European Spine Journal (2019) 28:2588–2601
https://doi.org/10.1007/s00586-019-06142-7

ORIGINAL ARTICLE

Complication rates of different discectomy techniques for the treatment of lumbar disc herniation: a network meta-analysis

Xiaolong Chen[1] · Uphar Chamoli[1,2] · Samuel Lapkin[3] · Jose Vargas Castillo[1] · Ashish D. Diwan[1]

Received: 24 May 2019 / Revised: 24 May 2019 / Accepted: 7 September 2019 / Published online: 16 September 2019

Abstract

Purpose The aim of this network meta-analysis (NMA) was to compare the complication rates of discectomy/microdiscectomy, percutaneous laser disc decompression (PLDD), percutaneous endoscopic lumbar discectomy (PELD), microendoscopic discectomy (MED), and tubular discectomy for symptomatic lumbar disc herniation (LDH).

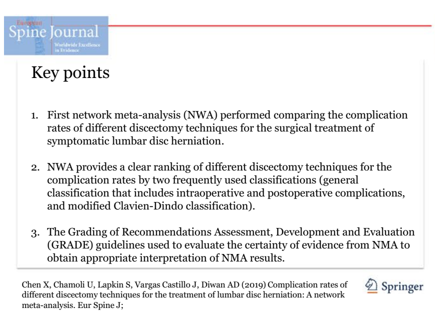
Methods We searched three online databases for randomized controlled trials (RCTs). Overall complication rates, complication rates per general and modified Clavien–Dindo classification schemes, and reoperation rates were considered as primary outcomes. Odds ratio with 95% confidence intervals for direct comparisons and 95% credible intervals for NMA results were reported. Surface under cumulative ranking curve (SUCRA) was used to estimate ranks for each discectomy technique based on the complication rates.

Results In total, 18 RCTs with 2273 patients were included in this study. Our results showed that there was no significant difference in any of the pairwise comparisons. PELD (SUCRA: 0.856) ranked the lowest for overall complication rates. Discectomy/microdiscectomy (SUCRA: 0.599) and PELD (SUCRA: 0.939) ranked the lowest for intraoperative and post-operative complication rates, respectively. Concerning modified Clavien–Dindo classification scheme, PELD (SUCRA: 0.803), MED (SUCRA: 0.730), and PLDD (SUCRA: 0.605) ranked the lowest for the occurrence of type I, II, and III complications, respectively. Tubular discectomy (SUCRA: 0.699) ranked the lowest for reoperation rates.

Conclusions The results of this NMA suggest that discectomy/microdiscectomy and PELD are the safest procedures for LDH with minimal intraoperative and post-operative complications, respectively. PELD, MED, and PLDD are the safest procedures for LDH in terms of minimal rates for complications necessitating conservative, pharmacological, and surgical treatment, respectively.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.



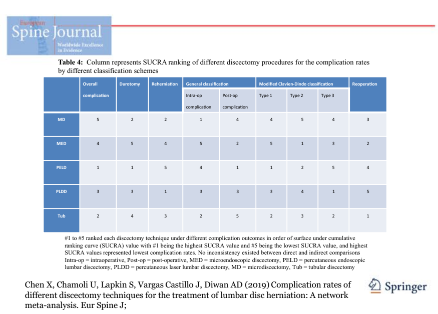
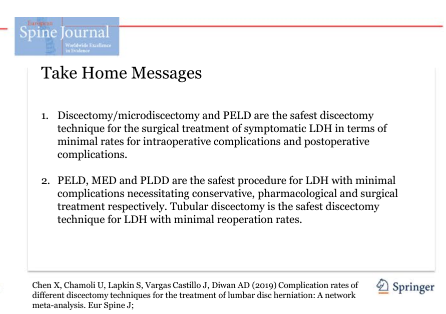


Table 4: Column represents SUCRA ranking of different discectomy procedures for the complication rates by different classification schemes

	Overall complication	Durotomy	Reherniation	General classification		Modified Clavien-Dindo classification			Reoperation
				Intra-op complication	Post-op complication	Type 1	Type 2	Type 3	
MD	5	2	2	1	4	4	5	4	3
MED	4	5	4	5	2	5	1	3	2
PELD	1	1	5	4	1	1	2	5	4
PLDD	3	3	1	3	3	3	4	1	5
Tub	2	4	3	2	5	2	3	2	1

#1 to #5 ranked each discectomy technique under different complication outcomes in order of surface under cumulative ranking curve (SUCRA) value with #1 being the highest SUCRA value and #5 being the lowest SUCRA value, and highest SUCRA values represented lowest complication rates. No inconsistency existed between direct and indirect comparisons Intra-op = intraoperative, Post-op = post-operative, MED = microendoscopic discectomy, PELD = percutaneous endoscopic lumbar discectomy, PLDD = percutaneous laser lumbar discectomy, MD = microdiscectomy, Tub = tubular discectomy



Keywords Lumbar disc herniation · Discectomy · Minimally invasive surgery · Complication · Network meta-analysis

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00586-019-06142-7) contains supplementary material, which is available to authorized users.

Extended author information available on the last page of the article

Introduction

Lumbar disc herniation (LDH) is a common affliction of the lumbar spine, which affects 1–2% of the general population in the USA annually [1–3]. Discectomy surgery is indicated for LDH patients who are nonresponsive to at least six weeks of non-surgical treatment or had a progressive neurological impairment or both [2, 4, 5]. Discectomy is the surgical technique to relieve nerve root compression and improve its function. However, the surgical trauma of spine and its supporting structures could lead to post-operative back pain, spinal instability, and sometimes recurrent herniation [6–8].

Minimally invasive techniques for LDH evolved in the 1970s with the first lumbar microdiscectomy reported in 1977 [9, 10]. A lumbar microdiscectomy procedure has smaller exposure and better visualization of the operative field through a microscope than open lumbar discectomy. Microdiscectomy and open discectomy may be performed using operating loupes with a headlight. Collectively, the two are now the most common surgical procedures for LDH. With the advent of emerging new technologies, further variants of minimally invasive surgical procedures have been developed to treat symptomatic LDH [11, 12] that allow less surgical trauma to the tissues and hence a faster recovery, such as percutaneous laser disc decompression (PLDD) [13], percutaneous endoscopic lumbar discectomy (PELD) [14], tubular discectomy [15], and microendoscopic discectomy (MED) [16].

The utility of any procedure is a complex mix of safety, efficacy, and cost. A procedure that has fewer complications will have a superior clinical utility as it directly impacts efficacy and cost. Different surgical interventions for LDH provide excellent outcomes, although they still carry approximately 20% risk of complications [17] such as durotomy, nerve root injury, haematoma and post-operative pain [18, 19]. Previous studies reporting on the safety and efficacy of different lumbar discectomy surgeries for LDH have not yielded conclusive results due to the pairwise nature of the comparisons [20–30].

Complication rates following different discectomy techniques are conduce to the selection of the surgical plan. However, the definition of complications in spine surgery is controversial. Surgeons routinely divide complications into intraoperative complications and post-operative complications, major and minor complications, and five complication grades following modified Clavien–Dindo classification [19, 31–34]. Although these basic approaches are commonly used, there are no accepted criteria to define major or minor complications. Standardization of the reported outcomes following discectomy for LDH will help surgeons identify, manage, and avoid perioperative and post-operative complications.

Network meta-analyses (NMA) are becoming more influential in informing clinicians and decision-makers as they provide rigorous means for indirect or direct comparisons of multiple interventions or treatments for the same pathology [35, 36]. Given the lack of substantial evidence regarding the hierarchy of different discectomy techniques regarding complication rates, we performed a NMA of all complications reported in discectomy studies to compare the complication rates of open discectomy/microdiscectomy, tubular discectomy, PLDD, PELD, and MED using two classification schemes (general classification that includes intraoperative and post-operative complications, and modified Clavien–Dindo classification).

Methods

Search strategy

Online databases EMBASE, MEDLINE, and Cochrane Central Register of Controlled Trials were searched in accordance with preferred reporting information for systematic reviews and meta-analyses (PRISMA) guidelines to identify all relevant studies published between January 1977 (microdiscectomy first reported) and January 2019 [37]. The search strategy consisted of keywords and commonly used synonyms including "lumbar spine", "intervertebral disc", "herniation", "discectomy", "microdiscectomy", "minimally invasive surgery", "endoscopic", "laser", and "percutaneous discectomy", with appropriate combinations of operators "AND", "OR", and "NOT" as described in the Electronic Supplementary Material 1 (ESM_1). We also evaluated the reference lists of relevant studies and identified additional studies for the purposes of the present study. Only studies published in English were considered. The review protocols were registered on PROSPERO (International Prospective Register of Systematic Reviews number, CRD42019120163).

Inclusion criteria

(1) Randomized controlled trials (RCT);
(2) Studies which reported on discectomy or microdiscectomy or PLDD or PELD or MED or tubular discectomy surgery for symptomatic LDH patients;
(3) Studies which reported at least one of the following outcomes: primary outcomes including overall complication rate and complications in two different classification schemes (General classification and Clavien–Dindo classification). Overall complication included all the complications related to various discectomy surgeries. Intraoperative general complications included mortality, thrombosis, and hepatitis; intraoperative

specific complications include durotomy, bleeding, nerve root injury, surgical error; post-operative general complications included urinary tract infection, miction disturbances (catheter required), pulmonary complication, deep venous thrombosis leg; post-operative specific complications included infection superficial, infection deep, haematoma, reherniation, neurologic problem, skin problem, psychological and coping problems. Modified Clavien–Dindo classification scheme includes five types of complications (type I: conservative treatment, without intervention or pharmacologic treatment; type II: pharmacologic treatment; type III: invasive intervention under general anaesthesia; type IV: intensive care unit management; type V: death).

Secondary outcome included the reoperation rate.

Exclusion criteria

(1) Studies which compared discectomy procedures with other spinal surgeries involving the use of an implant;
(2) Case reports, retrospective studies, reviews, and conference reports; in vitro biomechanical studies, computer modelling studies.

Study selection

Two reviewers (XLC and JVC) independently reviewed all titles and abstracts that were identified in the initial online search of databases. Full-text articles were further reviewed for all the relevant abstracts. Disagreements between the reviewers in the selection process for studies were either resolved by consensus or with the help from a third reviewer (ADD).

Data extraction

Two reviewers (XLC and JVC) extracted data independently using a standardized tool developed for this study. The reviewers collected the following data: methods (study design, sample size, inclusion and exclusion criteria, study period, mean duration of follow-up); participants (number of participants, age, gender); interventions (surgical procedure); and outcomes (for each primary outcome: number of subjects and occurrence rate in general complication classification, modified Clavien–Dindo classification, and reoperation rate).

Assessment of risk of bias in included studies

The 13 criteria recommended in the Cochrane Back and Neck Group guidelines [38] were used to assess the risk of bias. "Low risk", "high risk", or "unclear risk", was used to score the risk of bias for individual criteria. Thereafter, for the overall risk of bias evaluation, we considered a "low overall risk" of bias when seven or more of the 13 criteria were a low risk [38]. Studies with six or less low-risk criteria were considered a "high overall risk" of bias. We conducted a sensitivity analysis to assess the impact of including studies with a high overall risk of bias. As before, controversial scores were resolved by the third reviewer (ADD).

Statistical analysis

Regular meta-analysis was performed with RevMan (Review Manager 5.3 version. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014.). The Chi-squared (I^2) statistic was used to measure heterogeneity among the trials [39]. Statistical analysis software STATA (release 15, StataCorp LLC, TX) was used for performing the NMA [40]. We used the DerSimonian and Laird random-effects model to analyze data. The pooled estimates of odds ratio (OR) and 95% confidence intervals (CI) for direct comparisons and 95% credible intervals (CrI) for NMA results were reported. NMA results were also assessed by means of forest plots. The evaluation of inconsistency of treatment, which estimates whether the treatment effects from direct and indirect evidence are in agreement, is an important aspect of NMA. Node-splitting results were used to evaluate the consistency of each outcome between direct and indirect comparisons. The statistical significance was set at 5% ($\alpha = 0.05$). Surface under cumulative ranking curve (SUCRA) is a numeric presentation of the overall ranking of different techniques compared for hierarchical ordering. SUCRA results were used to evaluate the relative rank of each discectomy technique under different complication outcomes. A higher SUCRA value corresponded to a higher ranking and a lower complication rate in each comparison.

Evaluating the quality of evidence

The Grading of Recommendations Assessment, Development and Evaluation (GRADE) assessment rated the quality of evidence informing this NMA as high, moderate, low, or very low across five components-study limitations, imprecision, inconsistency in results, indirectness, and publication bias [41, 42] (ESM_2_Table 1). Based on GRADE guidelines for rating the certainty of evidence from NMA, NMA "summary of findings (SoF)" tables were used to present NMA results (ESM_2_Table 2).

Results

Selection, quality assessment, and network structure

The selection process for studies is illustrated in the PRISMA flow diagram (Fig. 1). A total of 1563 citations were identified through our literature search, and 12 from the review of the reference list. Of these, 255 studies were selected for abstract assessment after removal of duplicates, and then, 60 studies were selected for full-text article assessment for eligibility. Finally, 18 RCTs met the inclusion criteria for the present study [43–60].

Risk of bias in included studies

We described the risk of selection bias for each study according to the Cochrane Back and Neck Group guidelines [38]. The summary of the risk of bias assessment is presented in Fig. 2. Two out of the 18 studies had a high overall risk of bias [47, 58].

(1) Allocation: five studies were assessed as having a high risk of selection bias [44, 45, 53, 57, 61].
(2) Blinding: eleven studies [43, 45, 46, 50, 53, 57, 59–63] were deemed to have a high risk, and seven studies [44, 47, 48, 51, 52, 54, 58] were classified as unclear in terms of performance bias.

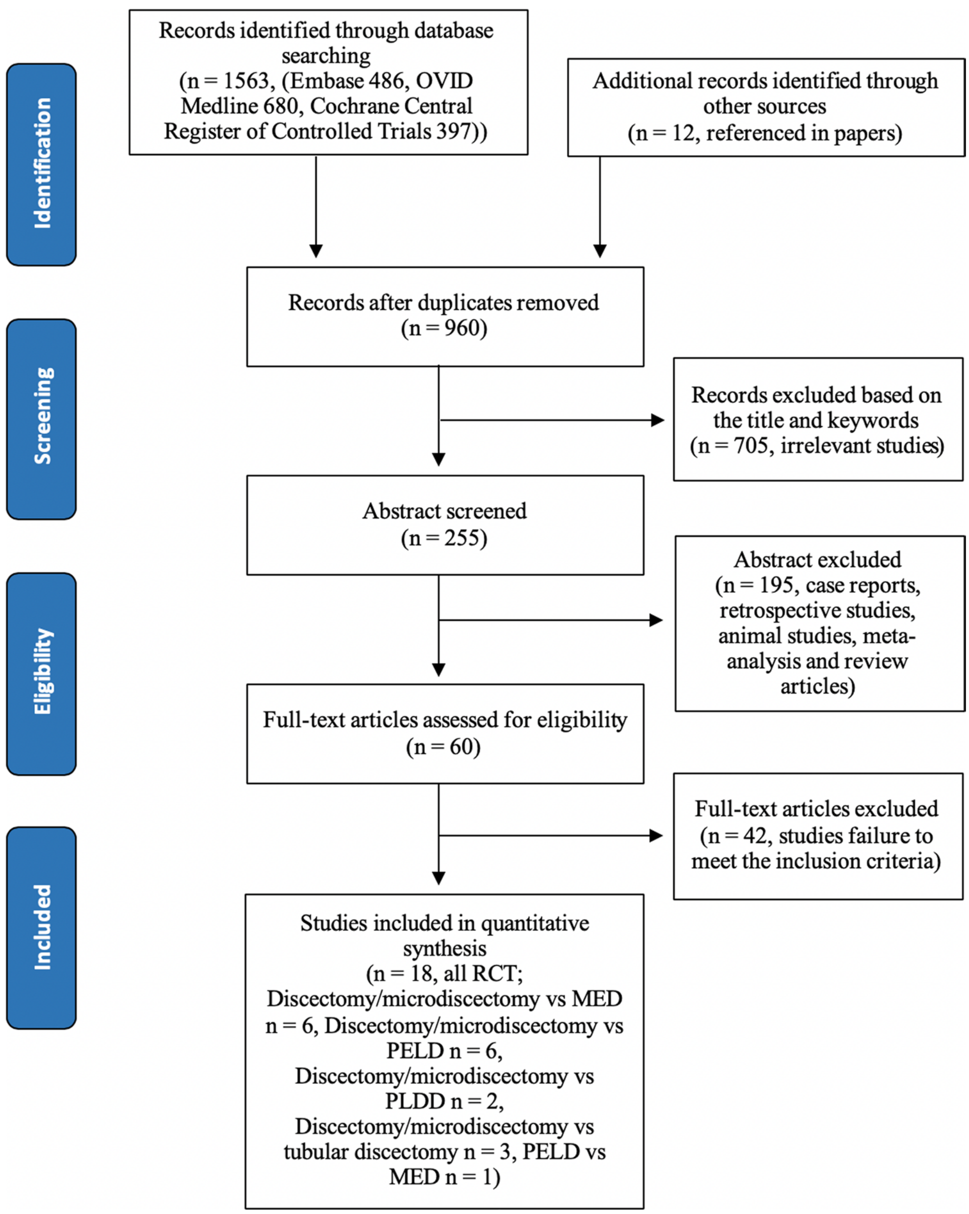


Fig. 1 Flow chart showing the search strategy conducted in accordance with the preferred reporting information for systematic reviews and meta-analyses (PRISMA) guidelines, and the results [37]. *MED* microendoscopic discectomy, *PELD* percutaneous endoscopic lumbar discectomy, *PLDD* percutaneous laser lumbar discectomy, *MD* microdiscectomy

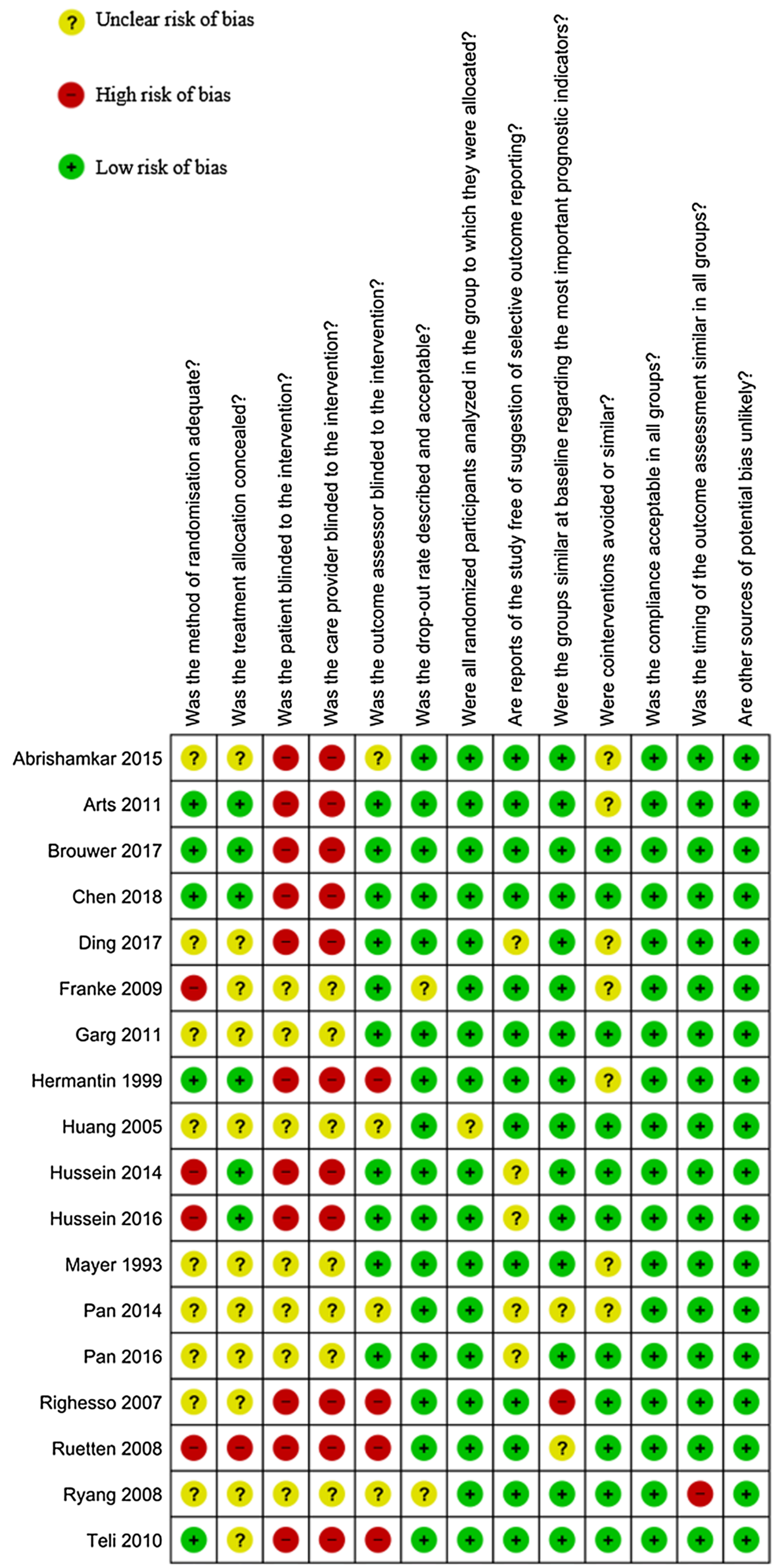


Fig. 2 Risk of bias summary: review authors' judgements about each risk of bias item for each included study. "Was the method of randomization adequate?", "Was the treatment allocation concealed?", and "Were the groups similar at baseline regarding the most important prognostic indicators?" were used to assess the selection bias. "Was the patient blinded to the intervention?", "Was the care provider blinded to the intervention?", "Were cointerventions avoided or similar?", and "Was the compliance acceptable in all groups?" were used to assess the performance bias. "Was the drop-out rate described and acceptable?" and "Were all randomized participants analyzed in the group to which they were allocated?" were used to assess the attrition bias. "Was the outcome assessor blinded to the intervention?" and "Was the timing of the outcome assessment similar in all groups?" were used to assess the detection bias. "Are reports of the study free of suggestion of selective outcome reporting?" was used to assess the reporting bias. "Are other sources of potential bias unlikely?" was used to assess the other bias

(3) Incomplete outcome data: all the studies were assessed as having low attrition bias except three studies that did not clearly report [44, 51, 58].
(4) Outcome assessment: five studies were assessed as having a high risk of detection bias [45, 50, 58, 61, 63].
(5) Selective reporting and other potential sources of bias: none were assessed as having a reporting bias or other bias.

Demographic data, surgical technique, and surgery-related complications from the 18 included studies are provided in Table 1. The number of studies reporting complications rates for different discectomy techniques varied: discectomy/microdiscectomy ($n=17$), MED ($n=7$), tubular microdiscectomy ($n=2$), PLDD ($n=2$), and PELD ($n=7$). The network formed by the direct comparisons between various surgical discectomy techniques is shown in Fig. 3.

Part 1: Pairwise comparisons using NMA

Overall complication rate, general classification of complications, modified Clavien–Dindo classification and reoperation rate related-outcomes The overall complication rates, durotomy rates, reherniation rates, intraoperative complication rates, post-operative complication rates, complication rates by modified Clavien–Dindo classification scheme, and reoperation rates are presented in ESM_2_Table 3 (direct pairwise comparisons) and ESM_2_Table 4 to ESM_2_Table 9 (all the comparisons between each pair of discectomy techniques) and the forest plots in Fig. 4 (NMA comparison). There was no significant difference in any of the pairwise comparisons.

Part 2: Ranking of discectomy techniques using NMA

SUCRA for ranking probability SUCRA was evaluated in order to rationally rank the complication rates among the procedures studied (Table 2). According to the standing list of the primary outcomes, we found that PELD (SUCRA: 0.856) had the lowest overall complication rates, followed by tubular discectomy (SUCRA: 0.506), PLDD (SUCRA: 0.470), MED (SUCRA: 0.351), and MD (SUCRA: 0.316). PELD (SUCRA: 0.672) and PLDD (SUCRA: 0.696) ranked the lowest for durotomy and reherniation rates, respectively. Discectomy/microdiscectomy (SUCRA: 0.599) had the lowest reported incidence of intraoperative complications, and PELD (SUCRA: 0.939) had the lowest reported incidence of post-operative complications. Concerning modified Clavien–Dindo classification of complications, PELD (SUCRA: 0.803), MED (SUCRA: 0.730), and PLDD (SUCRA: 0.605) held the first ranking for the occurrence of types I, II and III, respectively. Tubular discectomy (SUCRA: 0.699) had the lowest reoperation rate, whereas PLDD (SUCRA: 0.163) had the highest.

Part 3: Inconsistency test and evaluating the quality of evidence from NMA

Node-splitting results (Table 3) showed that no inconsistency existed between direct and indirect evidence. In the certainty assessment of NMA estimates of the 90 paired comparisons, 48 warranted low and 42 warranted moderate certainties (ESM_2_Table 10). All the low certainty results of NMA estimates were due to imprecision, inconsistency, and indirectness. The point estimates and credible intervals of comparisons between minimally invasive discectomy surgeries (PELD, MED, PLDD, and tubular discectomy) and discectomy/microdiscectomy showed no significant differences in the overall complication rates, complication rates by general classification and Clavien–Dindo classification, and reoperation rates (ESM_2_Table 10 and Fig. 4). The funnel plot showed no significant publication bias (ESM_3).

Discussion

In this study, we conducted a NMA of complication rates associated with various discectomy techniques for the surgical treatment of LDH. Complication rates in different classification schemes and reoperation data were extracted from 18 RCTs and analyzed. There were no obvious inconsistencies between indirect and direct evidence.

Our results showed that PELD had the lowest overall complication rates of the procedures analyzed. PELD and PLDD had the lowest rates of durotomy and reherniation. However, there is no significant difference between each discectomy technique concerning clinically significant complication and reoperation through direct evidence, which is consistent with the findings of prior meta-analyses [18, 20, 22, 23, 27, 29]. The SUCRA rankings in the present study provide a clear ranking of different discectomy techniques for the complication rates by different classification schemes (Table 4). The procedures from lowest to highest incidence were ordered according to their SUCRA score of overall complication rates as follows: PELD, tubular discectomy, PLDD, MED, and discectomy/microdiscectomy. An advantage with PELD compared to the other techniques is the coexisting of two major features of minimally invasive discectomy techniques: lesser trauma to soft tissues and better visualization of the operative field. We posit this to be the main cause of PELD ranking the lowest for overall complication rates. These findings are inconsistent with previously reported data [64], which may partly be due to the different definitions of surgical technique and complications in the present study.

Table 1 Demographic data, surgical technique and surgery-related complications for the selected studies

Study ID	Study design	Study location	Surgical procedures	Sample size	Gender (M/F)	Age (y)	Follow-up (m)	No. of complications								
								Total no	Intra-op		Post-op		Modified Clavien–Dindo classification			No. of Re-op
									General	Specific	General	Specific	Type I	Type II	Type III	
Garg 2011	RCT	India	MED	55	36/19	37	12	12		5	4	3	11		1	1
			Discectomy	57	44/13	38	12	15		5	9	1	11	3	1	0
Huang 2005	RCT	China	MED	10	6/4	39.2	18.9	1		1				1		0
			Discectomy	12	9/3	39.8	18.9	1				1		1		0
Hussein 2014	RCT	Egypt	MED	95	58/42	30.2	104.2	20		6	3	11	10	3	7	7
			Discectomy	90	54/46	31.5	101.3	23		5	1	17	8	5	10	10
Hussein 2016	RCT	Egypt	MED	37	20/17	30.5	25.5	6		1	2	3	3	1	2	3
			MD	36	21/15	31.9	26.2	11		2	2	7	4	3	4	7
Righesso 2007	RCT	Brazil	MED	21	10/11	42	24	3		1		2	2	1		1
			Discectomy	19	13/6	46	24	1				1		1		1
Teli 2010	RCT	Italy	MED	70	45/25	39	26 ± 2	19		8		11	11	1	8	8
			MD	72	48/24	40	26 ± 3	10		2		8	2	4	4	4
			Discectomy	70	46/24	39	26 ± 2	7		2		5	1	3	3	3
Hermantin 1999	RCT	USA	PELD	30	22/8	39	32									1
			Discectomy	30	17/13	40	31	1		1					1	1
Pan 2014	RCT	China	PELD	10	5/5		6	1				1		1		0
			Discectomy	10	5/5		6	0								0
Ruetten 2008	RCT	Germany	PELD	100	42/58	43	24	9				9	3		6	6
			MD	100	42/58	43	24	17			3	14	12		5	5
Mayer 1993	RCT	Germany	PELD	20	12/8	39.8	24	1				1			1	3
			MD	20	14/6	42.7	24	1				1			1	1
Pan 2016	RCT	China	PELD	48	26/22	39.5	16.7	3				3	3			0
			Discectomy	58	31/27	42.8	17.3	12		2	4	6	12			0
Ding 2017	RCT	China	PELD	50	30/20	41.3	12	1				1	1			0
			Discectomy	50	27/23	43.9	12	3				3		3		0

Table 1 (continued)

Study ID	Study design	Study location	Surgical procedures	Sample size	Gender (M/F)	Age (y)	Follow-up (m)	No. of complications									
								Total no	Intra-op		Post-op		Modified Clavien–Dindo classification			No. of Re-op
									General	Specific	General	Specific	Type I	Type II	Type III	
Abrishamkar 2015	RCT	Iran	Laser	100	82/18	39.7	12	7				7			7	7
			Discectomy	100	78/22	40.2	12	8				8			8	8
Brouwer 2017	RCT	Netherlands	Laser	55	36/19	43.2	24	6				6			6	29
			MD	57	33/24	43.7	24	7				7			7	12
Arts 2011	RCT	Netherlands	Tubular	166	84/82	41.6	24	58	2	18	3	35	42		16	23
			MD	159	88/71	41.3	24	40		15	3	22	30		10	14
Franke 2009	RCT	Germany	Tubular	52	31/21		12	4		2		2	2		2	2
			MD	48	29/19		12	8		3		5	3		5	5
Ryang 2008	RCT	Germany	Tubular	30	19/11	39.1	16	2				2			2	2
			MD	30	13/17	38.2	16	6		2		3	2		4	4
Chen 2018	RCT	China	PELD	80	52/28	40.2	12	11		4		7	6		5	5
			MED	73	37/36	40.7	12	12		1		10	6	1	3	3

None of the 18 RCT studies reported the incidence of type IV and type V complications according to the modified Clavien–Dindo classification

RCT Randomized controlled trials, *MED* microendoscopic discectomy, *PELD* percutaneous endoscopic lumbar discectomy, *PLDD* percutaneous laser lumbar discectomy, *MD* microdiscectomy, *M* male, *F* female, *Intra-op* intraoperative, *Post-op* post-operative, *Re-op* reoperation

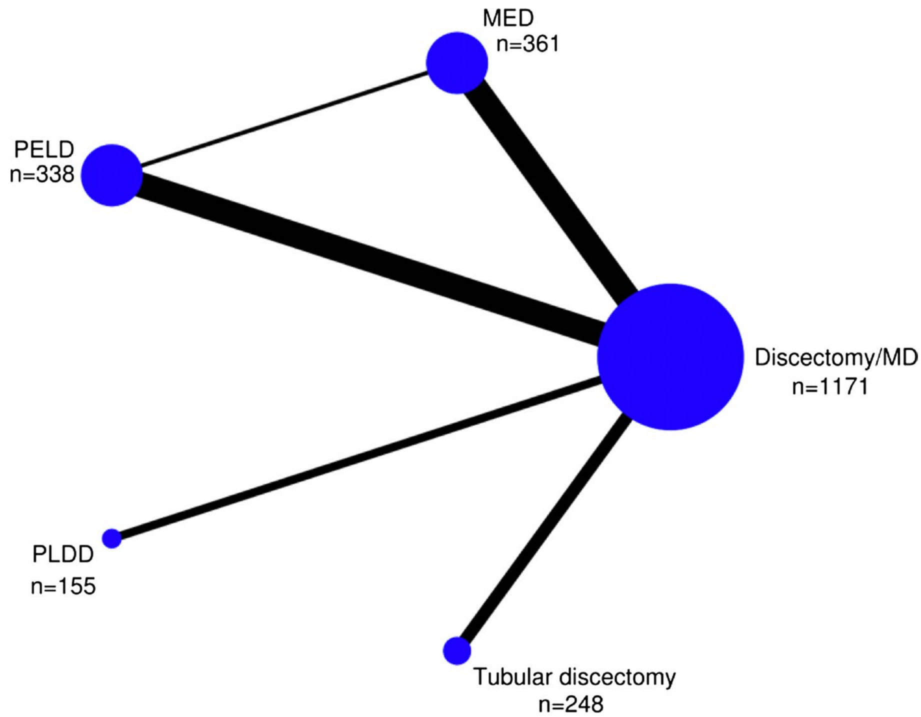


Fig. 3 Network comparisons of different surgical discectomy techniques. Each node represents a discectomy technique, and the size of the node indicates the sample size of patients for which complications data could be extracted from the literature. The lines between any two nodes represent the existence of a direct correlation. The thickness of the solid line between any two nodes depicts the number of existing direct comparisons between the two interventions. *MED* microendoscopic discectomy, *PELD* percutaneous endoscopic lumbar discectomy, *PLDD* percutaneous laser lumbar discectomy, *MD* microdiscectomy

Although quality assessment has been widely used in clinical research, there is still no consensus on formulating a standard to define and classify surgical complications. The general classification scheme categorizes complications into intraoperative and post-operative complications, according to the time when they become apparent [19]. It may be useful for the management of complications to have clear guidelines for symptoms. Our results showed that discectomy/microdiscectomy had the lowest intraoperative complication rates, whereas MED had the highest. Regarding post-operative complication rates, PELD showed the lowest complication rates and tubular discectomy had the highest. The risk for complications of lumbar microdiscectomy surgery can be minimized if certain requisites are considered, and also by meticulous attention to preoperative, intraoperative and post-operative details. A good visualization of discectomy technique has low incidence of intraoperative complications, and percutaneous discectomy technique has low incidence of post-operative complications.

Therapeutic consequences have been recommended as a way of classifying complications in spine surgery [31, 33]. Modified Clavien–Dindo classification for complications is based on the management required for each complication, which can guide the surgeons in deciding the most suitable surgical strategy according to the severity of surgical complications. We first used the modified Clavien–Dindo classification to evaluate the complications following different discectomy surgeries for symptomatic LDH. We found that PELD had the lowest complications that required conservative treatment. MED was associated with complications that usually did not require pharmacological intervention. PLDD was associated with complications that usually did not require a surgical intervention.

SUCRA scores were used to rank the effectiveness of each treatment. However, most comparisons were in low to very low certainty range, which may have resulted in misleading inferences of SUCRA rankings. Grading the evidence from a NMA can enable clinicians, policy makers, and patients to make informed decisions. Our results showed that 53.3% (48 in 90 paired comparisons) low certainty of NMA estimates was due to indirectness and imprecision (ESM_2_Table 10). Therefore, despite the high rates of low certainty, low risk of bias, no inconsistency and no publication bias support the SUCRA ranking of our NMA results.

Although the results of our NMA are comprehensive, there are still limitations that may affect our findings. First, the small size of direct comparisons and the small sample size in each treatment arm may have reduced the statistical robustness of the results. Second, there was substantial heterogeneity due to the inconsistency regarding the duration of follow-up. Finally, this NMA solely investigated the relative rank of each discectomy technique under different complication outcomes. Further research should be performed to explore complication rates of these discectomy techniques using a standardized complication scheme.

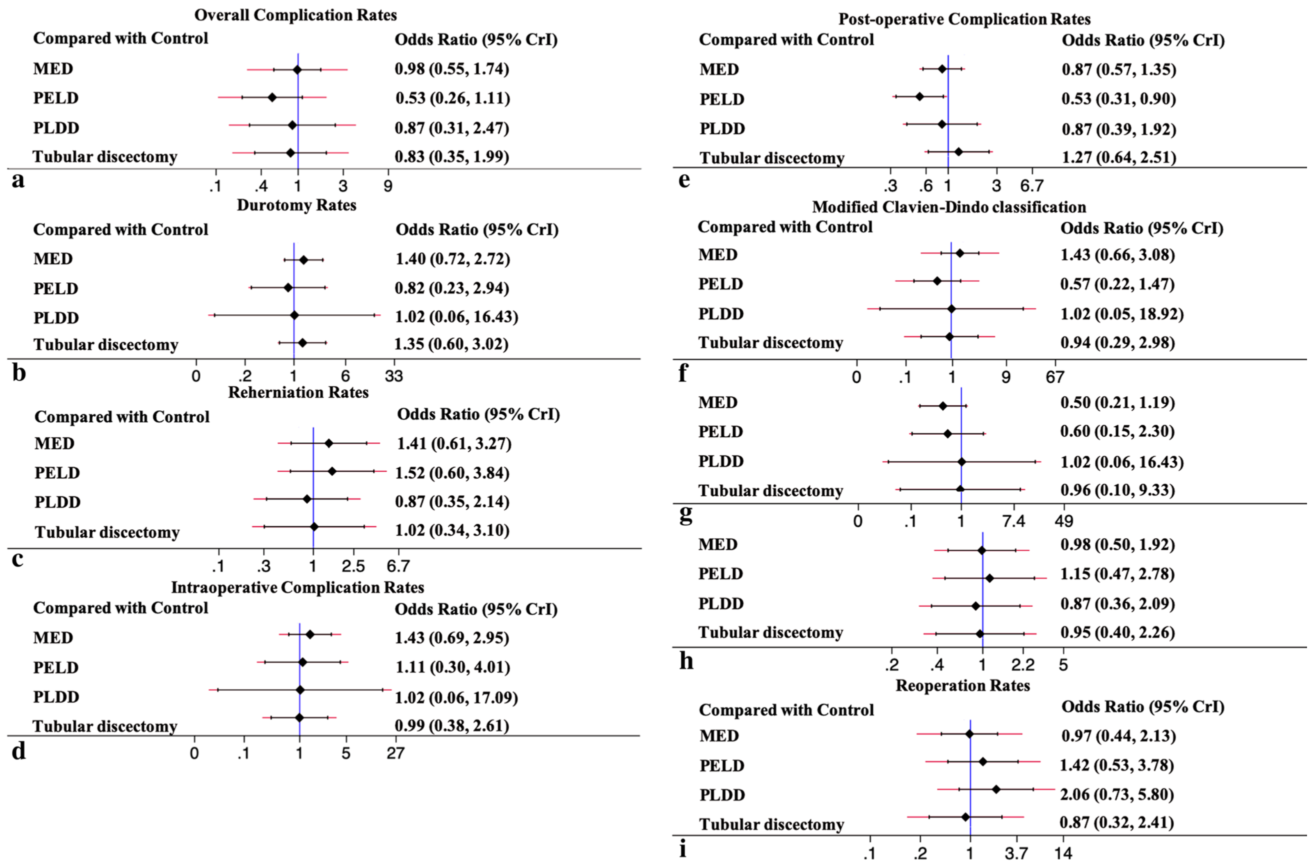


Fig. 4 Odds ratio with 95% credible intervals (CrI) of comparisons between the four minimally invasive discectomy techniques (PELD, PLDD, MED, and tubular discectomy) and microdiscectomy were used to measure relative efficacy. The results of comparisons were shown as follows: the overall complication rate (**a**), durotomy rates (**b**), reherniation rates (**c**), intraoperative complication rates (**d**), post-operative complication rates (**e**), the complication rates by modified Clavien–Dindo classification scheme (**f** shows type 1 complication rates, **g** shows type II complication rates, **h** shows type III complication rates, and Fig **i** shows reoperation rates). *MED* microendoscopic discectomy, *PELD* percutaneous endoscopic lumbar discectomy, *PLDD* percutaneous laser lumbar discectomy, *MD* microdiscectomy

Table 2 Surface under cumulative ranking curve (SUCRA) results for the complication rates by different classification schemes reported for different discectomy procedures

	MD/discectomy	MED	PELD	PLDD	Tubular discectomy
Overall complication	0.316	0.351	0.856	0.470	0.506
Durotomy	0.626	0.317	0.672	0.526	0.359
Reherniation	0.625	0.324	0.278	0.696	0.578
General classification					
Intra-op complication	0.599	0.302	0.500	0.524	0.574
Post-op complication	0.352	0.525	0.939	0.514	0.170
Modified Clavien–Dindo classification					
Type I	0.477	0.230	0.803	0.481	0.510
Type II	0.321	0.730	0.612	0.417	0.420
Type III	0.482	0.509	0.367	0.605	0.537
Reoperation	0.637	0.643	0.358	0.163	0.699

Intra-op Intraoperative, *Post-op* post-operative, *MED* microendoscopic discectomy, *PELD* percutaneous endoscopic lumbar discectomy, *Tub* tubular discectomy, *PLDD* percutaneous laser lumbar discectomy, *MD* microdiscectomy

Table 3 Node-splitting results of the network meta-analysis for all dichotomous outcomes. Odds ratio (OR) with 95% confidence intervals (CI) and p values were used to determine the difference between direct and indirect evidence

		Log_e OR (95% CI)			*P* (direct vs. indirect)
		Direct	Indirect	Network	
Overall complication	MD versus MED	0.07 (− 0.56, 0.69)	− 0.58 (− 2.18 − 1.01)	0.65 (− 1.07, 2.36)	0.516
	MD versus PELD	− 0.79 (− 1.65, 0.07)	− 0.14 (− 1.63, 1.34)	− 0.65 (− 2.36, 1.07)	0.516
	MED versus PELD	− 0.21 (− 1.56, 1.14)	− 0.86 (− 1.92, 0.20)	0.65 (− 1.07, 2.36)	0.516
Durotomy	MD versus MED	0.36 (− 0.31, 1.04)	− 0.23 (− 3.36, 2.91)	0.59 (− 2.62, 3.80)	0.718
	MD versus PELD	− 0.32 (− 1.75, 1.11)	0.27 (− 2.60, 3.14)	− 0.59 (− 3.80, 2.62)	0.718
	MED versus PELD	− 0.09 (− 2.88, 2.70)	− 0.68 (− 2.27, 0.90)	0.59 (− 2.62, 3.80)	0.718
Reherniation	MD versus MED	0.45 (− 0.50, 1.40)	− 0.19 (− 2.14, 1.76)	0.64 (− 1.54, 2.82)	0.565
	MD versus PELD	0.25 (− 0.84, 1.34)	0.89 (− 0.99, 2.77)	− 0.64 (− 2.82, 1.54)	0.565
	MED versus PELD	0.44 (− 1.18, 2.06)	− 0.20 (− 1.65, 1.26)	0.64 (− 1.54, 2.82)	0.565
Intra-op complication	MD versus MED	0.52 (− 0.17, 1.22)	− 1.91 (− 4.61, 0.79)	2.43 (− 0.36, 5.21)	0.088
	MD versus PELD	0.57 (− 2.06, 0.91)	1.85 (− 0.50, 4.21)	− 2.43 (− 5.21, 0.36)	0.088
	MED versus PELD	1.33 (− 0.92, 3.58)	− 1.10 (− 2.74, 0.55)	2.43 (− 0.36, 5.21)	0.088
Post-op complication	MD versus MED	− 0.14 (− 0.63, 0.36)	− 0.14 (− 1.40, 1.13)	− 0.002 (− 1.36, 1.36)	0.997
	MD versus PELD	− 0.64 (− 1.27, − 0.007)	− 0.64 (− 1.84, 0.56)	− 0.002 (− 1.36, 1.36)	0.997
	MED versus PELD	− 0.50 (− 1.60, 0.59)	− 0.50 (− 1.31, 0.30)	− 0.002 (− 1.36, 1.36)	0.997
Type I	MD versus MED	0.53 (− 0.24, 1.30)	− 0.83 (− 2.76, 1.11)	1.36 (− 0.71, 3.43)	0.198
	MD versus PELD	− 0.93 (− 2.00, 0.14)	0.43 (− 1.35, 2.22)	− 1.36 (− 3.43, 0.71)	0.198
	MED versus PELD	− 0.10 (− 1.71, 1.51)	− 1.46 (− 2.76, − 0.16)	1.36 (− 0.71, 3.43)	0.198
Type II	MD versus MED	− 0.81 (− 1.71, 0.10)	0.98 (− 2.56, 4.52)	− 1.78 (− 5.43, 1.87)	0.339
	MD versus PELD	− 0.23 (− 1.70, 1.25)	− 2.01 (− 5.35, 1.33)	1.78 (− 1.87, 5.43)	0.339
	MED versus PELD	− 1.20 (− 4.42, 2.01)	0.58 (− 1.15, 2.31)	− 1.78 (− 5.43, 1.87)	0.339
Type III	MD versus MED	0.03 (− 0.70, 0.77)	− 0.43 (− 2.36, 1.49)	0.47 (− 1.59, 2.52)	0.656
	MD versus PELD	0.01 (− 1.04, 1.06)	0.48 (− 1.30, 2.25)	− 0.47 (− 2.52, 1.59)	0.656
	MED versus PELD	0.44 (− 1.17, 2.05)	− 0.03 (− 1.31, 1.25)	0.47 (− 1.59, 2.52)	0.656
Reoperation	MD versus MED	− 0.01 (− 0.88, 0.86)	− 0.12 (− 2.34, 2.11)	− 0.10 (− 2.28, 2.49)	0.933
	MD versus PELD	0.33 (− 0.82, 1.47)	0.43 (− 1.66, 2.52)	− 0.10 (− 2.49, 2.28)	0.933
	MED versus PELD	0.44 (− 1.46, 2.34)	0.34 (− 1.10, 1.78)	0.10 (− 2.28, 2.49)	0.933

Odds ratio (OR) with 95% credible intervals (CrI) and *p* values were used to determine the difference between direct and indirect evidence

Intra-op Intraoperative, *Post-op* post-operative, *MED* microendoscopic discectomy, *PELD* percutaneous endoscopic lumbar discectomy, *PLDD* percutaneous laser lumbar discectomy, *MD* microdiscectomy

Table 4 Column represents SUCRA ranking of different discectomy procedures for the complication rates by different classification schemes

	Overall complication	Durotomy	Reherniation	General classification		Modified Clavien–Dindo classification			Reoperation
				Intra-op complication	Post-op complication	Type 1	Type 2	Type 3	
MD	5	2	2	1	4	4	5	4	3
MED	4	5	4	5	2	5	1	3	2
PELD	1	1	5	4	1	1	2	5	4
PLDD	3	3	1	3	3	3	4	1	5
Tub	2	4	3	2	5	2	3	2	1

[#]1 to #5 ranked each discectomy technique under different complication outcomes in order of surface under cumulative ranking curve (SUCRA) value with #1 being the highest SUCRA value and #5 being the lowest SUCRA value, and highest SUCRA values represented lowest complication rates. No inconsistency existed between direct and indirect comparisons

Intra-op Intraoperative, *Post-op* post-operative, *MED* microendoscopic discectomy, *PELD* percutaneous endoscopic lumbar discectomy, *PLDD* percutaneous laser lumbar discectomy, *MD* microdiscectomy, *Tub* tubular discectomy

Conclusion

This study is the first NMA to compare the complication rates of different discectomy techniques using two classification schemes (general classification and modified Clavien–Dindo classification) for the surgical treatment of symptomatic LDH. Our results show that PELD is the safest discectomy technique for the surgical treatment of symptomatic LDH in terms of minimal rates for overall complications, post-operative complications, and complications necessitating conservative treatment. Discectomy/microdiscectomy, MED, and PLDD are the safest procedure for LDH with minimal intraoperative complication rates, complications requiring pharmacological and surgical treatment, respectively. Tubular discectomy is the safest discectomy technique for LDH with minimal reoperation rates.

Acknowledgements The authors would like to thank Joyce Cornelius (outreach librarian, UNSW) for her help with developing the database search strategy.

Funding This work was supported by a Research Training Program scholarship and a University Postgraduate Award from the Australian Government and UNSW to XLC. A Clinical Travelling Fellowship from the International Society for the Study of the Lumbar Spine (ISSLS) in 2018 further supported this work.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest related to this work.

References

1. Benzakour T, Igoumenou V, Mavrogenis AF, Benzakour A (2018) Current concepts for lumbar disc herniation. Int Orthop 43:841–851. https://doi.org/10.1007/s00264-018-4247-6
2. Postacchini F (1999) Management of herniation of the lumbar disc. J Bone Jt Surg Br 81:567–576
3. Taylor VM, Deyo RA, Cherkin DC, Kreuter W (1994) Low back pain hospitalization. Recent United States trends and regional variations. Spine 19:1207–1212 **(discussion 1213)**
4. Maroon JC (2002) Current concepts in minimally invasive discectomy. Neurosurgery 51:S137–S145. https://doi.org/10.1227/01.NEU.0000031066.08137.64
5. Kreiner DS, Hwang SW, Easa JE, Resnick DK, Baisden JL, Bess S, Cho CH, DePalma MJ, Dougherty P 2nd, Fernand R, Ghiselli G, Hanna AS, Lamer T, Lisi AJ, Mazanec DJ, Meagher RJ, Nucci RC, Patel RD, Sembrano JN, Sharma AK, Summers JT, Taleghani CK, Tontz WL Jr, Toton JF, North American Spine S (2014) An evidence-based clinical guideline for the diagnosis and treatment of lumbar disc herniation with radiculopathy. Spine J 14:180–191. https://doi.org/10.1016/j.spinee.2013.08.003
6. Kim CH, Chung CK, Jahng TA, Yang HJ, Son YJ (2012) Surgical outcome of percutaneous endoscopic interlaminar lumbar diskectomy for recurrent disk herniation after open diskectomy. J Spinal Disord Tech 25:E125–E133. https://doi.org/10.1097/BSD.0b013e31825bd111
7. Ruetten S, Komp M, Merk H, Godolias G (2009) Recurrent lumbar disc herniation after conventional discectomy: a prospective, randomized study comparing full-endoscopic interlaminar and transforaminal versus microsurgical revision. J Spinal Disord Tech 22:122–129. https://doi.org/10.1097/BSD.0b013e318175ddb4
8. DePalma MJ, Ketchum JM, Saullo TR, Laplante BL (2012) Is the history of a surgical discectomy related to the source of chronic low back pain? Pain Physician 15:E53–E58
9. Yasargil MG (1977) Microsurgical operations for herniated lumbar disc. Adv Neurosurg 4:81–82
10. Caspar W (1977) A new surgical procedure for lumbar disc herniation causing less tissue damage through a microsurgical approach. Adv Neurosurg 4:74–80
11. Rasouli MR, Rahimi-Movaghar V, Shokraneh F, Moradi-Lakeh M, Chou R (2014) Minimally invasive discectomy versus microdiscectomy/open discectomy for symptomatic lumbar disc herniation. Cochrane Database Syst Rev 9:CD010328. https://doi.org/10.1002/14651858.CD010328.pub2
12. Deen HG, Fenton DS, Lamer TJ (2003) Minimally invasive procedures for disorders of the lumbar spine. Mayo Clin Proc 78:1249–1256
13. Katayama Y, Matsuyama Y, Yoshihara H, Sakai Y, Nakamura H, Nakashima S, Ito Z, Ishiguro N (2006) Comparison of surgical outcomes between macro discectomy and micro discectomy for lumbar disc herniation: a prospective randomized study with surgery performed by the same spine surgeon. J Spinal Disord Tech 19:344–347
14. Foley KT, Smith MM, Rampersaud YR (1999) Microendoscopic approach to far-lateral lumbar disc herniation. Neurosurg Focus 7:e5
15. Clark AJ, Safaee MM, Khan NR, Brown MT, Foley KT (2017) Tubular microdiscectomy: techniques, complication avoidance, and review of the literature. Neurosurg Focus 43:E7. https://doi.org/10.3171/2017.5.FOCUS17202
16. Foley MKT (1997) Microendoscopic discectomy. Tech Neurosurg 3:301–307
17. Yorimitsu E, Chiba K, Toyama Y, Hirabayashi K (2001) Long-term outcomes of standard discectomy for lumbar disc herniation: a follow-up study of more than 10 years. Spine 26:652–657
18. Shriver MF, Xie JJ, Tye EY, Rosenbaum BP, Kshettry VR, Benzel EC, Mroz TE (2015) Lumbar microdiscectomy complication rates: a systematic review and meta-analysis. Neurosurg Focus 39:E6. https://doi.org/10.3171/2015.7.FOCUS15281
19. Kraemer R, Wild A, Haak H, Herdmann J, Krauspe R, Kraemer J (2003) Classification and management of early complications in open lumbar microdiscectomy. Eur Spine J 12:239–246. https://doi.org/10.1007/s00586-002-0466-y
20. Kim M, Lee S, Kim HS, Park S, Shim SY, Lim DJ (2018) A comparison of percutaneous endoscopic lumbar discectomy and open lumbar microdiscectomy for lumbar disc herniation in the Korean: a meta-analysis. Biomed Res Int 2018:9073460. https://doi.org/10.1155/2018/9073460
21. Shi R, Wang F, Hong X, Wang YT, Bao JP, Liu L, Wang XH, Xie ZY, Wu XT (2018) Comparison of percutaneous endoscopic lumbar discectomy versus microendoscopic discectomy for the treatment of lumbar disc herniation: a meta-analysis. Int Orthop 43:923–937. https://doi.org/10.1007/s00264-018-4253-8
22. Ruan W, Feng F, Liu Z, Xie J, Cai L, Ping A (2016) Comparison of percutaneous endoscopic lumbar discectomy versus open lumbar microdiscectomy for lumbar disc herniation: A meta-analysis. Int J Surg 31:86–92. https://doi.org/10.1016/j.ijsu.2016.05.061
23. Cong L, Zhu Y, Tu G (2016) A meta-analysis of endoscopic discectomy versus open discectomy for symptomatic lumbar disk

herniation. Eur Spine J 25:134–143. https://doi.org/10.1007/s00586-015-3776-6
24. Wang XS, Sun RF, Ji Q, Zhao B, Niu XM, Wang R, Peng L, Tian XD (2014) A meta-analysis of interlaminar minimally invasive discectomy compared to conventional microdiscectomy for lumbar disk herniation. Clin Neurol Neurosurg 127:149–157. https://doi.org/10.1016/j.clineuro.2014.10.001
25. He J, Xiao S, Wu Z, Yuan Z (2016) Microendoscopic discectomy versus open discectomy for lumbar disc herniation: a meta-analysis. Eur Spine J 25:1373–1381. https://doi.org/10.1007/s00586-016-4523-3
26. Akinduro OO, Kerezoudis P, Alvi MA, Yoon JW, Eluchie J, Murad MH, Wang Z, Chen SG, Bydon M (2017) Open versus minimally invasive surgery for extraforaminal lumbar disk herniation: a systematic review and meta-analysis. World Neurosurg 108:924–938. https://doi.org/10.1016/j.wneu.2017.08.025
27. Qin R, Liu B, Hao J, Zhou P, Yao Y, Zhang F, Chen X (2018) Percutaneous endoscopic lumbar discectomy versus posterior open lumbar microdiscectomy for the treatment of symptomatic lumbar disc herniation: a systemic review and meta-analysis. World Neurosurg 120:352–362. https://doi.org/10.1016/j.wneu.2018.08.236
28. Chang X, Chen B, Li HY, Han XB, Zhou Y, Li CQ (2014) The safety and efficacy of minimally invasive discectomy: a meta-analysis of prospective randomised controlled trials. Int Orthop 38:1225–1234. https://doi.org/10.1007/s00264-014-2331-0
29. Li X, Chang H, Meng X (2018) Tubular microscopes discectomy versus conventional microdiscectomy for treating lumbar disk herniation: systematic review and meta-analysis. Medicine 97:e9807. https://doi.org/10.1097/MD.0000000000009807
30. Mu X, Wei J, Li P (2015) What were the advantages of microendoscopic discectomy for lumbar disc herniation comparing with open discectomy: a meta-analysis? Int J Clin Exp Med 8:17498–17506
31. Lebude B, Yadla S, Albert T, Anderson DG, Harrop JS, Hilibrand A, Maltenfort M, Sharan A, Vaccaro AR, Ratliff JK (2010) Defining "complications" in spine surgery: neurosurgery and orthopedic spine surgeons' survey. J Spinal Disord Tech 23:493–500. https://doi.org/10.1097/BSD.0b013e3181c11f89
32. Reis RC, de Oliveira MF, Rotta JM, Botelho RV (2015) Risk of complications in spine surgery: a prospective study. Open Orthop J 9:20–25. https://doi.org/10.2174/1874325001509010020
33. Dindo D, Demartines N, Clavien PA (2004) Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. Ann Surg 240:205–213
34. Ibanez FAL, Hem S, Ajler P, Vecchi E, Ciraolo C, Baccanelli M, Tramontano R, Knezevich F, Carrizo A (2011) A new classification of complications in neurosurgery. World Neurosurg 75:709–715. https://doi.org/10.1016/j.wneu.2010.11.010 **(discussion 604–711)**
35. Leucht S, Chaimani A, Cipriani AS, Davis JM, Furukawa TA, Salanti G (2016) Network meta-analyses should be the highest level of evidence in treatment guidelines. Eur Arch Psychiatry Clin Neurosci 266:477–480. https://doi.org/10.1007/s00406-016-0715-4
36. Rouse B, Chaimani A, Li T (2017) Network meta-analysis: an introduction for clinicians. Intern Emerg Med 12:103–111. https://doi.org/10.1007/s11739-016-1583-7
37. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 6:e1000097. https://doi.org/10.1371/journal.pmed.1000097
38. Furlan AD, Malmivaara A, Chou R, Maher CG, Deyo RA, Schoene M, Bronfort G, van Tulder MW (2015) 2015 Updated method guideline for systematic reviews in the Cochrane back and neck group. Spine 40:1660–1673. https://doi.org/10.1097/brs.0000000000001061
39. Higgins JPT, Green S (2011) Cochrane handbook for systematic reviews of interventions, version 510. The Cochrane Collaboration, London
40. Chaimani A, Higgins JP, Mavridis D, Spyridonos P, Salanti G (2013) Graphical tools for network meta-analysis in STATA. PLoS ONE 8:e76654. https://doi.org/10.1371/journal.pone.0076654
41. Balshem H, Helfand M, Schunemann HJ, Oxman AD, Kunz R, Brozek J, Vist GE, Falck-Ytter Y, Meerpohl J, Norris S, Guyatt GH (2011) GRADE guidelines: 3. Rating the quality of evidence. J Clin Epidemiol 64:401–406. https://doi.org/10.1016/j.jclinepi.2010.07.015
42. Puhan MA, Schunemann HJ, Murad MH, Li T, Brignardello-Petersen R, Singh JA, Kessels AG, Guyatt GH, Glow GW (2014) A GRADE Working Group approach for rating the quality of treatment effect estimates from network meta-analysis. BMJ 349:g5630. https://doi.org/10.1136/bmj.g5630
43. Ding ZM, Tao YQ (2017) Clinical outcomes of percutaneous transforaminal endoscopic discectomy versus fenestration discectomy in patients with lumbar disc herniation. J Int Transl Med 5:29–33. https://doi.org/10.11910/2227-6394.2017.05.01.06
44. Franke J, Greiner-Perth R, Boehm H, Mahlfeld K, Grasshoff H, Allam Y, Awiszus F (2009) Comparison of a minimally invasive procedure versus standard microscopic discotomy: a prospective randomised controlled clinical trial. Eur Spine J 18:992–1000. https://doi.org/10.1007/s00586-009-0964-2
45. Righesso O, Falavigna A, Avanzi O (2007) Comparison of open discectomy with microendoscopic discectomy in lumbar disc herniations: results of a randomized controlled trial. Neurosurgery 61:545–549. https://doi.org/10.1227/01.NEU.0000280008.72190.15
46. Abrishamkar S, Kouchakzadeh M, Mirhosseini A, Tabesh H, Rezvani M, Moayednia A, Ganjeifar B, Mahabadi A, Yousefi E, Kooshki AM (2015) Comparison of open surgical discectomy versus plasma-laser nucleoplasty in patients with single lumbar disc herniation. J Res Med Sci 20:1133–1137. https://doi.org/10.4103/1735-1995.172979
47. Pan L, Zhang P, Yin Q (2014) Comparison of tissue damages caused by endoscopic lumbar discectomy and traditional lumbar discectomy: a randomised controlled trial. Int J Surg 12:534–537. https://doi.org/10.1016/j.ijsu.2014.02.015
48. Pan Z, Ha Y, Yi S, Cao K (2016) Efficacy of transforaminal endoscopic spine system (TESSYS) technique in treating lumbar disc herniation. Med Sci Monitor 22:530–539. https://doi.org/10.12659/msm.894870
49. Ruetten S, Komp M, Merk H, Godolias G (2008) Full-endoscopic interlaminar and transforaminal lumbar discectomy versus conventional microsurgical technique: A prospective, randomized, controlled study. Spine 33:931–939
50. Teli M, Lovi A, Brayda-Bruno M, Zagra A, Corriero A, Giudici F, Minoia L (2010) Higher risk of dural tears and recurrent herniation with lumbar micro-endoscopic discectomy. Eur Spine J 19:443–450. https://doi.org/10.1007/s00586-010-1290-4
51. Huang TJ, Hsu RW, Li YY, Cheng CC (2005) Less systemic cytokine response in patients following microendoscopic versus open lumbar discectomy. J Orthop Res 23:406–411
52. Garg B, Nagraja UB, Jayaswal A (2011) Microendoscopic versus open discectomy for lumbar disc herniation: A prospective randomised study. J Orthop Surg 19:30–34
53. Hussein M (2016) Minimal incision, multifidus-sparing microendoscopic diskectomy versus conventional microdiskectomy for highly migrated intracanal lumbar disk herniations. J Am Acad Orthop Surg 24:805–813. https://doi.org/10.5435/JAAOS-D-15-00588
54. Mayer HM, Brock M (1993) Percutaneous endoscopic discectomy: surgical technique and preliminary results compared to microsurgical discectomy. J Neurosurg 78:216–225

55. Brouwer PA, Brand R, van den Akker-van Marle ME, Jacobs WC, Schenk B, van den Berg-Huijsmans AA, Koes BW, Arts MA, van Buchem MA, Peul WC (2017) Percutaneous laser disc decompression versus conventional microdiscectomy for patients with sciatica: Two-year results of a randomised controlled trial. Interv Neuroradiol 23:313–324. https://doi.org/10.1177/1591019917699981
56. Hermantin FU, Peters T, Quartararo L, Kambin P (1999) A prospective, randomized study comparing the results of open discectomy with those of video-assisted arthroscopic m. J Bone Joint Surg Am 81:958–965
57. Hussein M, Abdeldayem A, Mattar MM (2014) Surgical technique and effectiveness of microendoscopic discectomy for large uncontained lumbar disc herniations: a prospective, randomized, controlled study with 8 years of follow-up. Eur Spine J 23:1992–1999. https://doi.org/10.1007/s00586-014-3296-9
58. Ryang YM, Oertel MF, Mayfrank L, Gilsbach JM, Rohde V (2008) Standard open microdiscectomy versus minimal access trocar microdiscectomy: results of a prospective randomized study. Neurosurgery 62:174–181. https://doi.org/10.1227/01.NEU.0000296996.00030.3F
59. Arts MP, Brand R, van den Akker ME, Koes BW, Bartels RH, Tan WF, Peul WC (2011) Tubular diskectomy vs conventional microdiskectomy for the treatment of lumbar disk herniation: 2-year results of a double-blind randomized controlled trial. Neurosurgery 69:135–144. https://doi.org/10.1227/NEU.0b013e318214a98c **(discussion 144)**
60. Chen Z, Zhang L, Dong J, Xie P, Liu B, Wang Q, Chen R, Feng F, Yang B, Shu T, Li S, Yang Y, He L, Pang M, Rong L (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 28:300–310. https://doi.org/10.3171/2017.7.SPINE161434
61. Ruetten S, Komp M, Merk H, Godolias G (2008) Full-endoscopic interlaminar and transforaminal lumbar discectomy versus conventional microsurgical technique: a prospective, randomized, controlled study. Spine 33:931–939. https://doi.org/10.1097/BRS.0b013e31816c8af7
62. Brouwer PA, Brand R, van den Akker-van Marle ME, Jacobs WCH, Schenk B, van den Berg-Huijsmans AA, Koes BW, Arts MA, van Buchem MA, Peul WC (2017) Percutaneous laser disc decompression versus conventional microdiscectomy for patients with sciatica: Two-year results of a randomised controlled trial. Interventional Neuroradiology 23:313–324. https://doi.org/10.1177/1591019917699981
63. Hermantin FU, Peters T, Quartararo L, Kambin P (1999) A prospective, randomized study comparing the results of open discectomy with those of video-assisted arthroscopic microdiscectomy. J Bone Joint Surg Am 81:958–965
64. Feng F, Xu Q, Yan F, Xie Y, Deng Z, Hu C, Zhu X, Cai L (2017) Comparison of 7 surgical interventions for lumbar disc herniation: a network meta-analysis. Pain Physician 20:E863–E871

Affiliations

Xiaolong Chen[1] · Uphar Chamoli[1,2] · Samuel Lapkin[3] · Jose Vargas Castillo[1] · Ashish D. Diwan[1]

✉ Uphar Chamoli
u.chamoli@unsw.edu.au

[1] Spine Labs, Department of Orthopaedic Surgery, St. George and Sutherland Clinical School, University of New South Wales, Level 3, WR Pitney Building, Kogarah, NSW 2217, Australia

[2] School of Biomedical Engineering, Faculty of Engineering and Information Technology, University of Technology Sydney, Ultimo, NSW 2007, Australia

[3] School of Nursing, Faculty of Science, Medicine and Health, University of Wollongong, South Western Sydney Campus, Wollongong, NSW, Australia