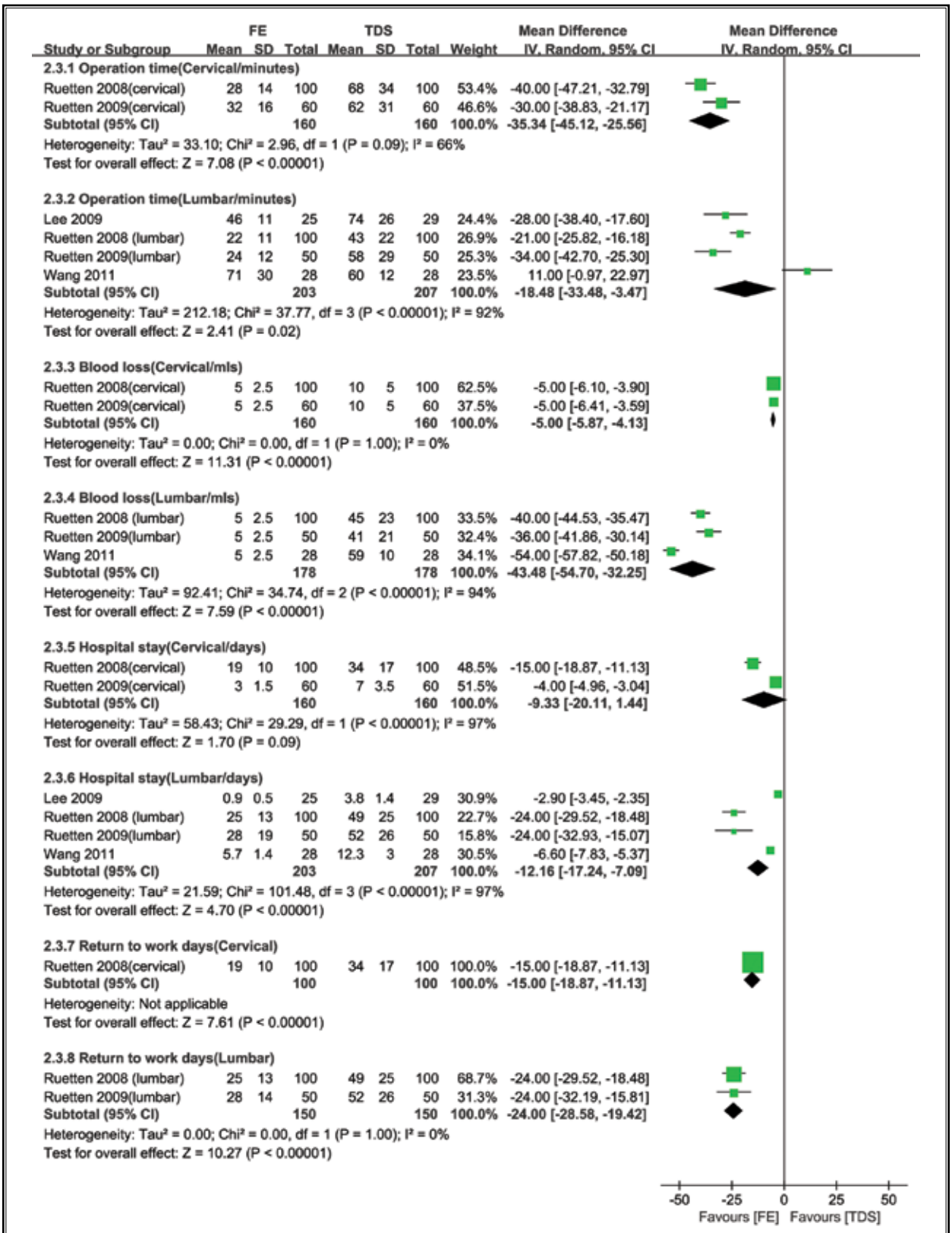

Fig. 4. *Forest plot and meta-analysis of perioperative parameters.*

Table 5. *The results of different meta-analysis outcomes for NASS and VAS scores.*

Outcomes	N	n	Effect estimates	*P*	Heterogeneity test
NASS neurology					
3 months (Cervical)	2	320	0.08 (-0.10, 0.27)	0.39	P = 0.05, I2 = 73%
3 months (Lumbar)	2	300	0.03 (-0.20, 0.26)	0.79	P = 0.69, I2 = 0%
6 months (Cervical)	2	320	0.20 (0.02, 0.38)	0.03	P = 1.00, I2 = 0%
6 months(Lumbar)	2	300	-0.16 (-0.40, 0.07)	0.17	P = 0.69, I2 = 0%
12 months (Cervical)	2	320	-0.13 (-0.02, 0.29)	0.09	P = 0.55, I2 = 0%
12 months(Lumbar)	2	300	0.13 (-0.08, 0.34)	0.22	P = 0.23, I2 = 30%
24 months (Cervical)	2	320	0.08 (-0.11, 0.28)	0.40	P = 0.27, I2 = 18%
24 months(Lumbar)	2	300	0.20 (-0.04, 0.44)	0.11	P = 1.00, I2 = 0%
NASS pain					
3 months (Cervical)	2	320	-0.18 (-0.38, 0.01)	0.06	P = 0.22, I2 = 34%
3 months (Lumbar)	2	300	-0.32 (-0.57, -0.08)	0.008	P = 0.43, I2 = 0%
6 months (Cervical)	2	320	-0.05 (-0.35, 0.24)	0.72	P = 0.09, I2 = 66%
6 months(Lumbar)	2	300	-0.26 (-0.56, 0.03)	0.08	P = 0.24, I2 = 28%
12 months (Cervical)	2	320	-0.07 (-0.25, 0.10)	0.41	P = 0.03, I2 = 79%
12 months(Lumbar)	2	300	-0.16 (-0.41, 0.09)	0.21	P = 0.71, I2 = 0%
24 months (Cervical)	2	320	-0.10 (-0.26, 0.06)	0.22	P = 100, I2 = 0%
24 months(Lumbar)	2	300	-0.13 (-0.39, 0.13)	0.32	P = 0.46, I2 = 0%
VAS score in arm/leg					
3 months (Arm)	2	320	-0.91 (-4.82, 3.01)	0.65	P = 0.002, I2 = 89%
3 months (Leg)	2	300	-3.19 (-4.07, -2.31)	<0.001	P = 0.38, I2 = 0%
6 months (Arm)	2	320	-0.93 (-4.85, 2.99)	0.64	P < 0.001, I2 = 93%
6 months(Leg)	2	300	0.12 (-3.79, 4.03)	0.95	P = 0.001, I2 = 91%
12 months (Arm)	2	320	1.91 (-0.04, 3.86)	0.06	P = 0.05, I2 = 75%
12 months(Leg)	2	300	-0.10 (-4.02, 3.81)	0.96	P = 0.002, I2 = 90%
24 months (Arm)	2	320	-1.53 (-2.51, -0.55)	0.002	P = 0.29, I2 = 12%
24 months(Leg)	4	410	-0.58 (-1.46, 0.29)	0.19	P = 0.15, I2 = 44%
VAS score in neck/back					
3 months (Neck)	2	320	-2.86 (-4.74, -0.97)	0.003	P = 0.13, I2 = 57%
3 months (Back)	2	300	-2.20 (-3.94, -0.45)	0.01	P < 0.001, I2 = 91%
6 months (Neck)	2	320	-2.50 (-4.28, -0.71)	0.006	P = 0.58, I2 = 0%
6 months(Back)	2	300	-2.63 (-4.39, -0.86)	0.004	P < 0.001, I2 = 91%
12 months (Neck)	2	320	-2.00 (-3.56, -0.44)	0.01	P = 1.00, I2 = 0%
12 months(Back)	2	300	-0.83 (-2.67, 1.01)	0.38	P = 0.12, I2 = 59%
24 months (Neck)	2	320	-0.09 (-2.04, 1.86)	0.93	P = 0.24, I2 = 27%
24 months(Back)	4	410	-1.98 (-6.36, 2.40)	0.38	P < 0.001, I2 = 93%

VAS: Visual analogue scale; NASS: German version of the North American Spine Society Instrument; N=numbers of trials; n=numbers of cases

the efficacy and safety of FE and TDS in surgical discectomy. Six trials comprising 730 patients were included and analyzed. Overall the quality of the literature was moderate, including 4 Grade I levels of evidence (4 RCTs) and 2 Grade II levels (2 non-RCTs).

Although the number of studies included in this analysis was small and our data are not sufficient to demonstrate the superior clinical effectiveness of FE over TDS, the results at least indicate the lack of evidence on this issue. Furthermore, there is an absence of strong evidence to support clinical applications. Although the included sample size was not large because

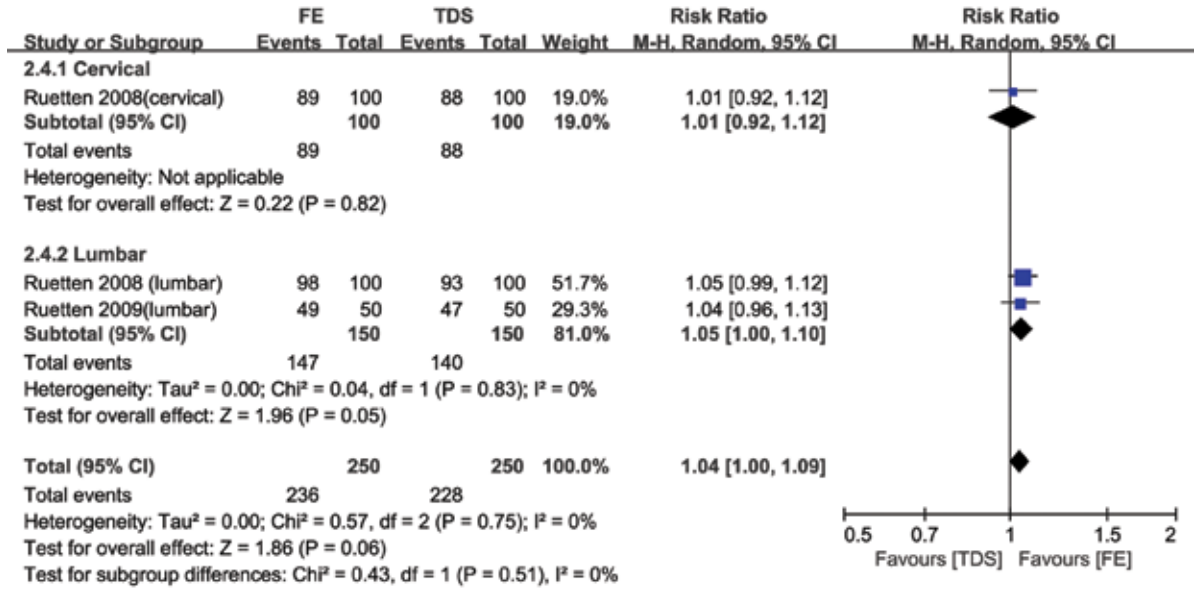

Fig. 5. *Forest plot and meta-analysis of clinical outcomes.*

Table 6. *The results of different meta-analysis outcomes.*

Outcomes	N	n	Effect estimates	P	Heterogeneity test
ODI improvements (Lumbar)					
3 months	2	300	0.06 (-10.68,10.81)	0.99	P = 0.01, I2 = 85%
6 months	2	300	-1.51 (-14.76,12.47)	0.87	P = 0.05, I2 = 74%
12 months	2	300	0.37 (-14.23,14.97)	0.96	P = 0.04, I2 = 77%
24 months	3	354	1.60 (-5.17,8.38)	0.64	P = 0.28, I2 = 21%
Instability (X-ray)	1	54	0.37 (0.01,9.56)	0.55	NA
Hilibrand criteria (Cervical)					
3 months	2	290	1.02 (0.97,1.06)	0.45	P = 0.50, I2 = 0%
6 months	2	289	1.01 (0.96,1.06)	0.66	P = 0.87, I2 = 0%
12 months	2	286	1.04 (0.98,1.09)	0.19	P = 0.48, I2 = 0%
24 months	2	274	1.02 (0.46,2.29)	0.29	P = 0.73, I2 = 0%
Clinical result	3	500	1.80 (0.93,3.45)	0.08	P = 0.51, I2 = 0%

ODI: Oswestry disability index; N=numbers of trials; n=numbers of cases

this is a relatively new technology, our conclusions are supported by the comprehensive evidence of credible outcomes from 730 cases in clinical trials. Therefore, the results of our meta-analysis are credible.

Although we have not provided a systematic and complete evaluation index for comparing the FE and TDS procedures, the main aspects of the clinical application were all included. In particular, as a new type of technology, our major concerns are the assessment of safety. Based on data from 6 trials including 730 patients and of low heterogeneity (Fig. 2), our analysis indicated a reduced incidence of complications in the FE group (14/363; 3.86%) compared to the TDS group (42/367, 11.4%). The subgroup analyses of the cervical (2 trials) and lumbar (4 trials) groups were also similar. In addition, the incidence of reoperation reported in 5 studies also showed no significant difference between the groups in the incidence of reoperation (FE group:

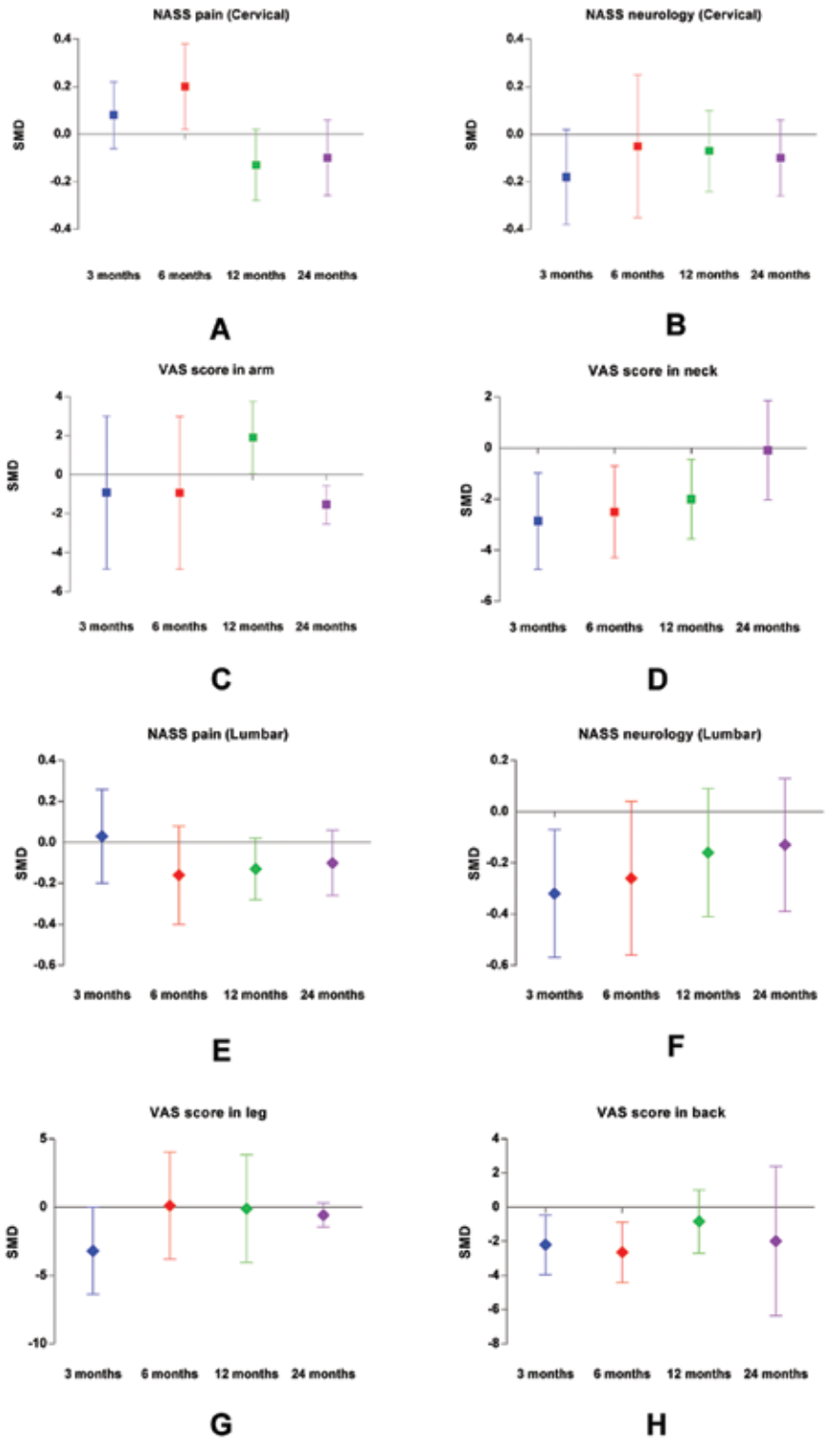

Fig. 6. *Dynamic results of different meta-analysis outcomes of NASS and VAS scores.*

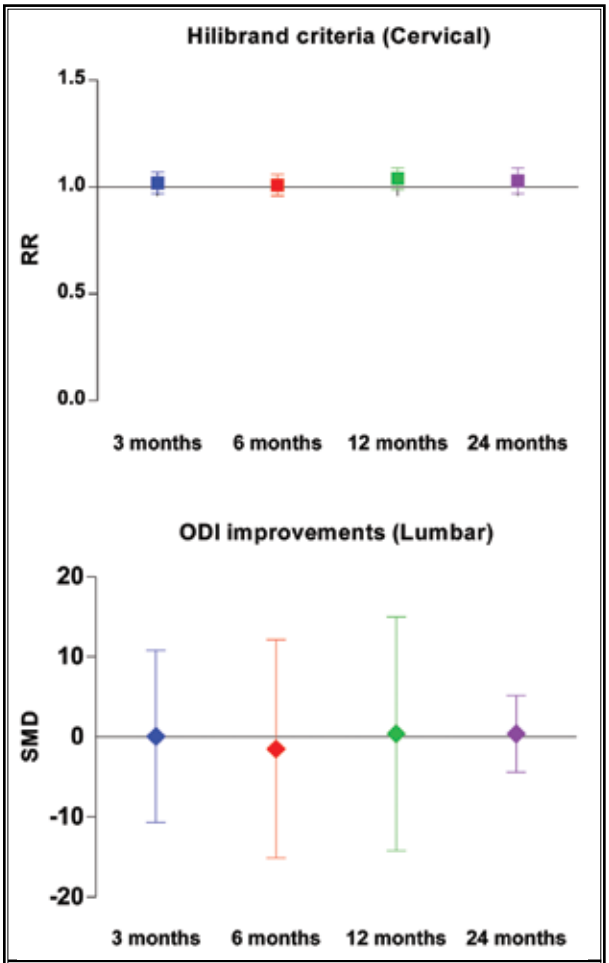

Fig. 7. *Dynamic results of different meta-analyses of Hilibrand criteria and Oswestery disability index improvement.*

25/335; TDS group: 25/339. RR: 1.02; $P = 0.94$, Fig. 3). In the subgroup analyses, there were also no significant differences between the FE group and TDS group (cervical subgroup: RR: 1.43; $P = 0.46$; lumbar subgroup: RR: 0.86; $P = 0.66$; Fig. 3). In a word, there is accumulating data to support minimally invasive spine surgery techniques (47-51), and these data may factor into the decision of when to use these techniques.

The comparison of perioperative parameters revealed significantly less blood loss ($P < 0.001$) and shorter operation times ($P < 0.05$) in the FE group compared to the TDS group (in both the cervical and lumbar subgroups). In addition, the FE procedure allows patients to leave the hospital sooner and return to work faster than the TDS procedure ($P < 0.05$ in all groups). These outcomes may reflect the incisions and muscle dissection involved in the procedures. The FE equipment is inserted through the paraspinal musculature directly over the targeted segment (52).

Clinical results were evaluated in 3 trials, and no significant differences in clinical efficacy between FE and TDS were identified. Moreover, this meta-analysis provides a dynamic detailed comparison of results, which is more convincing than merely contrasting end-point events. Although our data did not provide a definitive conclusion about which procedure is better or worse, the trend of the comparison result could be extrapolated and provide some useful evidence. For the NASS neurology, although a statistically significant reduction was only observed in the cervical subgroup at 6 months, there was evidence of a trend of higher scores for the FE procedure compared with the TDS procedure. Similarly, a trend of lower pain scores was observed in the FE group compared to the TDS group for both the cervical and lumbar NASS and VAS pain scores. In the cervical group, the Hilibrand criteria were used to evaluate efficacy in the 2 groups, and no differences were identified. In the lumbar group, there was also no difference in ODI improvement. Moreover, there were no differences in lumbar vertebral instability and adjacent disc degeneration, which may indicate that the FE surgical procedure can obtain a clinical outcome as effective as conventional open surgery (53-55).

We also searched systematic reviews and meta-analyses comparing minimally invasive discectomy to open discectomy (12,14,16-18,56). Most of the articles identified focused on microendoscopic discectomy and tubular discectomy. Of the 6 publications included in our study, 3 articles included one FE study, one included 2 studies, and one included 3 studies. None of the studies were about the FE procedure as a new technique being used in the clinic alone. This suggests a lack of evidence-based research. In our study, the 6 articles were all published within the last 3 years, which may indicate that minimally invasive discectomy is on the rise in clinical application.

This meta-analysis also has limitations. First, only 6 studies were included, and 4 of these had the same authors because of a lack of published literature. Second, in 4 clinical trials, the SD was estimated as half the mean of the clinical results for perioperative parameters, VAS and NASS, but this estimate did not affect the primary results. Third, some of the studies did not use the same surgical approach, but for this meta-analysis, the FE or TDS approaches were assumed to be similar. Finally, some between-study heterogeneity may be attributable to socioeconomic factors, nutrition, and matching

Table 7. *Systematic review and meta-analysis of minimally invasive discectomy vs open discectomy.*

Author	Year	Publication type	N	n	Patient	Intervention and Comparison		Outcome
						MID	OD	
Dasenbrock et al (14)	2012	M	6	837	DH	FE (1) MED (3) TUB (2)	6	Current evidence suggests that both OD and MID lead to a substantial and equivalent long-term improvement in leg pain. Adequate decompression may be the primary determinant of pain relief. Incidental durotomies occurred significantly more frequently during MID, but total complications did not differ between the techniques.
Rasouli et al (18)	2014	Cochrane review	11	1172	LDH	FE (1) MED (4) TUB (3) Others (3)	11	MID may be inferior in terms of relief of leg pain, LBP, and re-hospitalization; however, the differences in pain relief appeared to be small and may not be clinically important. The potential advantages of MID are lower risk of surgical site and other infections. MID may be associated with shorter hospital stay, but the evidence was inconsistent.
Kamper et al (17)	2014	S and M	29	4472	LDH	FE (2) Others (27)	29	There is moderate to low quality evidence of no differences in clinical outcomes between MI surgery and conventional microdiscectomy for LDH patients.
Evaniew et al (12)	2014	S and M	14	1590	DH	FE (3) MED (4) TUB (7)	14	Current evidence does not support the routine use of minimally invasive surgery for cervical or lumbar discectomy. Well-designed trials are needed given the lack of high-quality evidence.
Eichen et al (56)	2014	S and M	27	3211	DH	FE (0) Others (27)	27	Nucleoplasty reduces pain long term and improves patients' functional mobility. It is an effective, low-complication, minimally invasive procedure used to treat disc herniations.
Chang et al (16)	2014	M	16	2139	LDH	FE (1) MED (6) Others (9)	16	MID results in less suffering for patients during the hospital course with a similar clinical efficacy compared to OD. However, greater effort is required to reduce disc herniation recurrence to popularize MID.

S: Systematic Review; M: Meta-analysis; TUB: Tubular discectomy; MED: Microendoscopic discectomy; FE: Full-endoscopic discectomy; DH: Disc herniation; LDH: Lumbar disc herniation; LBP: low back pain; MID: Minimally invasive discectomy; OD: open discectomy.

criteria. These differences might be reduced by using a random-effects model but may not abolish it.

Conclusion

Based on this systematic review and meta-analysis of 24 months of safety and efficacy in clinical application, we conclude that the FE procedure is as effective as TDS but has the additional benefits of fewer complications and superior perioperative parameters. However, large-volume, well-designed RCTs with extensive follow-up are needed to confirm and update the findings of this analysis.

Author Contribution

Drs. LXC, ZCF, and DGB had full access to all data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Drs. LXC and LRW designed the study protocol. Dr. HCM managed the literature searches and summaries of previous related work and wrote the first draft of the manuscript. Drs. LXC, ZCF, and HCM provided revisions of intellectual content and final approval of the manuscript.

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