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REVIEW ARTICLE

Transforaminal endoscopic surgery for symptomatic lumbar disc herniations: a systematic review of the literature

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Abstract The study design includes a systematic literature review. The objective of the study was to evaluate the effectiveness of transforaminal endoscopic surgery and to compare this with open microdiscectomy in patients with symptomatic lumbar disc herniations. Transforaminal endoscopic techniques for patients with symptomatic lumbar disc herniations have become increasingly popular. The literature has not yet been systematically reviewed. A comprehensive systematic literature search of the MEDLINE and EMBASE databases was performed up to May 2008. Two reviewers independently checked all retrieved titles and abstracts and relevant full text articles for inclusion criteria. Included articles were assessed for quality and outcomes were extracted by the two reviewers independently. One randomized controlled trial, 7 non-randomized controlled trials and 31 observational studies were identified. Studies were heterogeneous regarding patient selection, indications, operation techniques, follow-up period and outcome measures and the methodological quality of these studies was poor. The eight trials did not find any statistically significant differences in leg pain reduction between the transforaminal endoscopic surgery group (89%) and the open microdiscectomy group (87%); overall improvement (84 vs. 78%), re-operation rate (6.8 vs. 4.7%) and complication rate (1.5 vs. 1%), respectively. In conclusion, current evidence on the effectiveness of transforaminal endoscopic surgery is poor and does not provide valid information to either support or refute using this type of surgery in patients with symptomatic lumbar disc herniations. High-quality randomized controlled trials with sufficiently large sample sizes are direly needed to evaluate if transforaminal endoscopic surgery is more effective than open microdiscectomy.

Keywords Lumbar disc herniation · Transforaminal · Endoscopic surgery · Minimally invasive surgery · Systematic review

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Introduction

Surgery for lumbar disc herniation can be classified into two broad categories: open versus minimally invasive surgery and posterior versus posterolateral approaches. Mixter and Barr in 1934 were the first authors to treat lumbar disc herniation surgically by performing an open laminectomy and discectomy [41]. With the introduction of the microscope, Caspar and Yasargil refined the original laminectomy into open microdiscectomy [4, 63]. Laminectomy and microdiscectomy are open procedures using a posterior approach. Currently, open microdiscectomy is the most widespread procedure for surgical decompression of radiculopathy caused by lumbar disc herniation, but

minimally invasive surgery has gained a growing interest. The concept of minimally invasive surgery for lumbar disc herniations is to provide surgical options that optimally address the disc pathology without producing the iatrogenic morbidity associated with the open surgical procedures. In the last decades, endoscopic techniques have been developed to perform discectomy under direct view and local anaesthesia.

Kambin and Gellmann in 1973 [22] in the United States and Hijikata in Japan in 1975 [12], independently performed a non-visualised, percutaneous central nucleotomy for the resection and evacuation of nuclear tissue via a posterolateral approach. In 1983, Forst and Housman reported the direct visualization of the intervertebral disc space with a modified arthroscope [9]. Kambin published the first intraoperative discoscopic view of a herniated nucleus pulposus in 1988 [21]. In 1989 and 1991 Schreiber et al. described 'percutaneous discoscopy', a biportal endoscopic posterolateral technique with modified instruments for direct view [52, 55]. In 1992, Mayer introduced percutaneous endoscopic laser discectomy combining forceps and laser [40]. With the further improvement of scopes (e.g. variable angled lenses and working channel for different instruments), the procedure became more refined. The removal of sequestered non-migrated fragments became possible using a biportal approach [25]. The concept of posterolateral endoscopic lumbar nerve decompression changed from indirect central nucleotomy (inside out, in which fragments are extracted through an annular fenestration outside the spinal canal) to transforaminal direct extraction of the non-contained and sequestered disc fragments from inside the spinal canal. In this article, the technique of direct nucleotomy is described as intradiscal and the technique directly in the spinal canal is described as intracanal technique; both are transforaminal approaches (Fig. 1).

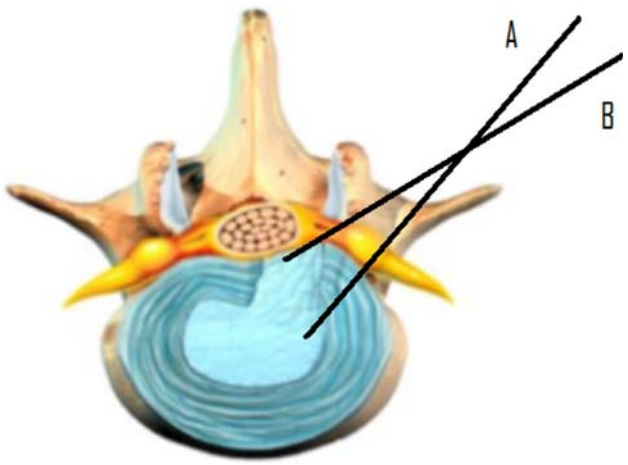

Fig. 1 Different posterolateral approaches to the lumbar disc. **a** The intradiscal technique, **b** the intracanal technique

The indications for transforaminal endoscopic treatment are the same as classical discectomy procedures [6, 24, 38]. To reach the posterior part of the epidural space, the superior articular process of the facet joint is usually the obstacle. Yeung and Knight used a holmium-YAG (yttrium-aluminium-garnet)—laser for ablation of bony and soft tissue for decompression, enhanced access and to improve intracanal visualisation [30, 64]. Yeung developed the commercially available Yeung Endoscopic Spine System (YESS) in 1997 [65] and Hoogland in 1994 developed the Thomas Hoogland Endoscopic Spine System (THESSYS). With this latter system, it is possible to enlarge the intervertebral foramen near the facet joint with special reamers to reach intracanal extruded and sequestered disc fragments and decompress foraminal stenosis [16].

Recently, also another minimally invasive technique, microendoscopic discectomy (MED), has been developed. In MED, a microscope is used and the spine is approached from a posterior direction and not transforaminal. Therefore, this technique is not considered in the current systematic review.

Endoscopic surgery for lumbar disc herniations has been available for more than 30 years, but at present a systematic review of all relevant studies on the effectiveness of transforaminal endoscopic surgery in patients with symptomatic lumbar disc herniations is lacking.

Methods

Objective

The objective of this systematic review was to assess the effectiveness of transforaminal endoscopic surgery in patients with symptomatic lumbar disc herniations. The main research questions were

1. What is the effectiveness of transforaminal endoscopic surgery?
   a. What is the effectiveness of the older intradiscal transforaminal technique and the more recently developed extracanal transforaminal technique?
   b. What is the effectiveness of transforaminal endoscopic surgery for the different types of herniations (mere lateral herniations versus central herniations versus all types of lumbar disc herniations)?
2. What is the effectiveness of transforaminal endoscopic surgery when compared with open microdiscectomy?

For this systematic review, we used the method guidelines for systematic reviews as recommended by the Cochrane Back Review Group [61]. Below the search

strategy, selection of the studies, data extraction, methodological quality assessment and data analysis are described in more detail. All these steps were performed by two independent reviewers and during consensus meetings potential disagreements between the two reviewers regarding these issues were discussed. If they were not resolved, a third reviewer was consulted.

Search strategy

An experienced librarian performed a comprehensive systematic literature search. The MEDLINE and EMBASE databases were searched for relevant studies from 1973 to May 2008. The search strategy consisted of a combination of keywords concerning the technical procedure and keywords regarding the anatomical features and pathology (Table 1). We conducted two reviews, one on lumbar disc herniation and one on spinal stenosis, and combined the search strategy for these two reviews for efficiency reasons. These keywords were used as MESH headings and free text words. The full search strategy is available upon request.

Selection of studies

The search was limited to English, German and Dutch studies, because these are the languages that the review authors are able to read and understand. Two review authors independently examined all titles and abstracts that met our search terms and reviewed full publications, when necessary. In addition, the reference sections of all primary studies were inspected for additional references. Studies were included that describe transforaminal endoscopic surgery for adult patients with symptomatic lumbar disc herniations. As we expected only a limited number of randomized controlled trials in this field, we also included observational studies (non-randomized controlled clinical trials, cohort studies, case–control studies and retrospective patient series). To be included, studies had to report on more than 15 cases, with a follow-up period of more than 6 weeks.

Table 1 Selection of terms used in our search strategy

Technical procedure	Anatomical features/disorder
Endoscopy	Spine
Arthroscopy	Back
Video-assisted surgery	Back pain
Surgical procedures, minimally invasive	Spinal diseases
Microsurgery	Disc displacement
Transforaminal	Intervertebral disc displacement
Discectomy	Spinal cord compression
Percutaneous	Sciatica
Foraminotomy, foraminoplasty discoscopy	Radiculopathy

Data extraction

Two review authors independently extracted relevant data from the included studies regarding design, population (e.g. age, gender, duration of complaints before surgery, etc), type of surgery, type of control intervention, follow-up period and outcomes. Primary outcomes that were considered relevant are pain intensity (e.g. visual analogue scale or numerical rating scale), functional status (e.g. Roland Morris Disability Scale, Oswestry Scale), global perceived effect (e.g. McNab score, percentage patients improved), vocational outcomes (e.g. percentage return to work, number of days of sick leave), and other outcomes (recurrences, complication, re-operation and patient satisfaction). We contacted primary authors where necessary for clarification of overlap of data in different articles.

Methodological quality assessment

Two review authors independently assessed the methodological quality of the included studies. Controlled trials were assessed using a criteria list recommended by the Cochrane Back review group as listed in Table 2 [61]. If studies met at least 6 out of the 11 criteria, the study was considered to have a low risk of bias (RoB). If only 5 or less of the criteria were met, the study was labelled as high RoB Non-controlled studies were assessed using a modified 5-point assessment score as listed in Table 3. Disagreements were resolved in a consensus meeting and a third review author was consulted when necessary.

Data analysis

To assess the effectiveness of transforaminal endoscopic surgery and to compare it to open microdiscectomy, the results of outcome measures were extracted from the original studies. The outcome data of some studies were recalculated, because the authors of the original papers did not handle drop outs, lost to follow-up and/or failed operations adequately. If a study reported several follow-up intervals, the outcome of the longest follow-up moment was used.

Because only one randomized trial was identified and the controlled trials were heterogeneous regarding study populations, endoscopic techniques, outcome measures, measurement instruments and follow-up moments, statistical pooling was not performed. The median and range (min–max) of the results of the individual studies for each outcome measure are presented.

Table 2 Criteria list for quality assessment of controlled studies

A	Was the method of randomization adequate?	Y	N	?
B	Was the treatment allocation concealed?	Y	N	?
C	Were the groups similar at baseline regarding the most important prognostic indicators?	Y	N	?
D	Was the patient blinded to the intervention?	Y	N	?
E	Was the care provider blinded to the intervention	Y	N	?
F	Was the outcome assessor blinded to the intervention?	Y	N	?
G	Were co-interventions avoided or similar?	Y	N	?
H	Was the compliance acceptable in all groups?	Y	N	?
I	Was the drop out rate described and acceptable?	Y	N	?
J	Was the timing of the outcome assessment in all groups similar?	Y	N	?
K	Did the analysis include an intention to treat analysis?	Y	N	?

? score unclear

A: A random (unpredictable) assignment sequence. Examples of adequate methods are computer generated random number table and use of sealed opaque envelopes. Methods of allocation using date of birth, date of admission, hospital numbers or alternation should not be regarded as appropriate

B: Assignment generated by an independent person not responsible for determining the eligibility of the patients. This person has no information about the persons included in the trial and has no influence on the assignment sequence or on the decision about eligibility of the patient

C: In order to receive a 'yes', groups have to be similar at baseline regarding demographic factors, duration and severity of complaints, percentage of patients with neurological symptoms and value of main outcome measure(s)

D: The reviewer determines if enough information about the blinding is given in order to score a 'yes

E: The reviewer determines if enough information about the blinding is given in order to score a 'yes'

F: The reviewer determines if enough information about the blinding is given in order to score a 'yes'

G: Co-interventions should either be avoided in the trial design or similar between the index and control groups

H: The reviewer determines if the compliance to the interventions is acceptable, based on the reported intensity, duration, number and frequency of sessions for both the index intervention and control intervention(s)

I: The number of participants who were included in the study but did not complete the observation period or were not included in the analysis must be described and reasons given. If the percentage of withdrawals and drop outs does not exceed 20% for short-term follow-up and 30% for long-term follow-up and does not lead to substantial bias a 'yes' is scored. (N.B. these percentages are arbitrary, not supported by literature)

J: The timing of outcome assessment should be identical for all intervention groups and for all important outcome assessments

K: All randomized patients are reported/analysed in the group they were allocated to by randomization for the most important moments of effect measurement (minus missing values) irrespective of non-compliance and co-interventions

Table 3 Criteria list for quality assessment of non-controlled studies

A	Patient selection/inclusion adequately described?	Y	N	?
B	Drop out rate described?	Y	N	?
C	Independent assessor?	Y	N	?
D	Co-interventions described?	Y	N	?
E	Was the timing of the outcome assessment similar?	Y	N	?

? score unclear

A: All the basic elements of the study population are adequately described; i.e. demography, type and level of disorder, physical and radiological inclusion and exclusion criteria, pre-operative treatment and duration of disorder

B: Are the patients of whom no outcome was obtained, described in quantity and reason for drop out

C: The data were assessed by an independent assessor

D: All co-interventions in the population during and after the operation are described

E: The timing of outcome assessment should be more or less identical for all intervention groups and for all important outcome assessments

Results

Search and selection

Two thousand five hundred and thirteen references were identified in MEDLINE and EMBASE that were potentially relevant for the reviews on lumbar disc herniation and spinal stenosis. After checking the titles and abstracts, a total of 123 full text articles were retrieved that were potentially eligible for this review on lumbar disc herniation. Reviewing the reference lists of these articles resulted in an additional 17 studies. Some patient cohorts

were described in more than one article. In these cases, all articles were used for the quality assessment of the study, but outcome data reporting the longest follow-up was used. After scrutinising all full text papers, 39 studies reported in 45 articles were included in this review. Sixteen studies (41%) had a mean follow-up of more than 2 years. The characteristics and outcomes of the included studies are presented in Tables 4, 5, 6 and 7.

Type of studies and methodological quality

A total of six prospective controlled studies and two retrospective controlled studies were included. Of the six prospective controlled studies, only the study by Hermantin et al. [11] was considered to have a low RoB. The other five prospective controlled studies and two retrospective controlled were labelled as a high RoB (the full RoB assessment is available upon request).

Furthermore, 12 studies were designed as prospective cohort (without control group) and there were 19 retrospective studies (also without control group). When it was unclear whether the study was prospective or retrospective, the study was considered retrospective.

Of the six prospective controlled studies, four compared transforaminal endoscopic surgery with open discectomy or microdiscectomy. All four were reported as randomized trials, but in three of them the method of randomization was inadequate. Mayer and Brock [39] did not describe the randomization method at all, and Krappel et al. [31] and Ruetten et al. [47] did not randomize, but allocated patients alternately to transforaminal endoscopic surgery or microdiscectomy. Only in the low RoB study by Hermantin et al. [11] randomization was adequately performed in 60 patients with non-sequestered lumbar disc herniations. However, the generalizability of this study is poor because patients with a specific type of herniated disc were selected and results are consequently not directly transferable to all patients with lumbar disc herniations.

Outcomes

1. What is the effectiveness of transforaminal endoscopic surgery?

No randomized controlled trials were identified. Outcomes of 31 observational, non-controlled studies are presented in Table 8. The median overall improvement of leg pain (VAS) was 88 (range 65–89%), global perceived effect (MacNab) 85 (72–94%), return to work of 90%, recurrence rate 1.7%, complications 2.8% and re-operations 7%.

1a. What is the effectiveness of the older intradiscal technique and the more recently developed intracanal technique?

No randomized controlled trials were identified. In Table 9 the results of 14 non-controlled studies describing the intradiscal technique and 16 non-controlled studies describing the intracanal technique are presented. The median leg pain improvement (VAS) was 83% (78–88%) for the intradiscal versus 88% (65–89%) for the intracanal technique and the results for global perceived effect were (MacNab) 85% (78–89%) versus 86% (72–93%), respectively; and other outcomes are listed in Table 9.

1b. What is the effectiveness of transforaminal endoscopic surgery for the different types of herniations (mere lateral herniations versus central herniations versus all types of lumbar disc herniations)?

No randomized controlled trials were identified. Six non-controlled studies described surgery for far-lateral herniations, one for central herniations and in 15 studies all types of herniations were included. The median GPE (MacNab) was 86% (85–86%) for lateral herniations, 91% for central herniations and 83% (79–94%) for all types of herniations. Other outcomes are listed in Table 10.

2. What is the effectiveness of transforaminal endoscopic surgery compared to open microdiscectomy?

Six controlled studies ($n = 720$) were identified that compared transforaminal endoscopic to open microdiscectomy. Four of them were prospective and two retrospective studies.

Only one randomized controlled trial ($n = 60$) with a low RoB was identified that compared pure intradiscal technique with open laminotomy [11]. There were no statistically significant differences between the two groups. The pain reduction in the transforaminal endoscopic surgery group was 71 versus 82% in the open laminotomy group after on average 32 months follow-up. The overall improvement was 97 versus 93%, re-operation rate 6.7 versus 3.3% and complication rate 6.7 versus 0%, respectively. Overall, the controlled studies found no differences in outcomes: leg pain reduction in the transforaminal endoscopic surgery group was 89 versus 87% in the open microdiscectomy group, overall improvement (GPE) was 84 versus 78%, re-operation rate 6.8 versus 4.7% and complication rate 1.5 versus 1.0%, respectively (Table 11). In none of the studies, there were any statistically significant differences between the intervention groups on pain improvement and global perceived effect. Ruetten et al. [47] ($n = 200$) reported statistically significant differences on return to work, but this was a secondary outcome and it was unclear how many subjects in each group had work and if groups were comparable regarding work status and history of work absenteeism at baseline.

In one study, transforaminal endoscopic surgery was compared with the same operation combined with

Table 4 Prospective controlled studies

Study/author, methodology	Main inclusion criteria, main exclusion criteria	Type/level LDH	Interventions/technique/instrumentation	Follow-up: duration and outcome	Comment
Hermantin et al. [11], randomized $n = 60$	Inclusion criteria	Type: intracanal LDH	Index: arthroscopic microdiscectomy	Follow-up I: mean 31 months (range 19–42), 0% lost to follow-up	
	Radiculopathy	Level: single level, L2–S1	Pure intradiscal technique Kambin technique biportal: $n = 2$	C: mean 32 months (range 21–42), 0% lost to follow-up	
	Post-tension sign		$n = 30$ ♀8 ♂22, mean 39 years, range 15–66	Pain (VAS) I: pre-op. 6.6, follow-up 1.9, difference 4.7 = 71%	
	Neurological deficit		Control: open Laminotomie, $n = 30$ ♀13 ♂17, mean 40 years, range 18–67	C: pre-op. 6.8, follow-up 1.2, difference 5.6 = 82%	
	Exclusion criteria			Return to work (mean): I: 27, C: 49 days	
	Sequestration			GPE (unclear instrument) I: 97%, C: 93% excellent + good	
	Previous surgery (same level)			PS (very satisfied) I: 73%, C: 67%	
	Central or lateral stenosis			Complications I: 6.7%, C: 0%	
				Re-operations I: 6.7%, C: 3.3%	
Hoogland et al. [16], not adequately randomized (birth date) $n = 280$	Inclusion criteria	Type: all LDH	Index: transforaminal endoscopic discectomy	Follow-up I: 24 months, 16% lost to follow-up	
	Radiculopathy	Level: single level, L2–S1	Intradiscal and intracanal technique, Thessys instrumentation, $n = 142$ ♀50 ♂92, mean 41 years, range 18–60	C: 24 months, 16% lost to follow-up	
	Post-tension sign		Control: transforaminal endoscopic discectomy combined with injection of low-dose (1,000 U) chymopapain. $n = 138$ ♀44 ♂94, mean 40.3 years, range 18–60	Pain leg (VAS) I: pre-op. 8.0, follow-up 2.0, difference 6.0 = 75%	
	Neurological deficit			C: pre-op. 8.2, follow-up 1.9, difference 6.3 = 77%	
	Exclusion criteria			Pain back (VAS) I: pre-op. 8.2, follow-up 2.6, difference 5.6 = 68%	
	Obesity			C: pre-op. 8.2, follow-up 2.8, difference 5.4 = 66%	
	Previous surgery (same level)			GPE (MacNab) I: 16% excellent, 33.8% good, 0.9% poor	
				C: 63% excellent, 27% good, 0.9% poor NS	
				PS I: 85%, C: 93% S	
				Recurrence I: 7.4%, C: 4.0%	
				Complications I: 2.1%, C: 2.2% NS	
				Re-operations I: 6.1%, C: 1.6%	

Table 4 continued

Study/author, methodology	Main inclusion criteria, main exclusion criteria	Type/level LDH	Interventions/technique/instrumentation	Follow-up: duration and outcome	Comment
Krappel et al. [31], not adequately randomized (alternating) $n = 40$	Inclusion criteria	Type: not specified	Index: endoscopic transforaminal nucleotomy	Follow-up I: range 24–36 months, 5% lost to follow-up	
	Radiculopathy	Level: single level, L4–S1	Pure intradiscal technique, Mathews technique, Sofamor–-Danek endoscope, $n = 20$ ♀? ♂?, mean 41 years, range 36–54	C: range 24–36 months, 0% lost to follow-up	
	Post-tension sign		Control: Open nucleotomy, $n = 20$ ♀? ♂?, mean 39 years, range 25–43	GPE (MacNab) I: 16% excellent, 68% good, 0% poor	
	Neurological deficit			C: 15% excellent, 60% good, 0% poor NS	
	Exclusion criteria			Return to work I: 100%, C 100%	
	Sequestration			Recurrence I: 5%, C 0%	
	High iliac crest			Complications I: 0%, C 0%	
				Re-operations I: 5%, C 0%	
Lee et al. [34], not adequately randomized, (preference of surgeon) $n = 300$	Inclusion criteria	Type: not specified	Index: percutaneous endoscopic laser discectomy (PELD), $n = 100$ ♀35 ♂65	Follow-up 12 months, 0% lost to follow-up	Authors included $n = 3$ patients in satisfactory group after re-operation. These were labelled as 'adverse effects' and 're-operations' in this review
	Radiculopathy	Level: single level, L3–S1	Pure intradiscal technique, Kambin technique	GPE (modified MacNab) I: 29%, C1: 20%, C2: 18% excellent	
	Exclusion criteria		Control 1: chemonucleolysis, $n = 100$ ♀24 ♂76	I: 39%,C1: 35%, C2: 30% good	
	Sequestration		Control 2: automated percutaneous discectomy, $n = 100$ ♀28 ♂72	I: 9%, C1: 18%, C2: 20% poor	
				Return to work (6 weeks) I: 81%, C1: 67%, C2: 66%	
				Complications I: 4%, C1: 10%, C2: 3%	
				Re-operations I: 9%, C1: 18%, C2: 20%	
Mayer and Brock [39], randomization not specified $n = 40$	Inclusion criteria	Type: not specified	Index: percutaneous endoscopic discectomy	Follow-up 24 months, 0% lost to follow-up	
	Radiculopathy	Level: single level, L2–L5	Pure intradiscal technique, modified Hjikata instrumentation, $n = 20$ ♀8 ♂12, mean 40 years, range 12–55	GPE (S/S-score) I: 70% satisfactory, 0% poor	
	Post-tension sign		Control: open microdiscectomy, $n = 20$ ♀6 ♂14, mean 42 years, range 19–63	C: 65% satisfactory, 15% poor	
	Neurological deficit			Patient satisfaction I: 55%, C: 55%	
	Exclusion criteria			Recurrence I: 5%, C: 0%	
	Sequestration			Complications I: 0%, C: 5%	
	Previous surgery (same level)			Re-operations I: 15%, C: 5%	
	Cauda syndrome				
	Segmental instability				

Table 4 continued

Study/author, methodology	Main inclusion criteria, main exclusion criteria	Type/level LDH	Interventions/technique/instrumentation	Follow-up: duration and outcome	Comment
Ruetten et al. [47], not adequately randomized (alternating by independent person) $n = 200$	Inclusion criteria Radiculopathy Neurological deficit Exclusion criteria Not specified	Type: all LDH Level: single level, L1–S1	Index: endoscopic transforaminal and interlaminar lumbar discectomy Intracanal technique, YESS, Richard Wolf instrumentation, $n = 100$ Control: open microdiscectomy, $n = 100$, mean 43 years, range 20–68 Overall, $n = 200$ ♀116 ♂84, mean 43 years, range 20−68	Follow-up I: 24 months, 8% lost to follow-up C: 24 months, 8% lost to follow-up Pain leg (VAS) I: pre-op.75, follow-up 8, difference 67 = 89% C: pre-op. 71, follow-up 9, difference 62 = 87% Pain back (VAS) I: pre-op. 19, follow-up 11, difference 8 = 42% C: pre-op. 15, follow-up 18, difference −3 = −8.3% Functional status: (ODI) I: pre-op. 75, follow-up 20, difference 55 = 73% C: pre-op. 73, follow-up 24, difference 49 = 67% Patient satisfaction I: 97%, C: 88% Return to work (mean) I: 25 days C: 49 days S Recurrence I: 6.6% C: 5.7% NS Complications I: 3%, C: 12% S Re-operations I: 6.8% C: 11.5	Authors excluded $n = 6$ from analyses due to revision surgery. These were taken into account in this review, $n = 41$ were operated via a transforaminal endoscopic technique, $n = 59$ patients were operative via an interlaminar endoscopic technique

Intervention as quoted in original article. Post-tension signs denotes positive tension signs (straight leg raising test or contralateral straight leg raising test)

Outcomes: *S* statistically significant, *NS* not statistically significant, *PS* patient satisfaction, *MacNab* MacNab score as described by MacNab [39]. The sum of 'excellent' and 'good' outcomes are labelled 'satisfactory', *GPE* global perceived effect, *S/S-score* Suezawa and Schreiber score [40], *ODI* Oswestry disability index [38]

Table 5 Retrospective controlled studies

Study, methodology	Main inclusion criteria, main exclusion criteria	Type/level LDH	Interventions/technique/instrumentation	Follow-up: duration and outcome	Comment
Kim et al. [26], all patients that underwent the procedures in a certain period	Inclusion criteria	Type: central, paramedian and foraminal LDH	Index: percutaneous transforaminal endoscopic discectomy (PTED)	Follow-up: mean 23.6 months (range 18–36), I: 2.5%, C: 3.5% non-responders	
	Radiculopathy	Level: single level, L1–S1	Intradiscal and intracanal technique, YESS, Richard Wolf instrumentation, $n = 295$ ♀107 ♂188, mean 35 years, range 13–83	GPE (MacNab) I: 47% excellent, 37% good, 5.4% poor	
				C: 48% excellent, 37% good, 6.6% poor NS	
	Post-tension sign		Control: open microdiscectomy, $n = 607$ ♀215 ♂392, mean 44 years, range 17–80	Recurrence I: 6.4% C: 6.8% NS	
	Neurological deficit			Complications I: 3.1% C: 2.0% NS	
	Exclusion criteria			Re-operations I: 9.5% C: 6.3% NS	
	Extraforaminal LDH				
	Previous surgery (same level)				
	Spinal stenosis				
	Segmental instability				
	Spondylolisthesis				
Lee et al. [32], randomly selected patients with follow-up > 3 years in both groups	Inclusion criteria	Type: not specified	Index: percutaneous endoscopic lumbar discectomy (PELD)	Follow-up I: mean 38 months (range 32–45), 0% lost to follow-up	Primary outcome of the study was a radiologic evaluation
	Radiculopathy	Level: single level, L4–S1	Pure intradiscal technique, instrumentation not specified, $n = 30$ ♀8 ♂22, mean 40 years, range 22–67	C: 35–42 (36) months, 0% non-responders	
	Exclusion criteria		Control: open microdiscectomy, $n = 30$ ♀8 ♂22, mean 40 years, range 20–64	GPE (MacNab) I: 80% excellent, 17% good, 3.3% poor	
	Stenosis			C: 78% excellent, 17% good, 0% poor	
	Segmental instability			Complications I: 0%, C: 0%	
				Re-operations I: 3.3%, C: 0%	

Intervention as quoted in original article. Post-tension signs denotes positive tension signs (straight leg raising test or contralateral straight leg raising test)

Table 6 Prospective cohort studies

Study	Main inclusion criteria, main exclusion criteria	Number of participants type/ level LDH	Interventions/technique/ instrumentation	Follow-up: duration and outcome	Comment
Hoogland et al. [17]	Inclusion criteria	$n = 262$ ♀76 ♂186, mean 46 years, range 18–80	Endoscopic transforaminal discectomy (ETD)	Follow-up: 24 months, 9% lost to follow-up	Authors included only patients with recurrent LDH, more than 6 months after open microdiscectomy or endoscopic surgery
	Previous surgery (same level)	Type: all LDH	Intradiscal and intracanal technique	Pain leg (VAS): pre-op. 8.5, follow-up 2.6, differences 5.9 = 69%	
	Recurrent disc herniation	Level: single level, L2–S1	Thessys instrumentation	Pain back (VAS): pre-op. 8.6, follow-up 2.9, difference 5.7 = 66%	
	Radiculopathy			GPE (MacNab): 31% excellent, 50% good, 2.5% poor	
	Post-tension sign			Patient satisfaction: 51% excellent, 35% good, 5% poor	
	Neurological deficit			Recurrence: 6.3%	
	Exclusion criteria			Complications: 1.1%	
	Not specified			Re-operations: 7%	
Hoogland and Schenkenbach [15]	Inclusion criteria	$n = 130$ ♀43 ♂87, mean 39 years	Endoscopic transforaminal discectomy (ETD)	Follow-up: 12 months, 5.1% lost to follow-up	
Schenkenbach and Hoogland [51]	Radiculopathy	Type: all LDH	Intradiscal and intracanal technique	Pain leg (VAS): difference 5.9	
	Post-tension sign	Level: single level, L2–S1	Thessys instrumentation	Pain back (VAS): difference 5.4	
	Neurological deficit			GPE (MacNab): 56% excellent, 27% good, 6% poor	
	Exclusion criteria			Return to work (6 weeks): 70%	
	Not specified			Complications: 1.5%	
				Re-operations: 4.6%	
Kafadar et al. [20]	Inclusion criteria	$n = 42$ ♀2 ♂40, range 18–74 years	Percutaneous endoscopic transforaminal discectomy (PETD)	Follow-up: mean 15 months (range 6–24) (SD 4), 0% lost to follow-up	Authors excluded $n = 8$ from analyses due to stopped procedures. These were taken into account in this review
	Radiculopathy	Type: all LDH	Pure intradiscal technique	GPE (S/S-score): 14% excellent, 36% good 36% poor	
	Post-tension sign	Level: single level, L4–L5	Karl Storz instrumentation	Recurrence: 0%	
	Neurological deficit			Complications: 45%	
	Exclusion criteria			Re-operations: 17%	
	Previous surgery(same level)				
	Spinal stenosis				
	Segmental instability				
	Calcified LDH				

Table 6 continued

Study	Main inclusion criteria, main exclusion criteria	Number of participants type/ level LDH	Interventions/technique/ instrumentation	Follow-up: duration and outcome	Comment
Kambin [23]; Kambin	Inclusion criteria	$n = 175$ ♀76 ♂99	Arthroscopic microdiscectomy and selective fragmentectomy	Follow-up: mean 48 months (range 24–78), 3.4% lost to follow-up	
	Radiculopathy	Type: all LDH	Pure intradiscal technique	GPE (Modified Presby, St Luke score): 77% excellent, 11% good, 12% failed	
	Post-tension sign	Level: single level, L2−S1	Kambin technique	Return to work (3 weeks): 95%	
	Neurological deficit		Biportal $n = 59$	Complications: 5.3%	
	Exclusion criteria			Re-operations: 7.7%	
	Large extraligamental LDH				
	Previous surgery (same level)				
	Cauda syndrome				
	Degenerative disc				
Knight et al. [27]; Knight et al. [29]	Inclusion criteria	$n = 250$ ♀? ♂?, mean 48 years, range 21–86	Endoscopic laser foraminoplasty (ELF)	Follow-up: mean 30 months (range 24–48) (SD 5.87), 3.2% lost to follow-up	Authors included also degenerative and lateral stenosis in this study
	Prior disc surgery $n = 75$	Type: All LDH	Intradiscal and intracanal technique	Pain (VAS > 50% improvement): 56%	
	Back pain	Level: single and multiple level, L2–S1	Richard Wolf instrumentation	Functional status (ODI): 60% improved ≥ 50%	
	Leg pain			Complications: 0.8%	
	Radiculopathy			Re-operations: 5.2%	
	Exclusion criteria				
	Cauda syndrome				
	Painless motor deficit				
Lee et al. [33]	Inclusion criteria	$n = 116$ ♀43 ♂73, mean 36 years, range 18–65	Percutaneous endoscopic lumbar discectomy (PELD)	Follow-up: mean 14.5 months (range 9–20), 0% lost to follow-up	
	Radiculopathy	Type: not specified	Intradiscal and intracanal technique	Pain leg (VAS): pre-op. 7.5, follow-up 2.6, difference 4.9 = 65%	
	Neurological deficit	Level: single level, L2–S1	YESS, Richard Wolf instrumentation	GPE (Modified MacNab): 45% excellent, 47% good, 6.0% poor	
	Non-contained or sequestered LDH			Return to work: average 14 days, range 1–48 days	
	Exclusion criteria			Recurrence: 0%	
	Previous surgery (same level)			Complications: 0%	
	Central or lateral stenosis			Re-operations: 0%	
	Segmental instability				

Table 6 continued

Study	Main inclusion criteria, main exclusion criteria	Number of participants type/ level LDH	Interventions/technique/ instrumentation	Follow-up: duration and outcome	Comment
Morgenstern et al. [42]	Inclusion criteria	$n = 144$ ♀48 ♂96, mean 46 years, range 18–76	Endoscopic spine surgery	Follow-up: mean 24 months (range 3–48), 0% lost to follow-up	Primary outcome of this study was to compare normal versus intensive physical therapy post operative revalidation
	Radiculopathy	Type: all LDH	Intradiscal and intracanal technique	GPE (MacNab): 83% excellent and good, 3% poor	
	Neurological deficit	Level: multiple level $n = 60$, L1–S1	YESS, Richard Wolf instrumentation	Complications: 9%	
	Exclusion criteria			Re-operations: 5.6%	
	Sequestration				
Ramsbacher et al. [45]	Inclusion criteria	$n = 39$ ♀21 ♂18, mean 50 years	Transforaminal endoscopic sequestrectomy (TES)	Follow-up: 6 weeks, 0% lost to follow-up	
	Radiculopathy	Type: all LDH	Intracanal technique	Pain leg (VAS): pre-op. 6.7, follow-up 0.8, difference 5.9 = 88%	
	Neurological deficit	Level: single level, L3–S1	Sofamor–Danek endoscope	Pain back (VAS): pre-op. 5.1, follow-up 1.3, difference 3.8 = 74%	
	Exclusion criteria			PS: 77% (very satisfied + satisfied)	
	Far migrated sequesters			Complications: 5.1%	
	Central or lateral stenosis			Re-operations: 10%	
	High iliac crest				
Ruetten et al. [46]	Inclusion criteria	$n = 517$ ♀277 ♂240, mean 38 years, range 16–78	Extreme-lateral transforaminal approach	Follow-up: 12 months, 10% lost to follow-up	
	Radiculopathy	Type: all LDH	Intracanal technique, Richard Wolf instrumentation, $n = 27$ bilateral	Pain leg (VAS): pre-op. 7.1, follow-up 0.8, difference 6.3 = 89%	
	Neurological deficit	Level: multiple level $n = 46$, L1–L5		Pain back (VAS): pre-op. 1.8, follow-up 1.6, difference 0.2 = 13%	
	Exclusion criteria			Functional status (ODI): pre-op. 78, follow-up 20, difference 58 = 74%	
	Far cranial/caudal migrated sequester			Recurrence: 6.9%	
	Previous surgery (same level)			Complications: 0%	
	Spinal stenosis			Re-operations: 6.9%	

Table 6 continued

Study	Main inclusion criteria, main exclusion criteria	Number of participants type/ level LDH	Interventions/technique/ instrumentation	Follow-up: duration and outcome	Comment
Sasani et al. [48]	Inclusion criteria	$n = 66$ ♀36 ♂30, median 52 years, range 35–73	Percutaneous endoscopic discectomy (PED)	Follow-up: 12 months, 0% lost to follow-up	
	Radiculopathy	Type: foraminal + extraforaminal LDH	Pure intradiscal technique Karl Storz instrumentation	Pain (VAS): pre-op. 8.2, follow-up 1.2, difference 7.0 = 85%	
	Post-tension sign	Level: single level, L2–L5		Functional status (ODI): pre-op. 78, follow-up 8, difference 70 = 90%	
	Neurological deficit			Complications: 6.1%	
	Exclusion criteria			Re-operations: 7.6%	
	Previous surgery (same level)				
Schubert and Hoogland [54]	Inclusion criteria	$n = 558$ ♀179 ♂379, mean 44 years, range 18–65	Transforaminal nucleotomy with foraminoplasty	Follow-up: 12 months, 8.7% lost to follow-up	
	Radiculopathy	Type: all LDH	Intracanal technique, Thessys instrumentation	Pain leg (VAS): pre-op. 8.4, follow-up 1.0, difference 7.4 = 88%	
	Post-tension sign	Level: single level, L2–S1		Pain back (VAS): pre-op. 8.6, follow-up 1.4, difference 7.2 = 84%	
	Neurological deficit			GPE (MacNab): 51% excellent, 43% good, 0.3% poor	
	Sequestration			Recurrence: 3.6%	
	Exclusion criteria			Complications: 0.7%	
	Previous surgery (same level)			Re-operations: 3.6%	
Suess et al. [57]	Inclusion criteria	$n = 25$ ♀11 ♂14, mean 48 years, range 26–72	Percutaneous transforaminal endoscopic sequestrectomy (PTFES)	Follow-up: 6 weeks, 0% lost to follow-up	All patients operated under general anaesthesia and EMG monitoring
	Radiculopathy	Type: foraminal + extraforaminal LDH	Pure intradiscal technique, instrumentation not specified	Pain leg (VAS): pre-op. 6.7, follow-up 0.8, difference 5.9 = 88%	
	Neurological deficit	Level: single level, L2–L5		Pain back (VAS): pre-op. 5.1, follow-up 1.3, difference 3.8 = 75%	
	Exclusion criteria			Complications: 4%	
	Cauda syndrome			Re-operations: 8%	
	Spinal stenosis				

Intervention as quoted in original article. Post-tension signs denotes positive tension signs (straight leg raising test or contralateral straight leg raising test)

Outcomes: *S* statistically significant, *NS* not statistically significant, *PS* patient satisfaction, *MacNab* MacNab score as described by MacNab [39]. The sum of 'excellent' and 'good' outcomes are labelled 'satisfactory', *GPE* global perceived effect, *S/S-score* Suezawa and Schreiber score [40], *Presby. St Luke score* Rush-Presbyterian-St Luke score [23], *ODI* Oswestry disability index [38]

Table 7 Retrospective cohort studies

Study	Main inclusion criteria, main exclusion criteria	Type /level LDH	Interventions/technique/ instrumentation	Follow-up: duration and outcome	Comment
Ahn et al. [3]	Inclusion criteria	$n = 43$ ♀11 ♂32, mean 46 years, range 22–72	Percutaneous endoscopic lumbar discectomy (PELD)	Follow-up: range 24–39 months, 0% non-responders	Authors included only patients with recurrent LDH, more than 6 months after open microdiscectomy
	Prior disc surgery	Type: all LDH	Intradiscal and intracanal technique, instrumentation not specified	Pain (VAS): pre-op. 8.7, follow-up 2.6, difference 6.1 = 70%	
	Radiculopathy	Level: single level, L3–S1		GPE (MacNab): 28% excellent, 53% good, 4.7% poor	
	Post-tension sign			Complications: 4.6%	
	Neurological deficit			Re-operations: 2.3%	
	Exclusion criteria				
	Segmental instability				
	Spondylolisthesis				
	Calcified fragments				
Chiu [5]	Inclusion criteria	$n = 2{,}000$ ♀990 ♂1010, mean 44 years, range 24–92	Transforaminal microdecompressive endoscopic assisted discectomy (TF-MEAD)	Follow-up: mean 42 months (range 6–72), 0% non-responders	Authors included also patients with stenosis and degenerative disc disease
	Virgin and prior disc surgery	Type: not specified	Intradiscal and intracanal technique	GPE (unclear instrument): 94% excellent or good, 3% poor	
	Pain in back	Level: single and multiple level	Karl Storz instrumentation	Complications: 1%	
	Radiculopathy			Re-operations: not specified	
	Neurological deficit				
	Exclusion criteria				
	Cauda syndrome				
	Painless motor deficit				
Choi et al. [6]	Inclusion criteria	$n = 41$, ♀23 ♂18, mean 59 years, range 32–74	Extraforaminal targeted fragmentectomy	Follow-up: mean 34 months (range 20–58), 4.9% non-responders	
	Radiculopathy	Type: extraforaminal LDH	Pure intradiscal technique, YESS, Richard Wolf instrumentation	Pain leg (VAS): pre-op. 8.6, follow-up 1.9, difference 6.7 = 78%	
	Post-tension sign	Level: single level, L4–S1		Return to work: mean 6 weeks (range 4–24)	
	Neurological deficit			Functional status (ODI): pre-op. 66.3, follow-up 11.5, difference 54.8 = 83%	
	Exclusion criteria			PS: 92%	
	Previous surgery (same level)			Recurrence: 5.1%	
	Central or lateral stenosis			Complications: 5.1%	
	Segmental instability			Re-operations: 7.7%	
	Calcified disc				

Table 7 continued

Study	Main inclusion criteria, main exclusion criteria	Type /level LDH	Interventions/technique/ instrumentation	Follow-up: duration and outcome	Comment
Ditsworth [7]	Inclusion criteria	$n = 110$ ♀40 ♂70, median 55 years, range 20 to > 60	Endoscopic transforaminal lumbar discectomy	Follow-up: range 24–48 months, 0% non-responders	
	Radiculopathy	Type: all LDH	Intradiscal and intracanal technique	GPE (MacNab): 91% excellent or good, 4.5% poor	
	Post-tension sign	Level: single level	Flexible endoscope	Recurrence: 0%	
	Neurological deficit			Complications: 0.9%	
	Exclusion criteria			Re-operations: 4.5%	
	Spinal stenosis				
	Segmental instability				
Eustacchio [8]	Inclusion criteria	$n = 122$ ♀36 ♂86, median 55 years, range 18–89	Endoscopic percutaneous transforaminal treatment	Follow-up: mean 35 months (range 15–53), 0% non-responders	Authors excluded $n = 10$ from analyses due to stopped procedures. These were taken into account in this review
	Radiculopathy	Type: all LDH	Intradiscal and intracanal technique instrumentation not specified	GPE (MacNab): 45% excellent, 27% good, 27% poor	
	Post-tension sign	Level: multiple level $n = 4$, L2–S1		Functional status (PROLO): 71.9% excellent or good	
	Neurological deficit			Return to work: 94%	
	Exclusion criteria			Recurrence: 12%	
	Cauda syndrome			Complications: 9%	
				Re-operations: 27%	
Haag [10]	Inclusion criteria	$n = 101$	Transforaminal endoscopic microdiscectomy	Follow-up: mean 28 months (range 15–26), 9% non-responders	Authors excluded $n = 3$ from analyses due to technical problems during procedures. These were taken into account in this review
	Radiculopathy	Type: all LDH	Pure intradiscal technique	PS: good: 66%, satisfied: 9%, poor: 25%	
	Neurological deficit	Level: single level, L2–S1	Sofamor–Danek instrumentation	Complications: 7.6%	
	Exclusion criteria			Re-operations: 17%	
	Discus narrowing				
	Calcified disc				
Hochschuler [13]	Inclusion criteria	$n = 18$ ♀5 ♂13, mean 31 years, range 18–55	Arthroscopic microdiscectomy (AMD)	Follow-up: mean 9 months (range 4–13), 0% non-responders	
	Radiculopathy	Type: not specified	Pure intradiscal technique	Re-operations: 11%	
	Exclusion criteria	Level: L3−S1	Kambin technique		
	Previous operation (same level)				
	Sequestration				
	High iliac crest				

Table 7 continued

Study	Main inclusion criteria, main exclusion criteria	Type /level LDH	Interventions/technique/ instrumentation	Follow-up: duration and outcome	Comment
Hoogland [14]	Inclusion criteria	$n = 246$	Transforaminal endoscopic discectomy with foraminoplasty	Follow-up: 24 months, 0% non-responders	Authors included also patients with foraminal stenosis
	Not specified	Type: not specified	Intracanal technique, Thessys instrumentation	GPE (MacNab): 86% excellent or good, 7.7% poor	
	Exclusion criteria	Level: not specified		Complications: 1.2%	
	Not specified			Re-operations (1st year): 3.5%	
Iprenburg [18]	Inclusion criteria	$n = 149$ ♀62 ♂87, mean 43 years, range 17–82	Transforaminal endoscopic surgery	Follow-up: not specified, 29% non-responders	
	Not specified	Type: all LDH	Intracanal technique, Thessys instrumentation	Pain (VAS): not specified	
	Exclusion criteria	Level: single level, L3–S1		Functional status (ODI): not specified	
	Central stenosis			Recurrence: 6%	
				Complications: not specified	
				Re-operations: not specified	
Jang et al. [19]	Inclusion criteria	$n = 35$ ♀20 ♂15, mean 61 years, range 22–84	Transforaminal percutaneous endoscopic discectomy (TPED)	Follow-up: mean 18 months (range 10–35), 0% non-responders	
	Radiculopathy	Type: foraminal and extraforaminal LDH	Intradiscal and intracanal technique, instrumentation not specified	Pain (VAS): pre-op. 8.6, follow-up 3.2, difference 5.4 = 63%	
	Exclusion criteria	Level: single level, L2–S1		GPE (MacNab): 86% excellent or good, 8.6% poor	
	Previous surgery (same level) segmental instability			Recurrence: 0%	
	Spinal stenosis			Complications: 17%	
	Listhesis			Re-operations: 8.6%	
Lew et al. [35]	Inclusion criteria	$n = 47$ ♀12 ♂35, mean 51 years, range 30–70	Transforaminal percutaneous endoscopic discectomy	Follow-up: mean 18 months (range 4–51), 0% non-responders	
	Radiculopathy	Type: foraminal and extraforaminal LDH	Pure intradiscal technique	GPE (MacNab): 85% excellent or good, 11% poor	
	Post-tension sign	Level: L1–L5	Surgical dynamics instrumentation	Return to work: 89%	
	Neurological deficit			Complications: 0%	
	Exclusion criteria			Re-operations: 11%	
	Previous surgery (same level)				

Table 7 continued

Study	Main inclusion criteria, main exclusion criteria	Type /level LDH	Interventions/technique/ instrumentation	Follow-up: duration and outcome	Comment
Mayer and Brock [39]	Inclusion criteria	$n = 30$ ♀11 ♂19	Percutaneous endoscopic lumbar discectomy (PELD)	Follow-up: range 6–18 months, 0% non-responders	Twenty of the patients were described in a prospective study [41]. In this review reoperations were labelled as moderate or poor outcome on GPE
	Radiculopathy	Type: not specified	Pure intradiscal technique, instrumentation not specified	GPE (S/S-score): 67% excellent or good, 33% moderate or poor	
	Post-tension sign	Level: multiple level $n = 1$, L2–L5		Return to work: 7.1 ± 4.2 weeks, 90% (6 months)	
	Neurological deficit			Complications: 3.3%	
	Exclusion criteria			Re-operations: 3.3%	
	Sequestration				
	Previous surgery (same level)				
	Cauda syndrome				
	Segmental instability				
	Spinal stenosis				
	Listhesis				
Savitz [49, 50]	Inclusion criteria	$n = 300$ ♀132 ♂168, range 16–81 years	Percutaneous lumbar discectomy with endoscope	Follow-up: 6 months, 0% non-responders	
	Radiculopathy				
	Post tension sign	Type: not specified	Pure intradiscal technique, Kambin technique	Return to work (6 months): 67%	
	Neurological deficit				
	Exclusion criteria	Level: multiple level $n = 40$, L2–S1		Complications: 5.3%	
	Previous surgery (same level)				
	Sequestration			Re-operations: 1.3%	
	Obesity				
Schreiber and Suezawa [53]; Suezawa and Schreiber [58]; Leu and Schreiber [36]; Schreiber and Leu [52]	Inclusion criteria	$n = 174$ ♀68 ♂106, mean 39 years, range 16–81	Percutaneous nucleotomy with discoscopy	Follow-up: mean 28 months, 0% non-responders	Authors included also patients with degenerative disc disease, only the scores from LDH are quoted in this review
	Radiculopathy	Type: not specified	Pure intradiscal technique	GPE (S/S-score): 85% excellent or good	
	Exclusion criteria	Level: multiple level $n = 25$	Modified Hijikata instrumentation biportal	Complications: 10%	
	Sequestration			Re-operations: 21%	
Shim et al. [56]	Inclusion criteria	$n = 71$ ♀39 ♂32, mean 45 years, range 21–74	Transforaminal endoscopic surgery	Follow-up: mean 6 months (range 3–9), 0% non-responders	$n = 14$ patients with L5–S1 level LDH are operated via a interlaminar approach
	Radiculopathy	Type: not specified	Pure intradiscal technique	GPE (MacNab): 33% excellent, 45% good, 6.5% poor	
	Exclusion criteria	Level: single level, T12–S1	YESS, Richard Wolf instrumentation	Complications: 2.8%	
	Not specified			Re-operations: 7.0%	

Table 7 continued

Study	Main inclusion criteria, main exclusion criteria	Type /level LDH	Interventions/technique/ instrumentation	Follow-up: duration and outcome	Comment
Tsou and Yeung [59]	Inclusion criteria	$n = 219$ ♀83 ♂136, mean 42 years range 17–71	Transforaminal endoscopic decompression	Follow-up: mean 20 months (range 12–108), 11.9% non-responders	Possible patient overlap with other study [65]
	Radiculopathy	Type: central LDH	Intradiscal and intracanal technique	GPE (MacNab): 91% excellent or good, 5.2% poor	
	Neurological deficit	Level: single level, L3–S1	YESS, Richard Wolf instrumentation	Recurrence: 2.7%	
	Exclusion criteria			Complications: 2.7%	
	Sequestration			Re-operations: 4.6%	
	Previous operation (same level)				
Tzaan [60]	Inclusion criteria	$n = 134$ ♀56 ♂78, mean 38 years, range 22–71	Transforaminal percutaneous endoscopic lumbar discectomy (TPELD)	Follow-up: mean 38 months (range 3–36), 0% non-responders	
	Pain in leg and back	Type: all LDH	Pure intradiscal technique	GPE (modified MacNab): 28% excellent, 61% good, 3.7% poor	
	Exclusion criteria	Level: multiple level $n = 20$, L2–S1	Instrumentation not specified	Recurrence: 0.7%	
	Sequestration			Complications: 6.0%	
	Spinal stenosis			Re-operations: 4.5%	
	Calcified disc				
	Segmental instability				
	Cauda syndrome				
Wojcik [62]	Inclusion criteria	$n = 43$ ♀25 ♂18, mean 30 years	Endoscopically assisted percutaneous lumbar discectomy	Follow-up: 18 months, 16.3% non-responders	
	Radiculopathy	Type: not specified	Pure intradiscal technique	GPE (unclear instrument): 64% good, 36% satisfied, 0% poor	
	Exclusion criteria	Level: not specified	Modified Hijikata instrumentation	Complications: not specified	
	Sequestration			Re-operations: not specified	
	Chronic back pain				
Yeung and Tsou [65]	Inclusion criteria	$n = 307$ ♀102 ♂205, mean 42 years, range 18–72	Posterolateral endoscopic excision for lumbar disc herniation	Follow-up: mean 19 months (range 12–?), 8.8% non-responders	Possible patient overlap with other study [65]
	Prior disc surgery $n = 31$	Type: all LDH	Intradiscal and intracanal technique	GPE (MacNab): 84% excellent or good, 9.3% poor	
	Radiculopathy	Level: single level, L2–S1	YESS, Richard Wolf instrumentation	Recurrence: 0.7%	
	Neurological deficit			Complications: 3.9%	
	Exclusion criteria			Re-operations: 4.6%	
	Sequestration				
	Central and lateral stenosis				

? unknown, is not described in the study

Intervention as quoted in original article, Post-tension signs denotes positive tension signs (straight leg raising test or contralateral straight leg raising test)

Outcomes: *S* statistically significant, *NS* not statistically significant, *PS* patient satisfaction, *MacNab* MacNab score as described by MacNab [39]. The sum of 'excellent' and 'good' outcomes are labelled 'satisfactory', *GPE* global perceived effect, *S/S-score* Suezawa and Schreiber score [40], *ODI* Oswestry disability index [38], *PROLO* prolo functional-economic outcome rating scale [44]

Table 8 Overall outcome, non-controlled studies

Outcome measure (instrument)	Studies (patients)	Outcome median (min–max)
Pain leg (VAS)	7 (n = 1,558)	88% (65–89%) improvement
Pain back (VAS)	5 (n = 1,401)	74% (13–84%) improvement
Pain (region not specified) (VAS)	3 (n = 144)	70% (63–85%) improvement
GPE (MacNab)	15 (n = 2,544)	85% (72–94%) satisfactory
		6% (0.3–27%) poor
Functional status (ODI)	3 (n = 624)	83% (74–90%) improvement
Patient satisfaction	3 (n = 181)	78% (75–92%) satisfactory
Return to work	5 (n = 757)	90% (67–95%)
Recurrence	13 (n = 2,612)	1.7% (0–12%)
Complication	28 (n = 6,336)	2.8% (0–40%)
Re-operation	28 (n = 4,135)	7% (0–27%)

Outcomes: *MacNab* MacNab score as described by MacNab [39]. The sum of 'excellent' and 'good' outcomes are labelled 'satisfactory', *GPE* global perceived effect, *ODI* Oswestry disability index [38]

Table 9 Intradiscal and intracanal techniques, outcomes non-controlled studies

Outcome measure (instrument)	Studies	Outcome median (min–max)
Pure intradiscal technique 14 studies (n = 1,267) intradiscal technique		
Pain leg (VAS)	2 (n = 66)	83% (78–88%) improvement
Pain back (VAS)	1 (n = 25)	75% improvement
Pain (region not specified) (VAS)	1 (n = 66)	85% improvement
GPE (MacNab)	3 (n = 279)	85% (78–89%) satisfactory
		6.5% (3.7–11%) poor
Recurrence	3 (n = 217)	0.7% (0–5.1%)
Complication	12 (n = 1,206)	5.3 % (0–40%)
Re-operation	14 (n = 1,267)	7.5% (1.3–30%)
Intracanal technique 16 studies (n = 4,985)		
Pain leg (VAS)	5 (n = 1,524)	88% (65–89%) improvement
Pain back (VAS)	4 (n = 1,408)	70% (13–84%) improvement
Pain (region not specified) (VAS)	2 (n = 78)	67% (63–70%) improvement
GPE (MacNab)	12 (n = 2,292)	86% (72–93%) satisfactory
		6% (0.3–9.3%) poor
Recurrence	10 (n = 2,395)	3.2% (0–12%)
Complication	17 (n = 5,362)	2.1% (0–17%)
Re-operation	15 (n = 3,098)	4.6% (0–27%)

Outcomes: *MacNab* MacNab score as described by MacNab [39]. The sum of 'excellent' and 'good' outcomes are labelled 'satisfactory', *GPE* global perceived effect

chymopapain, and one study compared endoscopic surgery with chemonucleolysis and automated discectomy (Table 4).

Discussion

In the current review, all available evidence regarding the effectiveness of transforaminal endoscopic surgery was identified and systematically summarized. We identified 1 randomized controlled trial, 7 non-randomized controlled trials and 31 observational studies. The methodological quality of these studies was poor. The eight trials did not find any statistically significant differences in leg pain reduction between the transforaminal endoscopic surgery group (89%) and the open microdiscectomy group (87%); overall improvement (84 vs. 78%), re-operation rate (6.8 vs. 4.7%) and complication rate (1.5 vs. 1%), respectively. We conclude that current evidence on the effectiveness of transforaminal endoscopic surgery is poor and does not provide valid information to either support or refute using this type of surgery in patients with symptomatic lumbar disc herniations. High-quality randomized controlled trials with sufficiently large sample sizes are direly needed.

This study has a number of limitations that should be considered when drawing conclusions regarding the effectiveness of transforaminal endoscopic surgery for lumbar disc herniations. The included studies in this review were heterogeneous with regard to the selection of patients, the indications for surgery, the surgical techniques used

Table 10 Outcomes of improvement in lateral herniations, central herniations and all types of herniations

Outcome measure (instrument)	Studies	Outcome median (min–max)
Type: far-lateral LDH 6 studies ($n = 214$)		
Pain (region not specified) (VAS)	4 ($n = 167$)	82% (63–88%) improvement
GPE (MacNab)	2 ($n = 52$)	86% (85–86%) satisfactory
		9.8% (8.6–11%) poor
Functional status (ODI)		
Recurrence	2 ($n = 76$)	2.6% (0–5.1%)
Complication	5 ($n = 214$)	5.1% (0–17%)
Re–operation	5 ($n = 214$)	8.0% (7.6–11%)
Type: central LDH 1 study ($n = 71$)		
GPE (MacNab)	1 ($n = 71$)	91% satisfactory
		12% poor
Complication	1 ($n = 71$)	2.7%
Re-operation	1 ($n = 71$)	4.6%
Type: all LDH 15 studies ($n = 3{,}067$)		
Pain leg (VAS)	4 ($n = 1{,}374$)	88% (69–89%) improvement
Pain back (VAS)	4 ($n = 1{,}374$)	70% (13–84%) improvement
Pain (region not specified) (VAS)	1 ($n = 43$)	70% improvement
GPE (MacNab)	9 ($n = 1{,}810$)	83% (79–94%) satisfactory
		4.6% (0.3–9.3%) poor
Recurrence	9 ($n = 2{,}201$)	3.6% (0–12%)
Complication	15 ($n = 2{,}934$)	4.9% (0–45%)
Re-operation	15 ($n = 2{,}934$)	5.6% (2.3–27%)

LDH lumbar disc herniation, *Type* in transversal section, subdivided in central, paramedian, foraminal and extraforaminal herniations

Table 11 Outcomes of improvement of transforaminal endoscopic versus open microdiscectomy

Outcome measure (instrument)	Studies	Outcome median (min–max)
Endoscopic (index) versus open microdiscectomy (control)		
Pain leg (VAS)	1 ($n = 200$)	Index 89% improvement
		Control 87% improvement
Pain back (VAS)	1 ($n = 200$)	Index 42% improvement
		Control −8.3% improvement
Pain (region not specified) (VAS)	1 ($n = 60$)	Index 71% improvement
		Control 82% improvement
GPE (MacNab/other)	5 ($n = 1{,}102$)	Index 84% (70–97%) satisfactory
		1.7% (0–5.4%) poor
		Control 78% (65–93%) satisfactory
		3.3% (0–15%) poor
Recurrences	4 ($n = 1{,}182$)	Index 5.7% (5–6.6%)
		Control 2.9% (0–6.8%)
Complications	6 ($n = 1{,}302$)	Index 1.5% (0–6.7%)
		Control 1.0% (0–12%)
Re-operations	6 ($n = 1{,}302$)	Index 6.8% (3.3–15%)
		Control 4.7 % (0–11.5%)

I index intervention, *C* control intervention

and the duration of follow-up. Furthermore, different outcome measures were used in the studies and different instruments used for the same outcomes. Below we will elaborate on the most important sources of heterogeneity in more detail.

Selection of patients

Patient selection and in/exclusion criteria were often not clearly described. Amongst others, this includes physical examinations, radiological findings, the period and type

of pre-operative therapies and duration of symptoms. In most studies, patients received some type of preoperative conservative treatment for a few months, but the exact content of the conservative treatment was not specified. Also, duration of symptoms before surgery differed amongst studies and in some studies patients with acute onset (<2 weeks) of complaints were also included. In some studies only 'virgin discs' were included, whilst in others a previous disc operation was not an exclusion criterion or it was not mentioned if patients with a previous disc operation were excluded or not. In two studies only recurrent herniations after open microdiscectomy were treated with transforaminal endoscopic surgery [3, 17]. Some studies included only lateral or central herniations, whereas others included all herniations. Given this, there is much heterogeneity in patient selection between the studies which hinders comparability between studies.

Techniques

Indications for endoscopic surgery have changed over time with the introduction of new techniques, scopes and instruments. Initially non-contained, sequestered and central herniations were exclusion criteria for endoscopic surgery and L5–S1 level herniations were not always possible to reach as the diameter of the foramen intervertebral decreases in the lumbar area from cranial to caudal [46]. In the earlier studies of transforaminal endoscopic surgery, discectomy was performed through a fenestration in the lateral annulus and the focus was limited on central debulking and reduction in intradiscal pressure. Later studies described that the hernia was extracted from the spinal canal with or without an intradiscal debulking. We found comparable outcomes for these intradiscal and intracanal techniques. However, one could debate whether these procedures are really two different techniques. The main distinction is a 10° difference in direction and may be within the limits of measurement error and anatomical variation. Far-lateral herniations occur in 3–11% of lumbar disc herniations and usually cause severe sciatic pain [1, 2, 43, 44]. Some reports mentioned more difficulty to assess an extraforaminal herniated lumbar disc through an open procedure and it is often associated with the substantial bone removal [35]. Because transforaminal endoscopic surgery is a posterolateral approach to the spine, lateral herniations might be more easily reached [60]. With lateral herniations, the angle of the instruments should be steeper and, thus, the insertion closer to the midline [6, 19]. We compared the effect of transforaminal endoscopic surgery for lateral herniations with central and all herniations. All outcomes were comparable.

Methodological quality

Most studies had major design weaknesses and the quality of the identified studies was poor, indicating that studies had a high RoB. Only one adequately randomized controlled trial was identified. In most studies, randomization was not performed at all, not performed adequately or not described adequately. Obviously, patients and surgeons cannot be blinded for the surgical intervention. However, many other important quality items were also not met by the majority of studies. Although transforaminal endoscopic surgery for lumbar disc herniation was introduced about 30 years ago and many patients have undergone this intervention since its introduction, only one randomized controlled trial with a low RoB has been published. Only high-quality, randomized controlled trials with sufficiently large sample sizes comparing transforaminal endoscopic surgery to other surgical techniques for lumbar disc herniations can provide strong evidence regarding its effectiveness. Preferably, these trials should be conducted by independent research institutes.

Outcome measures

The most frequently used outcome measures in the included studies are the VAS score for pain and the MacNab score for global perceived effect. To compare the VAS scores across studies, we calculated the percentage of improvement between the postoperative and preoperative scores. The MacNab score is a 4-point scale ranging from 1 (excellent); 2 (good), 3 (fair) to 4 (poor). In most studies 'excellent' and 'good' were combined and labelled 'satisfactory'. Although a close inspection of the score 'good' on the MacNab, reveals that patients still have occasionally ongoing symptoms, sufficient to interfere with normal work or capacity to enjoy leisure activities [37]. We considered labelling this as a 'satisfactory' outcome was somewhat too positive. Therefore, whenever possible, we presented the original MacNab scores. Although some studies used validated outcomes (e.g. the Oswestry Disability Questionnaire for low back pain-specific functional disability) others used non-validated outcomes, or did not describe at all how disability and improvement were measured. Future trials should use valid and reliable instruments to measure the primary outcomes.

Adverse effects

Recurrences

Eighteen studies reported recurrence rates of lumbar disc herniations, but the definition of recurrence varied. In

this review, we defined a recurrence as a re-appearance of a symptomatic lumbar disc herniation at the same level after a pain-free interval of longer than a month. When in a study the symptomatic hernia appeared within a month, we considered it a recurrence. The median recurrence rate of included studies was 1.7% (range 0–12%). The reported recurrence rate in the literature of open microdiscectomy is similar with reported ranges from 5 to 11% [60]. The controlled studies found no significant difference in recurrences between the two techniques.

Re-operation

In the observational studies, the median re-operation rate was 7% (0–27%). The controlled studies found no significant differences in re-operation percentages between endoscopic transforaminal surgery and open microdiscectomy (6.8 vs. 4.7%). As in most surgical interventions, adequate patient selection and accurate diagnosis seem very important. Most common cause for re-operations was persistent complaints due to missed lateral bony stenosis and remnant fragments [23].

Complications

One of the suggested advantages of transforaminal endoscopic surgery compared with open microdiscectomy is a lower complication rate [28]. Because of the small incision and minimal internal tissue damage, the revalidation period is supposed to be shorter and scar tissue minimised [29]. In the current review, we found no severe neurological injury and a mean percentage of complications after transforaminal endoscopic surgery of 2.8%. There were no substantial differences in serious complications between endoscopic surgery and open microdiscectomy. Most reported complications were transient dysaesthesia or hypaesthesia. However, it has to be noted that none of the included studies was specifically designed for the assessment of adverse effects, and, therefore, these results have to be interpreted cautiously; also, disadvantages have been reported. Transforaminal endoscopic surgery has a steep learning curve that requires patience and experience, especially for those unfamiliar with percutaneous techniques. In some studies, the patients operated at the beginning of the learning curve had worse outcome [10, 20, 26, 56, 60]. Some patients may experience local anaesthesia as a disadvantage. In three studies, the operations were performed under general anaesthesia [47, 48, 57]. Comprehensive preoperative information about the intervention and permanent communication and constant observation during the operation is of major importance.

Future research

Only randomized controlled trials that are adequately designed, conducted and reported and that have a low RoB will provide sufficient evidence regarding the effectiveness of transforaminal endoscopic surgery for lumbar disk herniation. High-quality, randomized controlled trials with sufficiently large sample sizes that compare the effectiveness of transforaminal endoscopic surgery with open microdiscectomy for lumbar disc herniations are needed. The short hospital stay, shorter revalidation period and earlier return to work may result in an economic advantage, although this has never been evaluated. Economic evaluations should be performed alongside these trials to assess the cost-effectiveness and cost utility of transforaminal endoscopic surgery.

Conclusion

This systematic review assessed the effectiveness of transforaminal endoscopic surgery. Of the 39 studies included in this review, most studies had major design weaknesses and were considered having a high RoB. Only one randomized controlled trial was identified, but this trial had poor generalizability. No significant differences in pain, overall improvement, patient satisfaction, recurrence rate, complications and re-operations were found between transforaminal endoscopic surgery and open microdiscectomy. Current evidence on the effectiveness of transforaminal endoscopic surgery is poor and does not provide valid information to either support or refute using this type of surgery in patients with symptomatic lumbar disc herniations.

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