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Systematic Review/Meta-Analysis

Discectomy versus sequestrectomy in the treatment of lumbar disc herniation: a systematic review and meta-analysis

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Abstract

BACKGROUND CONTEXT: Lumbar disc herniation (LDH) is a leading cause of low back pain (LBP) and leg pain and may require surgical treatment in case of persistent pain and/or neurological deficits. Conventional discectomy involves removing the herniated fragment and additional material from the disc space, potentially accelerating disc degeneration and contributing to chronic LBP. Conversely, by resecting the herniated fragment only, sequestrectomy may reduce postoperative LBP while increasing the risk of LDH recurrence.

PURPOSE: To compare discectomy versus sequestrectomy in terms of risk of reherniation, reoperation rate, complications, pain, satisfaction, and perioperative outcomes (operative time, blood loss, length of stay [LOS]).

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STUDY DESIGN: Systematic review and meta-analysis.
METHODS: A systematic search of PubMed/MEDLINE and Scopus databases was performed through May 1, 2024 for both randomized and nonrandomized studies. The search was conducted according to PRISMA guidelines. The RoB-2 and MINORS tools were utilized to assess the risk of bias in included studies. The quality of the evidence was evaluated according to the GRADE approach. Relevant outcomes were pooled for meta-analysis.
RESULTS: A total of 16 articles (1 randomized controlled trial with 2 follow-up studies, 6 prospective studies, and 7 retrospective studies) published between 1991 and 2020 involving 2009 patients were included for analysis. No significant differences were noted between discectomy versus sequestrectomy in terms of risk of reherniation (OR: 0.85, 95% CI: 0.57 to 1.26, p=.42), reoperation rate (OR: 0.95, 95% CI: 0.64 to 1.40, p=.78), and complications (OR: 1.03, 95% CI: 0.50 to 2.11, p=.94). Although LBP (MD: −0.06, 95% CI: −0.39 to 0.28, p=.74) and leg pain intensity (MD: 0.11, 95% CI: −0.21 to 0.42, p=.50) were similar postoperatively, significantly better outcomes were reported by patients treated with sequestrectomy at 1 year (leg pain: MD: 0.37, 95% CI: 0.19 to 0.54, p<.0001) and 2 years (LBP: MD: 0.19, 95% CI: 0.03 to 0.34, p=.02; leg pain: MD: 0.20, 95% CI: 0.09 to 0.31, p=.0005). Sequestrectomy also resulted in a higher patient satisfaction (OR: 0.60, 95% CI: 0.40 to 0.90, p=.01) and shorter operative time (MD: 8.71, 95% CI: 1.66 to 15.75, p=.02), while blood loss (MD: 0.18, 95% CI: −2.31 to 2.67, p=.89) and LOS (MD: 0.02 days, 95% CI: −0.07 to 0.12, p=.60) did not significantly differ compared to discectomy.
CONCLUSIONS: Based on the current evidence, discectomy and sequestrectomy do not significantly differ in terms of risk of reherniation, reoperation rate, and postoperative complications. Patients treated with sequestrectomy may benefit from a marginally higher pain improvement, better satisfaction outcomes, and a shorter operative time, although the clinical relevance of these differences needs to be validated in larger, prospective, randomized studies.

Keywords: Discectomy; Fragmentectomy; Intervertebral disc degeneration; Lumbar disc herniation; Microdiscectomy; Minimally invasive spine surgery; Sequestrectomy

Introduction

Lumbar disc herniation (LDH) is one of the most common causes of low back pain (LBP) and sciatica, affecting approximately 1%−2% of the general population [1]. While conservative treatment successfully resolves symptoms in most cases, surgery is still needed in a subset of patients presenting with untreatable pain and/or neurological deficits [2]. Indeed, surgical treatment of LDH is the most popular procedure performed in patients with sciatica in the USA [3].

Since its introduction in 1934 [4], lumbar discectomy has been the most common approach to achieve surgical decompression in the setting of LDH. Despite several historical variations, the contemporary technique employs an interlaminar approach with partial resection of the laminae and ligamentum flavum to access the spinal canal, and ultimately the disc space to remove the herniated disc material. This includes not only the herniated fragment itself, but also complete, radical, or subtotal discectomy with curettage of the cartilaginous endplates (CEPs) in some reports, with the objective of limiting the risk of reherniation as much as possible [5]. However, aggressive removal of the disc material may result in accelerated intervertebral disc degeneration (IDD) with premature development of spondylosis, segmental instability, and refractory chronic LBP, potentially culminating in the development of failed back surgery syndrome [6,7].

Therefore, an increasing number of recent reports have been advocating the use of a less invasive approach consisting of the removal of the herniated fragment only, namely fragmentectomy or sequestrectomy. By addressing the cause of radiculopathy without further disrupting the intervertebral disc, sequestrectomy has been demonstrated to provide prompt pain resolution with better outcomes in terms of satisfaction and function compared to discectomy [8]. However, limited removal of the disc material has also been associated with possibly higher rates of LDH recurrence needing reoperation, which may eventually affect the cost-effectiveness and long-term success of the procedure [8,9]. Currently, there is no consensus on whether discectomy or sequestrectomy yields superior outcomes in terms of symptom resolution, risk of recurrence, and long-term consequences.

The aim of this systematic review was to compare reherniation, reoperation, and complication rates between discectomy and sequestrectomy, and to assess which technique results in better outcomes in terms of LBP, leg pain, satisfaction, operative time, blood loss, and length of stay (LOS).

Materials and methods

This systematic review was conducted following established standards for rigor, quality, and transparency established by the PCORI Methods Guide [10], IOM Standards for Systematic Reviews [11] and the Agency for Healthcare Research and Quality (AHRQ) [12]. The study has been reported following Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [13,14]. The review protocol has been registered within the International Prospective Register of Systematic Reviews (PROSPERO) database under the ID CRD42024494991.

Electronic literature search

A systematic search of PubMed/MEDLINE, Scopus, and Cochrane databases was performed on May 1, 2024 for literature published from inception to May 2024. The aim of this systematic review was to compare the clinical outcomes of discectomy versus sequestrectomy in the surgical treatment of LDH. According to the PICOS framework, we searched for studies including patients aged ≥18 years affected by single-level LDH (P) who underwent either discectomy (I) or sequestrectomy (C) and reporting reherniation rate and additional outcomes including reoperation rate, complications, perioperative outcomes (operative time, blood loss, LOS), radiological changes, and patient-reported outcome measures (PROMs) related to pain, disability, and satisfaction (O). Randomized controlled trials (RCTs) and comparative observational cohort studies with ≥10 patients per group were included (S). Duplicates, reviews, meta-analyses, case reports, letters to the editor, cadaveric studies, technical notes, preclinical studies, commentaries, and articles written in languages other than English were also excluded from the analysis. The complete search strategy is reported in Supplementary Materials.

Study selection

The initial search of the articles was conducted by two reviewers (LA and EdR). In case of disagreements, a third reviewer (GV) was involved to solve inconsistencies. The following search order was used: titles and abstract were screened first, then full texts of papers not excluded based on abstract nor title were analyzed. The article screening workflow is reported in a PRISMA flow diagram.

Data extraction

General study characteristics extracted included: authors, year of publication, country, sample size, mean age, sex, body mass index (BMI), mean follow-up, study design, technical description of both intervention (discectomy) and comparator (sequestrectomy), reherniation and reoperation rates, return to work, PROMs of disability (Oswestry Disability Index [ODI]), leg and LBP severity (visual analog scale [VAS]), patient satisfaction (VAS, Patient Satisfaction Index [PSI], Odom's criteria), functionality (Prolo scale, Hannover Activities of Daily Living Questionnaire [FFbH]), and quality of life (short form [SF]-36), use of analgesic medications, perioperative outcomes (operative time, intraoperative blood loss, and LOS), and radiological outcomes (disc height change, magnetic resonance imaging [MRI] alterations). When specified, reherniation was described as symptom recurrence associated with MRI evidence of same-level recurrent LDH. Reoperation included both patients with reherniation requiring revision surgery and subjects who underwent additional lumbar spine surgical procedures (e.g., due to the development of instability, stenosis, LDH at other levels, etc.).

Risk of bias

The Risk of Bias (RoB)-2 tool [15] was utilized to assess the quality of RCTs, whereas the Methodological Index for Nonrandomized Studies (MINORS) tool [16] was used to assess the risk of bias of nonrandomized clinical trials (NRCTs). To avoid imprecision, the included papers were rated independently by two reviewers (LA and EdR) and verified by a third reviewer (GV). Publication bias was evaluated using funnel plots for outcomes analyzed by at least 10 studies.

Quality of evidence

For the outcomes of reherniation rate, LBP severity, leg pain severity, complications (other than reherniation), satisfaction, and operative time, the overall strength of evidence across included studies was evaluated according to the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework [17]. The overall quality of the evidence was based on studies with the lowest risk of bias. In defining the quality (strength) of a body of evidence regarding a specific outcome, the overall quality was downgraded by 1 or 2 levels based on the following: (1) risk of bias due to study limitations, (2) consistency (heterogeneity) of results, (3) directness of evidence, (4) precision of effect size estimates, and (5) publication or reporting bias. The initial quality of the overall body of evidence was set as "High" for RCTs and "Low" for observational studies. As most included studies were observational and the only RCT was characterized by a considerable risk of bias, the initial quality of the overall body of the evidence was set as "Low".

Statistical analysis

Meta-analysis was performed using mean differences (MD) with 95% confidence intervals (Cl) for continuous variables and odds ratios (OR) tfor dichotomous variables. If a study describing continuous outcomes reported median and range values, mean and standard deviations were calculated according to Wan et al. [18]. The level of significance (p) was set at 0.05. Heterogeneity was assessed using the I^2 statistics, being classified as "low" ($I^2 \leq 25\%$), "moderate" (I^2=26%−74%), or "high" ($I^2 \geq 75\%$). Pooled estimates were calculated by inverse variance for LBP severity, leg pain severity, operative time, blood loss, and LOS, while the Mantel-Haenszel method was used for patient satisfaction, reherniation, reoperation and complication rates. In the evaluation of leg and LBP severity, follow-up periods were categorized as postoperative (from operation to 6 months postoperatively), 1 year and 2 years. Random effect models were employed when heterogeneity was statistically significant; otherwise, a fixed effect model was applied. Formal analysis was conducted with Review Manager (v. 5.4, Cochrane Collaboration, UK).

Results

Study selection

A total of 1,022 studies were identified through the initial search. 643 studies remained after duplicate removal and 617 articles were excluded following title and abstract screening. Then, 26 full-text articles were sought for retrieval, with 1 report not being found. Eventually, 25 manuscripts were screened. Out of these studies, 9 were excluded (study protocol, n=1; study interventions not matching eligibility criteria n=4; percutaneous or endoscopic interventions, n=3; inappropriate outcomes, n=1). After this process, 16 articles were included (Fig. 1).

Study characteristics

Included studies consisted of 1 RCT [19] with 2 follow-up studies reporting outcomes at a later timepoint [20,21], 6 prospective studies (PS) [8,9,22−25] and 7 retrospective studies (RS) [26,27]. These reports were published between 1991 [26] and 2020 [25,28] from Turkey [8,22,28], Germany [19−21,23,24,29], USA [9,26], UK [27], South Korea [30,31], Canada [32], and Austria [25]. Collectively, 2,009 patients (1,078 in the discectomy group vs. 931 in the sequestrectomy group) were assessed, with a mean age of 44.1 and 46.3 years, respectively. Follow-up ranged from a minimum of 1 to 132 months (Table 1). All included patients were diagnosed with single-level LDH via a combination of clinical, imaging, and electrophysiological investigations, and were considered eligible for surgical decompression. Surgery was performed either using an

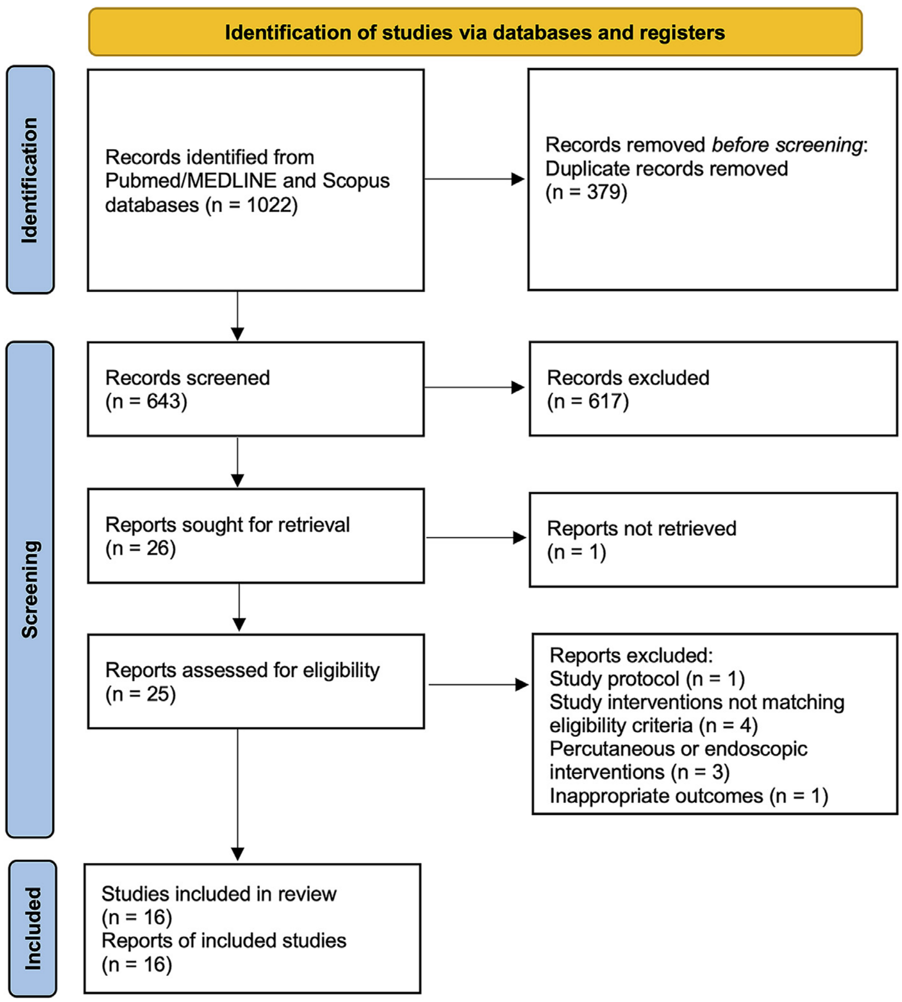


Fig. 1. Search strategy flow diagram according to the Preferred Eeporting Stems for Systematic reviews and Meta-Analyses (PRISMA) statement.

Table 1
Patient demographics, design, and risk of bias of included studies.

Study	Country	Sample size		Age (mean, range or ± SD)		Sex (M/F)		BMI (kg/m^2 ± SD)		Follow-up (mean, range or ± SD; months)		Study design	Risk of bias	
		D	S	D	S	D	S	D	S	D	S		RoB-2	MINORS
Kotil 2014 [8]	Turkey	85	40	41.1, 18−74	39.9, 22−69	37/84	19/21	-	-	60.2, 49.0−68.0	60.2, 50.5−66.0	PS	-	15/24
Thome 2005 [19]	Germany	42	42	40.0 ± 10.0	42.0 ± 9.0	23/19	24/18	25.0 ± 5.0	26.0 ± 4.0	18		RCT	Some concerns	-
Balderston 1991 [26]	USA	43	40	34.0, 25−59	37.0, 22−61	23/20	22/18	-	-	31.2	40.0	RS	-	10/24
Barth 2008a [20]	Germany	35	38	41.3 ± 9.9	40.8 ± 8.7	19/16	20/18	25.6 ± 5.1	25.6 ± 3.6	24		RCT	Some concerns	-
Barth 2008b [21]	Germany	35	38	41.3 ± 9.9	40.8 ± 8.7	19/16	20/18	25.6 ± 5.1	25.6 ± 3.6	24		RCT	Some concerns	-
Boyaci 2016 [22]	Turkey	92	78	46.2 ± 12.1	45.3 ± 11.5	48/44	41/37	27.8 ± 3.1	28.0 ± 5.5	35.2 ± 6.8	34.4 ± 5.4	PS	-	19/24
Carragee 2006 [9]	USA	30	46	38.4, 19−55	37.5, 22−57	16/14	25/21	-	-	24		PS	-	16/24
Fakouri 2011 [27]	UK	72	24	38.4 ± 8.4	37.2 ± 12.9	46/26	15/9	-	-	32.4 ± 5.7	33.4 ± 7.1	RS	-	15/24
Faulhauer 1995 [29]	Germany	100	100	44.8, 20−75	51.9, 25−78	57/43	66/34	-	-	42.7, 4.0−82.0		RS	-	12/24
Baek 2012 [30]	South Korea	101	74	42.9, 19−68	48.3, 18−69	60/41	40/34	-	-	22.3, 4.0−45.0	23.8, 4.0−45.0	RS	-	14/24
Altinel 2020 [28]	Turkey	70	70	50.4 ± 12.1	50.2 ± 16.4	33/37	34/36	-	-	25.3 ± 4.0	27.1 ± 5.6	RS	-	13/24
Kast 2008 [23]	Germany	88	80	41.9 ± 8.5	45.5 ± 10.5	51/37	47/33	-	-	24		PS	-	18/24
Park 2013 [31]	South Korea	57	57	47.6	50.0	31/26	33/24	-	-	14		RS	-	14/24
Schick 2009 [24]	Germany	100	100	49.5 ± 13.7	51.8 ± 13.9	50/50	64/36	-	-	35.4	34.1	PS	-	16/24
Shamji 2014 [32]	Canada	98	74	44.1 ± 1.7	44.4 ± 1.4	62/36	47/27	28.0 ± 0.9	28.8 ± 0.7	72, 48.0−132.0		RS	-	16/24
Thaler 2020 [25]	Austria	30	30	45.0 ± 10.0	51.0 ± 13.0	14/16	20/10	-	-	1.0, 0.6−4.8		PS	-	18/24

BMI, body mass index; D, discectomy; MINORS, Methodological Index for nonrandomized studies; PS, prospective study; RCT, randomized clinical trial; RoB-2, risk of bias-2; RS, retrospective study; S, sequestrectomy; SD, standard deviation.

open [26,31] or a microscopic approach [8,9,19−25,27−30,32]. In most studies, decompression was achieved through partial resection of the lamina (hemilaminectomy or laminotomy). In patients who underwent discectomy, after removal of sequestered fragments (if present), the annulus fibrosus (AF) was incised and the nucleus pulposus (NP) was accessed to either resect loose fragments only [22,24] or extensively remove the NP tissue [9,19−21,23,25−31], including curettage of the CEPs in some cases [8,32]. In subjects treated with sequestrectomy, removal of the herniated fragment was performed without accessing the disc space in any case. Surgical details, outcomes, complications, and conclusions of included studies are summarized in Table 2

Risk of bias

The RoB-2 tool for RCTs and the MINORS score for NRCTs were used to assess the risk of bias in each study. For RCTs, we found 3 studies with an overall risk of bias identified as “some concerns”. The MINORS tool was adopted to assess the quality of evidence of included NRCTs, with an average score of 15.1/24, indicating a substantial risk of bias (Table 1). No significant publication bias was found when analyzing investigated outcomes by funnel plots (Supplementary Materials).

Risk of LDH recurrence and reoperation

Thirteen studies [8,9,20,22−24,26−32] reported the reherniation rate after a follow-up of at least 1 year, ranging from 1.5 to 12.4% in patients treated with discectomy and 1.0−19.0% in those who underwent sequestrectomy. Despite this slight discrepancy, no statistically significant difference was found following meta-analysis (OR: 0.85, 95% CI: 0.57−1.26, p=.42, I^2: 4% [p=.40]; Fig. 2A).

Reoperation was described in 12 studies [9,20,22−24,26−32]. While in most cases revision surgery was performed due to recurrent LDH, some studies also reported the need for reoperation as a consequence of LDH at a different level, or development of spinal stenosis at the same or a different level [23,26,32]. The reoperation rate ranged from 3.0 to 12.4% after discectomy and from 1.0 to 19.0% following sequestrectomy, although no statistically significant difference emerged at meta-analysis (OR: 0.95, 95% CI: 0.64−1.40, p=.78, I^2: 0% [p=.70]; Fig. 2B).

Complications

Complications were reported in 7 studies [8,19,22,24,26−28]. These included dural tear, development of postoperative neurological deficits, superficial wound infection, and epidural hematoma with an occurrence rate of 3.7% following discectomy and 3.0% after sequestrectomy. The meta-analysis of pooled results revealed no statistically significant difference between the two groups (OR: 1.03, 95%

Table 2
Surgical techniques, outcomes, complications, and conclusions of included studies.

Study	Surgical technique		Outcomes	Complications, n (%)	Conclusion
	D	S			
Kotil 2014 [8]	Microscopic hemilaminectomy followed by removal of sequestered fragments, opening of the PLL, and thorough curettage of the disc space until reaching the CEPs	Microscopic hemilaminectomy followed by removal of the sole sequestered fragment	VAS LBP VAS leg pain ODI Disc height change Operative time Blood loss LOS Analgesic use Reherniation rate	Dural tear D: 5 (5.8); S: 1 (1.3) Postoperative neurological deficit D: 2 (2.3); S: 1 (1.3) Superficial wound infection D: 3 (3.5); S: 2 (5.0) Reherniation rate 1 y: D: 1 (1.3); S: 1 (2.1) 5 y: D: 1 (1.5); S: 2 (4.1)	Compared to sequestrectomy, microdiscectomy was associated with a lower reherniation rate but higher LBP severity in the short term
Thome 2005 [19]	Microscopic laminotomy followed by AF incision and resection of the NP tissue with rongeurs	Microscopic laminotomy followed by removal of the sole herniated fragment	VAS LBP VAS leg pain Prolo scale PSI Operative time Reherniation rate SF-36	Superficial wound infection D: 1 (2.4); S: 0 (0.0) Reherniation rate D: 4 (10.0); S: 2 (5.0) Reoperation rate D: 5 (12.4); S: 2 (5.0) Dural tear D: 0 (0.0); S: 0 (0.0)	Sequestrectomy did not yield a higher incidence of symptomatic recurrences compared with microdiscectomy
Balderston 1991 [26]	Open hemilaminectomy with removal of as much NP tissue as possible	Open hemilaminectomy with removal of the sole herniated fragment	VAS LBP VAS leg pain Reherniation rate Disc height change	Reherniation rate D: 5 (11.6); S: 5 (12.5) Reoperation rate D: 5 (11.6); S: 6 (15,0) Dural tear D: 1 (2.5); S: 0 (0.0)	No significant differences in terms of postoperative pain, reherniation, and reoperation rate were found between disc space curettage and fragment excision
Barth 2008a [20]	Microscopic laminotomy followed by AF incision and resection of the NP tissue with rongeurs	Microscopic laminotomy followed by removal of the sole herniated fragment	Reherniation rate Time to reherniation VAS LBP VAS leg pain Prolo scale PSI SF-36 Analgesic use	Reherniation rate D: 4 (10.5); S: 5 (12.5)	Reherniation rates within 2 years after sequestrectomy and microdiscectomy were comparable, although clinical outcomes after microdiscectomy seemed to worsen over time
Barth 2008b [21]	Microscopic laminotomy followed by AF incision and resection of the NP tissue with rongeurs	Microscopic laminotomy followed by removal of the sole herniated fragment	MRI changes		Sequestrectomy demonstrated significantly less postoperative IDD than standard microdiscectomy after 2 years
Boyaci 2016 [22]	Microscopic laminotomy followed by removal of the herniated fragments, AF incision, and removal of loose NP fragments without proceeding deeper than the AF border	Microscopic laminotomy followed by removal of the sole herniated fragment without entering the disc space	VAS ODI Operative time Reherniation rate Analgesic use LOS	Reherniation rate D: 4 (4.4); S: 2 (2.6) Dural tear D: 2 (2.1); S: 0 (0.0) Superficial wound infection D: 2 (2.1); S: 2 (2.6)	Sequestrectomy was characterized by shorter operating time, lower rate of perioperative complications, and lesser use of analgesic medications

Table 2 (***Continued***)

Study	Surgical technique		Outcomes	Complications, n (%)	Conclusion
	D	S			
Carragee 2006 [9]	Microscopic laminotomy (and possibly facetectomy) with removal of the extruded fragment in addition to any material in the disc space	Microscopic laminotomy (and possibly facetectomy) with removal of the extruded fragment and loose pieces in the disc space	VAS LBP VAS leg pain ODI Analgesic use Reherniation rate Reoperation rate Return to work Satisfaction	Reherniation rate D: 2 (9.0); S: 9 (18.0) Reoperation rate D: 2 (7.0); S: 5 (10.0)	Despite a trend toward a higher reherniation rate, better clinical outcomes and higher overall satisfaction ratings were seen in the limited discectomy group
Fakouri 2011 [27]	Conventional microdiscectomy with AF incision and removal of as loose fragments and soft disc materials as possible	Microscopic laminotomy followed by removal of the sole herniated fragment	VAS Operative time Analgesic use Reherniation rate Reoperation rate LOS	Dural tear D: 5 (6.4); S: 0 (0.0) Superficial wound infection D: 3 (3.9); S: 1 (4.2) Reherniation rate D: 4 (5.6); S: 1 (4.2) Reoperation rate D: 4 (5.6); S: 1 (4.2)	Microscopic sequestrectomy was more successful with lesser operating time, fewer intraoperative complications, and lesser reherniation rate compared with discectomy in selected cases
Faulhauer 1995 [29]	Conventional microdiscectomy with AF incision and removal of as loose fragments and soft disc materials as possible	Microscopic laminotomy followed by removal of the sole herniated fragment	Reherniation rate Reoperation rate Postoperative instability	Reherniation rate D: 7 (7.0); S: 2 (2.0) Reoperation rate D: 7 (7.0); S: 2 (2.0)	Simple fragment excision in selected cases provided probably less, at least not more recurrences and less instability issues
Baek 2012 [30]	Conventional microdiscectomy with piecemeal removal of disc fragments	Microscopic laminotomy followed by opening of the PLL with a laser and fragmentectomy	VAS LBP VAS leg pain Operation time Reherniation rate	Reherniation rate D: 7 (6.9); S: 3 (4.1) Reoperation rate D: 7 (6.9); S: 3 (4.1)	Fragmentectomy did not increase recurrence rates or cause significant differences in postoperative VAS scores for leg and LBP
Altinel 2020 [28]	Microscopic laminotomy followed by removal of the herniated fragment, AF cross-shaped incision, and disc removal until the ALL	Microscopic laminotomy followed by removal of the sole herniated fragment	VAS LBP VAS leg pain Analgesic use Reherniation rate LOS	Dural tear D: 2 (2.9); S: 4 (5.8) Superficial wound infection D: 1 (1.4); S: 1 (1.4) Reherniation rate D: 6 (8.6); S: 10 (14.3) Reoperation rate D: 6 (8.6); S: 8 (11.4)	Although many noninvasive procedures have been proposed, discectomy remains an effective approach with a low recurrence rate
Kast 2008 [23]	Microscopic laminotomy followed by AF incision and evacuation and curettage of all loose and soft fragments	Microscopic laminotomy followed by removal of the sole herniated fragment	VAS LBP VAS leg pain Reherniation rate FFbH	Reherniation rate D: 2 (3.9); S: 1 (2.1) Reoperation rate D: 3 (5.9); S: 3 (6.4) Superficial wound infection D: 0 (0.0); S: 0 (0.0)	No increase of recurrence rate and no differences among clinical performance scores were found between discectomy and sequestrectomy
Park 2013 [31]	Conventional discectomy (removal of the herniated disc and degenerative nucleus from the intervertebral disc space)	Herniotomy (removal of the herniated disc fragment only)	VAS ODI Odom's criteria Reherniation rate	Reherniation rate D: 3 (5.2); S: 4 (7.0)	While clinical outcomes were similar, herniotomy did not seem to entail a higher rate of recurrences compared with conventional discectomy

Table 2 (***Continued***)

Study	Surgical technique		Outcomes	Complications, n (%)	Conclusion
	D	S			
Schick 2009 [24]	Microscopic laminotomy followed by removal of the herniated disc, AF incision, and removal of loose disc material from the intervertebral space by rongeurs	Microscopic laminotomy followed by removal of the sole herniated disc without entering the disc space	VAS LBP VAS leg pain ODI Analgesic use LOS Reherniation rate Reoperation rate	Epidural hematoma D: 0 (0.0); S: 1 (1.0) Reherniation rate D: 3 (3.0); S: 1 (1.0) Reoperation rate D: 3 (3.0); S: 1 (1.0)	Sequestrectomy is a safe procedure and did not yield a higher incidence of reherniations compared with discectomy
Shamji 2014 [32]	Microscopic laminotomy followed by AF incision creating a rectangular window, removal of available disc material from within the disc space, curettage of the superior and inferior CEPs, and removal of additional material	Microscopic laminotomy followed by limited resection of disc material outside of the AF either contained or extruded from within the PLL. In the setting of disc protrusions without frank herniation, an annulotomy was created, and disc material posterior to the vertebral body was removed	LOS Blood loss Operative time Reherniation rate Reoperation rate Satisfaction	Reherniation rate D: 6 (6,0); S: 11 (15.0)* Reoperation rate D: 10 (10.0); S: 14 (19.0)*	While not differing in terms of blood loss, operative time, and LOS, sequestrectomy was associated with a higher reoperation rate compared to discectomy
Thaler 2020 [25]	Standard microdiscectomy with removal of herniated disc material and disc tissue from the intervertebral space	Microscopic laminotomy followed by removal of the sole herniated fragment	VAS LBP VAS leg pain BRT		Sequestrectomy and microdiscectomy were associated with similar effects on pain and BRT after surgery

AF, annulus fibrosus; ALL, anterior longitudinal ligament; BRT, brake reaction time; CEP, cartilaginous endplate; D, discectomy; FFbH, Hannover Activities of Daily Living Questionnaire; IDD, intervertebral disc degeneration; LBP, low back pain; LOS, length of stay; MRI, magnetic resonance imaging; NP, nucleus pulposus; ODI, Oswestry disability index; PLL, posterior longitudinal ligament; PSI, Patient Satisfaction Index; S, sequestrectomy; SF-36, Short Form-36; VAS, visual analog scale.

* $p<.05$.

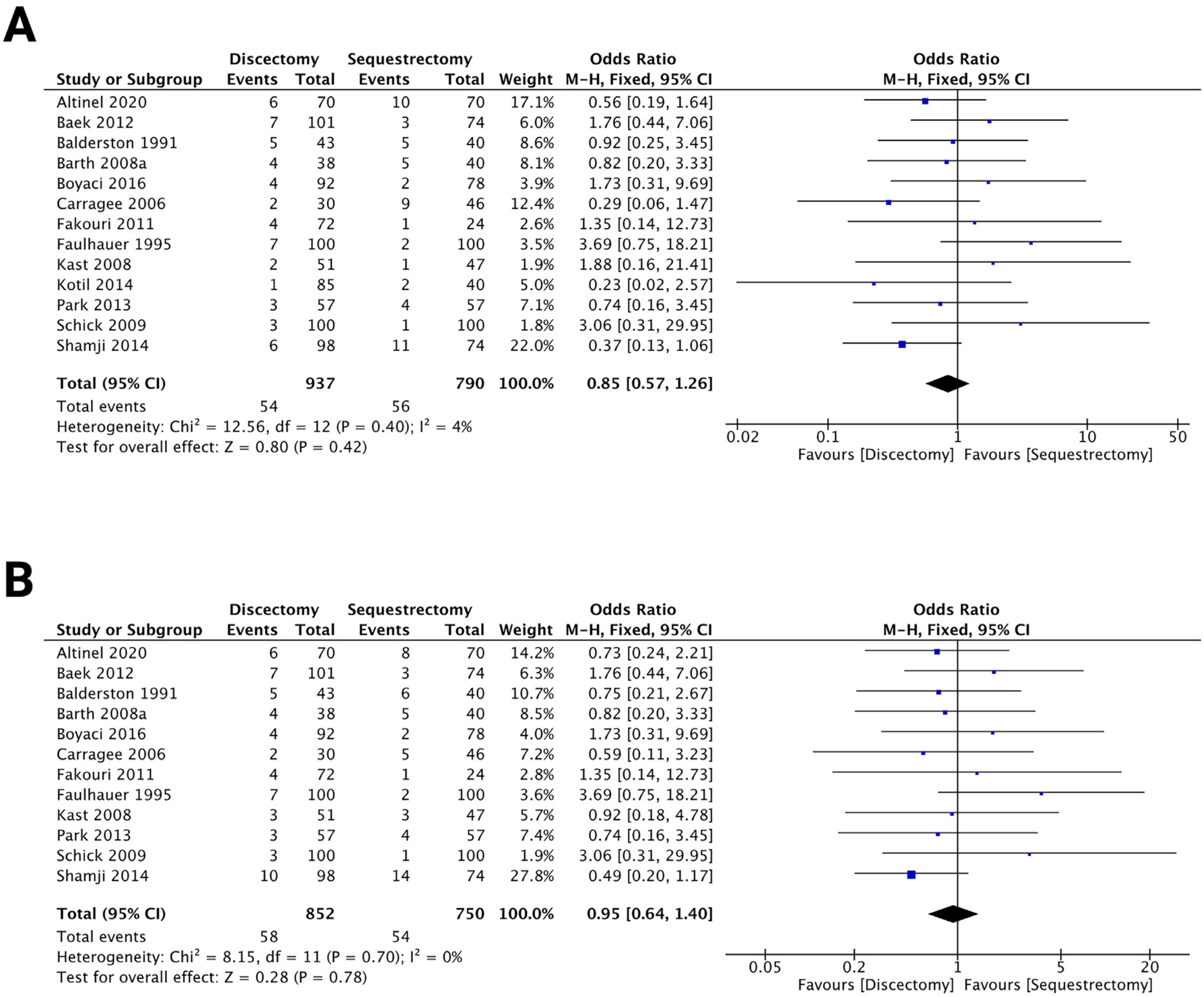


Fig. 2. Forest plots of reherniation (A) and reoperation rates (B) in patients who underwent discectomy versus sequestrectomy.

CI: 0.50−2.11, p=.94, I^2: 0% [p=.87]; Fig. 3A). The subgroup analysis of the dural tear rates among included studies did not show any statistically significant difference (OR: 1.67, 95% CI: 0.64−4.37, p=.30, I^2: 0% [p=.58]; Fig. 3B).

Patient-reported outcomes

LBP severity in the early postoperative period was reported by 4 studies [19,22,25,30], which showed no statistically significant difference between discectomy and sequestrectomy (MD: −0.06, 95% CI: −0.39 to 0.28, p=.74, I^2: 65% [p=.04]; Fig. 4A). Likewise, no significant difference was found by analyzing the pooled results of the 3 studies [8,9,19] describing LBP severity at 1 year after surgery (MD: 0.43, 95% CI: −0.44 to 1.31, p=.33, I^2: 81% [p=.005]; Fig. 4B). However, when combining the results of the 6 studies [8,9,20,23,24,27] reporting LBP intensity at 2 years, a statistically significant difference was found in favor of sequestrectomy (MD: 0.19, 95% CI: 0.03 to 0.34, p=.02, I^2: 16% [p=.31]; Fig. 4C).

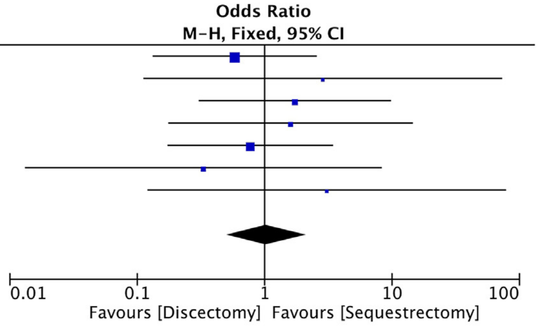
Leg pain intensity in the early follow-up period was described by 4 studies [19,22,25,30], which did not display significant intergroup differences (MD: 0.11, 95% CI: −0.21 to 0.42, p=.50, I^2: 51% [p=.11]; Fig. 5A). However, a statistically significant difference favoring sequestrectomy was found when analyzing leg pain severity at 1 year [8,9,19] (MD: 0.37, 95% CI: 0.19-0.54, p<.0001, I^2: 0% [p=.72]; Fig. 5B) and 2 years [8,9,20,23,24,27] (MD: 0.20, 95% CI: 0.09−0.31, p=.0005, I^2: 0% [p=.47]; Fig. 5C).

Patient satisfaction following either surgical treatment was reported by 5 studies [9,20,24,31,32]. Overall, 59.7% of patients who underwent discectomy and 67.5% of those who received sequestrectomy reported excellent to good outcomes, resulting in a statistically significant difference (OR: 0.60, 95% CI: 0.40−0.90, p=.01, I^2: 0% [p=.94]; Fig. 6).

A

Study or Subgroup	Discectomy Events	Discectomy Total	Sequestrectomy Events	Sequestrectomy Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Altinel 2020	3	70	5	70	32.8%	0.58 [0.13, 2.54]
Balderston 1991	1	43	0	40	3.4%	2.86 [0.11, 72.23]
Boyaci 2016	4	92	2	78	14.2%	1.73 [0.31, 9.69]
Fakouri 2011	5	77	1	24	9.8%	1.60 [0.18, 14.38]
Kotil 2014	5	85	3	40	26.3%	0.77 [0.17, 3.40]
Schick 2009	0	100	1	100	10.2%	0.33 [0.01, 8.20]
Thome 2005	1	42	0	42	3.3%	3.07 [0.12, 77.59]
Total (95% CI)		**509**		**394**	**100.0%**	**1.03 [0.50, 2.11]**
Total events	19		12			

Heterogeneity: Chi² = 2.53, df = 6 (P = 0.87); I² = 0%
Test for overall effect: Z = 0.07 (P = 0.94)



B

Study or Subgroup	Discectomy Events	Discectomy Total	Sequestrectomy Events	Sequestrectomy Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Altinel 2020	2	70	4	70	56.5%	0.49 [0.09, 2.74]
Balderston 1991	1	43	0	40	7.3%	2.86 [0.11, 72.23]
Boyaci 2016	2	92	0	78	7.6%	4.34 [0.21, 91.70]
Fakouri 2011	5	72	0	24	10.0%	3.99 [0.21, 74.90]
Kotil 2014	5	85	1	40	18.6%	2.44 [0.28, 21.58]
Thome 2005	0	42	0	42		Not estimable
Total (95% CI)		**404**		**294**	**100.0%**	**1.67 [0.64, 4.37]**
Total events	15		5			

Heterogeneity: Chi² = 2.89, df = 4 (P = 0.58); I² = 0%
Test for overall effect: Z = 1.04 (P = 0.30)

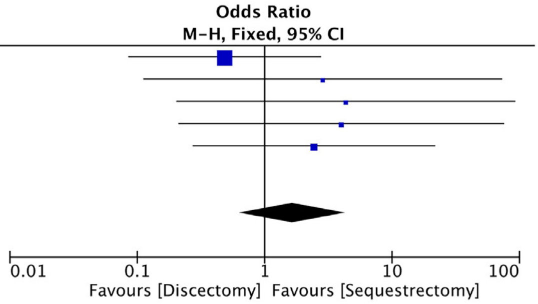
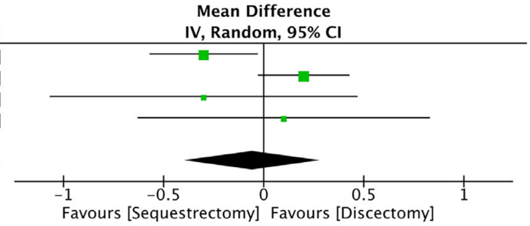


Fig. 3. Forest plot of overall complication rates (A) and dural tears (B) in patients who underwent discectomy versus sequestrectomy.

A

Study or Subgroup	Discectomy Mean	Discectomy SD	Discectomy Total	Sequestrectomy Mean	Sequestrectomy SD	Sequestrectomy Total	Weight	Mean Difference IV, Random, 95% CI
Baek 2012	1.6	1	101	1.9	0.8	74	34.8%	−0.30 [−0.57, −0.03]
Boyaci 2016	1.6	0.8	92	1.4	0.7	78	37.1%	0.20 [−0.03, 0.43]
Thaler 2019	1	1.3	30	1.3	1.7	30	13.5%	−0.30 [−1.07, 0.47]
Thome 2005	3.2	1.7	42	3.1	1.7	42	14.5%	0.10 [−0.63, 0.83]
Total (95% CI)			**265**			**224**	**100.0%**	**−0.06 [−0.39, 0.28]**

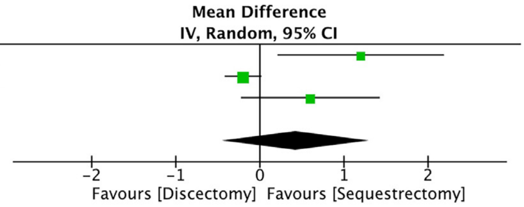
Heterogeneity: Tau² = 0.07; Chi² = 8.50, df = 3 (P = 0.04); I² = 65%
Test for overall effect: Z = 0.33 (P = 0.74)



B

Study or Subgroup	Discectomy Mean	Discectomy SD	Discectomy Total	Sequestrectomy Mean	Sequestrectomy SD	Sequestrectomy Total	Weight	Mean Difference IV, Random, 95% CI
Carragee 2006	3	2.5	30	1.8	1.4	46	27.6%	1.20 [0.22, 2.18]
Kotil 2014	1.9	0.8	85	2.1	0.4	40	41.4%	−0.20 [−0.41, 0.01]
Thome 2005	1.6	2.1	42	1	1.7	42	30.9%	0.60 [−0.22, 1.42]
Total (95% CI)			**157**			**128**	**100.0%**	**0.43 [−0.44, 1.31]**

Heterogeneity: Tau² = 0.47; Chi² = 10.42, df = 2 (P = 0.005); I² = 81%
Test for overall effect: Z = 0.97 (P = 0.33)



C

Study or Subgroup	Discectomy Mean	Discectomy SD	Discectomy Total	Sequestrectomy Mean	Sequestrectomy SD	Sequestrectomy Total	Weight	Mean Difference IV, Fixed, 95% CI
Barth 2008a	2.9	2.6	35	1.8	1.9	38	2.1%	1.10 [0.05, 2.15]
Carragee 2006	2	1.96	30	1.5	0.9	46	4.1%	0.50 [−0.25, 1.25]
Fakouri 2011	1.6	0.9	72	1.2	0.8	24	15.8%	0.40 [0.02, 0.78]
Kast 2008	4.1	3	88	4.1	2.9	80	2.9%	0.00 [−0.89, 0.89]
Kotil 2014	1.2	0.4	85	1.1	0.5	40	73.6%	0.10 [−0.08, 0.28]
Schick 2009	3.7	3	45	3.3	2.9	46	1.6%	0.40 [−0.81, 1.61]
Total (95% CI)			**355**			**274**	**100.0%**	**0.19 [0.03, 0.34]**

Heterogeneity: Chi² = 5.98, df = 5 (P = 0.31); I² = 16%
Test for overall effect: Z = 2.41 (P = 0.02)

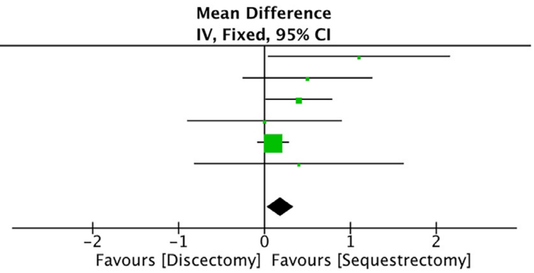
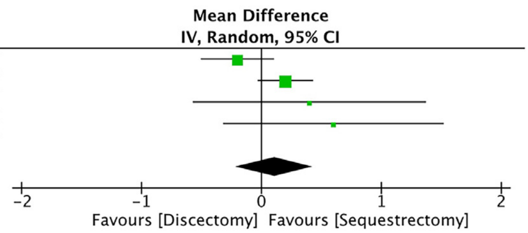


Fig. 4. Forest plots of low back pain intensity in the postoperative period (A), at 1 year (B), and 2 years (C) in patients who underwent discectomy versus sequestrectomy.

A

Study or Subgroup	Discectomy Mean	Discectomy SD	Discectomy Total	Sequestrectomy Mean	Sequestrectomy SD	Sequestrectomy Total	Weight	Mean Difference IV, Random, 95% CI
Baek 2012	2.3	1	101	2.5	1	74	37.4%	−0.20 [−0.50, 0.10]
Boyaci 2016	1.6	0.8	92	1.4	0.7	78	43.8%	0.20 [−0.03, 0.43]
Thaler 2019	1.4	2.1	30	1	1.7	30	9.0%	0.40 [−0.57, 1.37]
Thome 2005	1.3	2.5	42	0.7	1.7	42	9.8%	0.60 [−0.31, 1.51]
Total (95% CI)			**265**			**224**	**100.0%**	**0.11 [−0.21, 0.42]**

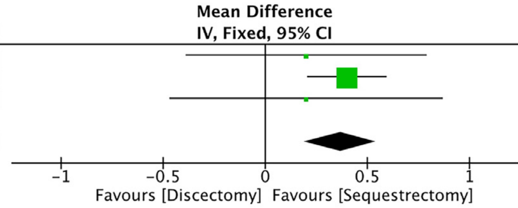
Heterogeneity: Tau² = 0.05; Chi² = 6.09, df = 3 (P = 0.11); I² = 51%
Test for overall effect: Z = 0.67 (P = 0.50)



B

Study or Subgroup	Discectomy Mean	Discectomy SD	Discectomy Total	Sequestrectomy Mean	Sequestrectomy SD	Sequestrectomy Total	Weight	Mean Difference IV, Fixed, 95% CI
Carragee 2006	1.2	1.47	30	1	0.9	46	8.9%	0.20 [−0.39, 0.79]
Kotil 2014	0.8	0.6	85	0.4	0.46	40	84.1%	0.40 [0.21, 0.59]
Thome 2005	0.8	1.7	42	0.6	1.4	42	6.9%	0.20 [−0.47, 0.87]
Total (95% CI)			**157**			**128**	**100.0%**	**0.37 [0.19, 0.54]**

Heterogeneity: Chi² = 0.67, df = 2 (P = 0.72); I² = 0%
Test for overall effect: Z = 4.11 (P < 0.0001)



C

Study or Subgroup	Discectomy Mean	Discectomy SD	Discectomy Total	Sequestrectomy Mean	Sequestrectomy SD	Sequestrectomy Total	Weight	Mean Difference IV, Fixed, 95% CI
Barth 2008a	1.6	2.4	38	1.2	1.8	40	1.4%	0.40 [−0.55, 1.35]
Carragee 2006	1	1.47	30	1.2	1.1	46	3.4%	−0.20 [−0.81, 0.41]
Fakouri 2011	1.6	0.9	72	1.2	0.8	24	8.7%	0.40 [0.02, 0.78]
Kast 2008	2.8	2.9	88	3.1	2.8	80	1.7%	−0.30 [−1.16, 0.56]
Kotil 2014	0.4	0.5	85	0.2	0.2	40	84.2%	0.20 [0.08, 0.32]
Schick 2009	3.3	4	45	2.6	3.3	46	0.6%	0.70 [−0.81, 2.21]
Total (95% CI)			**358**			**276**	**100.0%**	**0.20 [0.09, 0.31]**

Heterogeneity: Chi² = 4.57, df = 5 (P = 0.47); I² = 0%
Test for overall effect: Z = 3.49 (P = 0.0005)

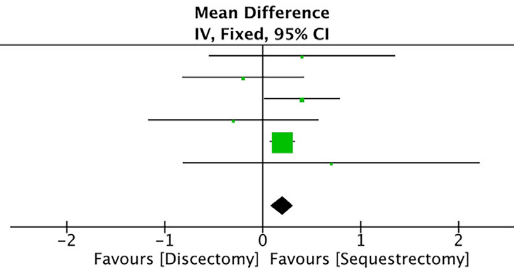


Fig. 5. Forest plots of leg pain intensity in the postoperative period (A), at 1 year (B), and 2 years (C) in patients who underwent discectomy versus sequestrectomy.

Lumbar disc herniation-related disability was assessed with the ODI in 5 studies [8,9,22,24,31]. Boyaci et al. [22] showed that postoperative ODI scores were significantly lower in the sequestrectomy group (14.0±11.3 vs. 17.4±15.9, p<.05), whereas Park et al. [31] did not report any significant difference between the two groups. No statistically significant intergroup difference was reported by the other studies at later follow-up timepoints (from 1 to 5 years) [8,9,24].

The need for analgesic medications after surgery was reported by 7 studies [8,9,20,22,24,27,28]. In the study from Kotil et al. [8], patients needed only one analgesic and anti-inflammatory drug in the first 10 postoperative days following sequestrectomy, whereas patients who underwent discectomy needed two different medications. Likewise, Schick et al. [24] also showed that the postoperative consumption of anti-inflammatory and muscle relaxant drugs was significantly increased following discectomy compared to sequestrectomy (p=.029). Carragee et al. [9] reported that pain medication usage was significantly higher in patients treated with discectomy at 1 year after surgery (p=.03), whereas no significant differences were found at 2 years postoperatively. Similar trends were also described by Altinel et al. [28], although the differences failed to reach statistical significance. In the 2-year follow-up of the RCT originally published by Thomé and colleagues [20], patients reported significantly less pain-related drug use

Study or Subgroup	Discectomy Events	Discectomy Total	Sequestrectomy Events	Sequestrectomy Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Barth 2008a	32	38	35	40	8.9%	0.76 [0.21, 2.74]
Carragee 2006	22	30	40	46	14.0%	0.41 [0.13, 1.34]
Park 2013	17	27	23	32	12.9%	0.67 [0.22, 1.99]
Schick 2009	22	100	34	100	44.0%	0.55 [0.29, 1.03]
Shamji 2014	82	98	65	74	20.1%	0.71 [0.29, 1.71]
Total (95% CI)		**293**		**292**	**100.0%**	**0.60 [0.40, 0.90]**
Total events	175		197			

Heterogeneity: Chi² = 0.78, df = 4 (P = 0.94); I² = 0%
Test for overall effect: Z = 2.49 (P = 0.01)

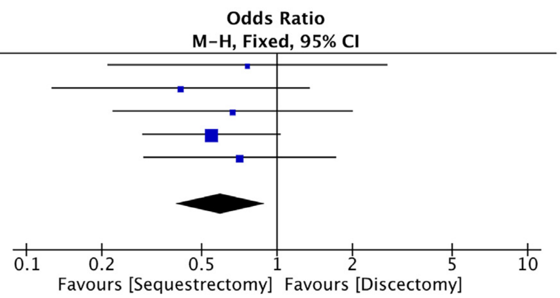


Fig. 6. Forest plot of satisfaction in patients who underwent discectomy versus sequestrectomy.

after sequestrectomy (p=.029), since the intake of painkillers notably increased in the discectomy group between early and late follow-ups. Similarly, Boyaci et al. [22] showed that the rate of patients needing at least 1 analgesic at the last follow-up was significantly higher among individuals who were treated with discectomy (16.3 vs. 10.2%, p<.05). Conversely, no statistically significant intergroup difference was reported by Fakouri et al. [27], despite the similar length of follow-up.

Patient functionality was assessed by 3 studies [19,20,23]. In the study by Kast et al. [23], no statistically significant differences were found between discectomy- and sequestrectomy-treated patients at a mean of 2 years of follow-up. In the RCT by Thomé et al. [19,20], comparable proportions of patients experiencing good-to-excellent outcomes were reported at 4−6 months and 2 years after surgery, although functionality significantly improved with time only in patients receiving sequestrectomy (p=.03). Furthermore, patients treated with sequestrectomy also showed significantly better outcomes at the physical functioning, vitality, and social functioning subscales of the SF-36 (p<.05).

Perioperative outcomes

Operative time was reported by 6 studies [19,22,27,28,30,32]. According to our meta-analysis, the duration of sequestrectomy procedures was significantly lower compared to discectomy (MD: 8.71 min, 95% CI: 1.66−15.75, p=.02, I^2: 98% [p<.00001]; Fig. 7A). Intraoperative blood loss was described by 3 studies [19,28,32], which did not show significant intergroup differences (MD: 0.18 mL, 95% CI: −2.31 to 2.67, p=.89, I^2: 0% [p=.43]; Fig. 7B). Similarly, LOS was reported by 4 studies [19,22,27,28] and did not significantly differ between patients who received discectomy versus sequestrectomy (MD: 0.02 days, 95% CI: −0.07 to 0.12, p=.60, I^2: 0% [p=.97]; Fig. 7C).

Radiologic changes

Barth et al. [21] performed an extensive assessment of the effect of discectomy and sequestrectomy on IDD changes at MRI at 2 years of follow-up. In terms of disc dehydration, a significant drop in disc signal intensity was found in both groups, irrespective of the surgical technique. However, subjects treated with discectomy demonstrated a significantly higher proportion of loss of disc height (p=.048) and CEP degeneration, with a higher rate of new-onset Modic type 2 and 3 changes compared to the sequestrectomy group (p=.004). On the other hand, patients treated with sequestrectomy exhibited a higher rate of postoperative same-level extrusions (p=.009), although their

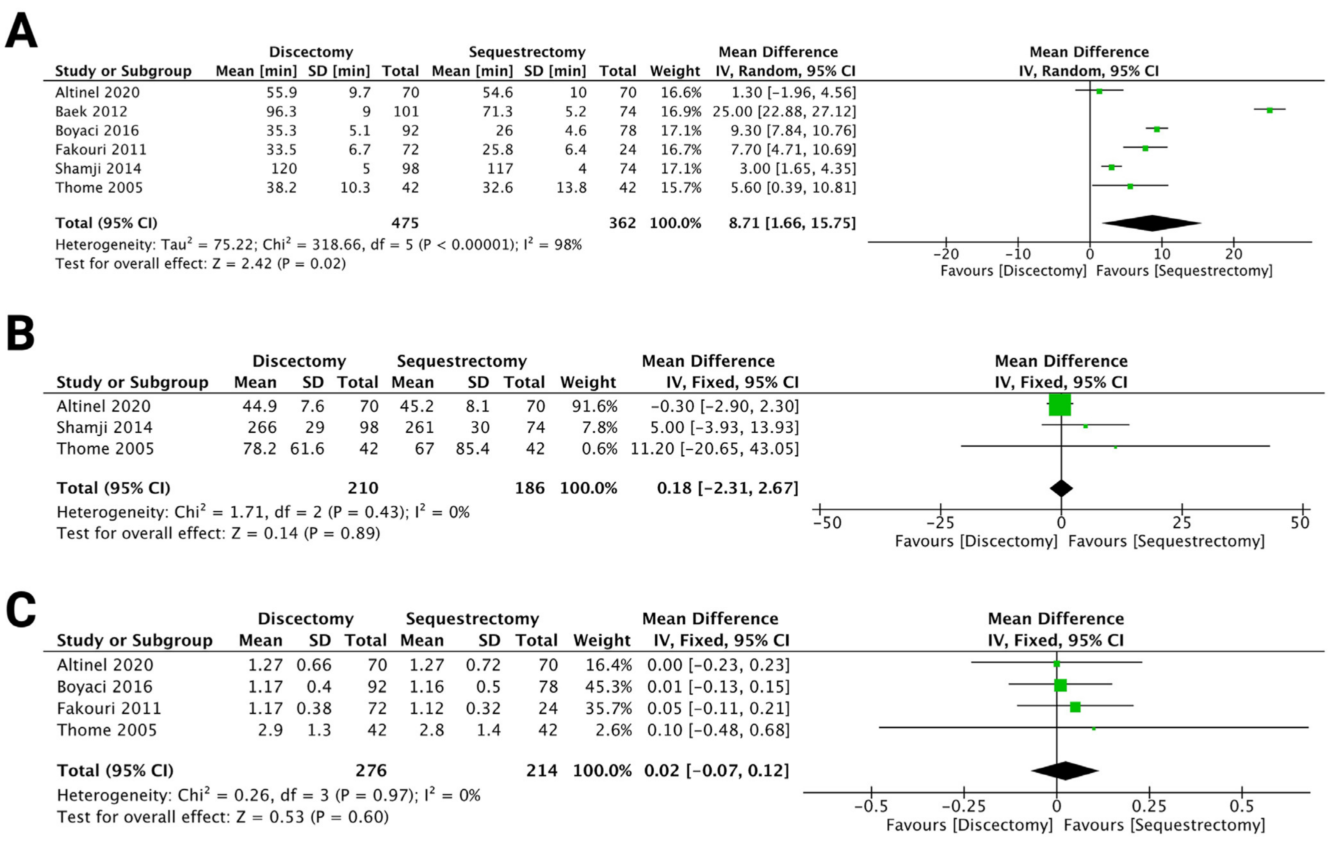


Fig. 7. Forest plots of operative time (A), intraoperative blood loss (B), and length of hospital stay (C) in patients who underwent discectomy versus sequestrectomy.

Certainty assessment							№ of patients		Effect		Certainty	Importance
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	Discectomy	Sequestrectomy	Relative (95% CI)	Absolute (95% CI)		
Reherniation (follow-up: range 4 months to 132 months)												
13	non-randomised studies	serious	not serious	not serious	not serious	none	54/937 (5.8%)	56/790 (7.1%)	**OR 0.85** (0.57 to 1.26)	**10 fewer per 1.000** (from 29 fewer to 17 more)	⊕○○○ Very low	CRITICAL
LBP severity (follow-up: mean 2 years; assessed with: VAS; Scale from: 1 to 10)												
6	non-randomised studies	serious	not serious	not serious	not serious	none	355	274	-	MD **0.19 higher** (0.03 higher to 0.34 higher)	⊕○○○ Very low	IMPORTANT
Leg pain severity (follow-up: mean 2 years; assessed with: VAS; Scale from: 1 to 10)												
6	non-randomised studies	serious	not serious	not serious	not serious	none	358	276	-	MD **0.2 higher** (0.09 higher to 0.31 higher)	⊕○○○ Very low	IMPORTANT
Complications (follow-up: range 4 months to 66 months)												
7	non-randomised studies	serious	not serious	not serious	not serious	none	19/509 (3.7%)	12/394 (3.0%)	**OR 1.03** (0.50 to 2.01)	**1 more per 1.000** (from 15 fewer to 29 more)	⊕○○○ Very low	IMPORTANT
Satisfaction (follow-up: range 14 months to 132 months; assessed with: Odom's criteria, VAS, PSI)												
5	non-randomised studies	serious	not serious	not serious	not serious	none	175/293 (59.7%)	197/292 (67.5%)	**OR 0.6** (0.4 to 0.9)	**120 fewer per 1.000** (from 221 fewer to 24 fewer)	⊕○○○ Very low	IMPORTANT
Operative time (min)												
6	non-randomised studies	serious	very serious[a]	not serious	not serious	none	475	362	-	MD **8.71 higher** (1.66 higher to 15.75 higher)	⊕○○○ Very low	IMPORTANT

a. Statistical heterogeneity as per I^2 was 98% and statistically significant ($p<0.00001$). Abbreviations: CI: confidence interval; OR: odds ratio; MD: mean difference; PSI: Patient Satisfaction Index; VAS: visual analog scale.

Fig. 8. GRADE evidence and summary of findings table.

size and location did not significantly vary between groups. No statistically significant difference in radiographic disc height change was found between patients treated with discectomy versus sequestrectomy up to 5 years after surgery in other studies [8,26].

Quality of the evidence

The quality of the evidence across the various outcomes analyzed as per the GRADE framework is outlined as a table of summary of findings in Fig. 8. The overall certainty of the evidence on the presented results was graded as very low considering the limited quality of studies available on the subject analyzed.

Discussion

The primary goial of surgical treatment of LDH is to decompress the affected nerve root by removing the herniated disc material, thereby alleviating pain and promoting recovery from neurological deficits [2]. However, the risk of recurrent LDH following surgery has been reported to range between 5 and 15% and often requires reoperation, which is burdened by an increased rate of complications due to epidural scarring and suboptimal outcomes [33]. Historically, the risk of recurrence has been imputed to incomplete removal of unstable disc fragments (“discectomy dogma” [20]), which could reherniate upon axial loading. On the other hand, aggressive discectomy has been associated with accelerated IDD and development of chronic LBP and other sequelae [5]. In the last two decades, sequestrectomy has been increasingly performed with favorable outcomes both in terms of patient outcomes and risk of reherniation [9], although the superiority of one approach over the other is still to be determined.

In this systematic review and meta-analysis, we found no significant differences between discectomy and sequestrectomy in terms of reherniation risk, reoperation rates, and postoperative complications. However, patients who underwent sequestrectomy reported higher satisfaction scores, significantly lower LBP at 2 years, and reduced leg pain at both 1 and 2 years. Furthermore, sequestrectomy was associated with significantly shorter operative time, while no differences were observed in intraoperative blood loss and LOS between the two techniques. Our findings align with previous reviews [34−36], which also failed to identify substantial differences between discectomy and sequestrectomy. Nonetheless, given the shorter surgical time, comparable complication and recurrence rates, and favorable trends in patient-reported outcomes, sequestrectomy may be considered a viable alternative to conventional discectomy.

Despite the lack of significant differences in reherniation rates, several confounders across the included studies may have influenced these outcomes. Except for the RCT by Thomé et al. [19−21] and the study from Thaler et al. [25], in which allocation to either discectomy or sequestrectomy was randomized, the decision between the two techniques was made preoperatively or intraoperatively by the surgeon in most studies. The most adequate strategy was decided based on a combination of patient preference [22], MRI features (e.g., wide-base disc protrusion vs. free fragment [31]) and intraoperative findings (e.g., unstable AF, large annular defects, contained LDH vs. sequestered fragments with small annular defects and stable AF [8,9,23,24,27,29,30]). Consequently, confounding by indication might have biased the results against discectomy, in which the higher prevalence of larger annular defects may have predisposed to reherniation, thus mitigating the differences in recurrence rates between the two groups. Nevertheless, reported reherniation rates in both groups were low and consistent with the previous literature [33,37]. Another potential confounding factor involved the challenge of distinguishing a real reherniation (i.e., new-onset LDH at the same level) from incomplete removal of the initial LDH. In most studies, reherniation was diagnosed by combining the recurrence of the preoperative symptom pattern and confirmation of same-level LDH during follow-up MRI. Only the study from Park et al. [31] reported the routine use of postoperative MRI to accurately distinguish truly reherniated patients from those with remnant disc material from index surgery.

Since the introduction of microdiscectomy, an increasing number of innovative minimally invasive approaches have been developed to further reduce surgical invasiveness while optimizing patient outcomes. However, the limited access to the surgical site has raised concerns about whether minimally invasive procedures are as safe and effective as open approaches, particularly regarding complete LDH removal [38]. In our study, microscopic discectomy or sequestrectomy was performed in all but two studies [26,31] employing open approaches. Despite the limited statistical power to compare open versus microscopic techniques, reoperation rates in these two studies did not greatly differ from those reported for microscopic decompression. This is consistent with a recent network meta-analysis that found no significant differences in terms of reoperation rates between open and minimally invasive approaches [39].

Although similar, small technical differences between discectomy and sequestrectomy (e.g., open vs. microscopic decompression, width of laminotomy, facetectomy, extent and shape of annulotomy, extent of nucleotomy, CEP curettage) may have impacted not only the risk of recurrence, but also the rate of complications, reoperation, operative time, blood loss, and postoperative pain. While the intensity of LBP and leg pain was comparable between discectomy and sequestrectomy in the early postoperative period (within 6 months), significantly better results were found in patients treated with the latter at longer follow-up timepoints. Indeed, these patients showed less pain and a lower need for painkillers at both short [8] and long term follow-ups [9,20,24]. According to the authors, these benefits may be attributed to the lower invasiveness of sequestrectomy, which limits access to the disc space and avoids damage to the CEPs and other stabilizing structures. By contrast, aggressive discectomy has been associated with decreased disc height, facet joint overloading, segmental instability, and spondylosis, leading to unfavorable outcomes [20]. By addressing only the cause of nerve root compression, sequestrectomy may provide symptom relief without significantly increasing the risk of IDD at the operated segment. This has been also demonstrated by the study of Barth and colleagues [21], who reported that discectomy was more commonly associated with disc height collapse and development of CEP degeneration. However, despite statistical significance, the differences in LBP and leg pain between the two groups were relatively small (LBP at 2 years: 0.19, leg pain at 1 year: 0.37, leg pain at 2 years: 0.20), falling below the minimal clinically important difference reported following surgery for LDH (2.0 for VAS LBP and 3.0 for VAS leg pain) [40]. Hence, these findings should be interpreted with caution.

In comparison to discectomy, sequestrectomy was also characterized by a significantly lower operative time of 8.71 minutes by obviating the need to access the disc space. This may result in cost savings of up to 400$ per case, according to recent estimates [41], and might also reduce the complication rates and intraoperative blood loss, although this was not demonstrated by our meta-analysis.

Our findings suggest that sequestrectomy is a safe and effective alternative to discectomy for treating LDH. This challenges the traditional assumption that isolated removal of the herniated fragment increases the risk of recurrence or results in incomplete decompression with worse postoperative outcomes [20]. Additionally, by requiring limited access to the disc space, sequestrectomy is well-suited for minimally invasive and "keyhole" endoscopic approaches, which may further enhance postoperative results [42]. However, caution is warranted when considering sequestrectomy in specific cases, such as highly migrated LDHs, concurrent lumbar spinal stenosis or cauda equina syndrome [43,44], where extensive decompression is essential to prevent persistent symptoms or neurological deficits.

This study has some limitations. First, the notable risk of bias in the included studies may have significantly affected the external validity of their results and limited the generalizability of pooled outcomes. Furthermore, although the surgical techniques were classified as either discectomy or sequestrectomy, they varied significantly across studies in terms of approach (e.g., open vs. microscopic), width of decompression (e.g., laminectomy vs. laminotomy), extent of NP removal, CEP curettage, etc. Overall, these factors might have introduced confounding affecting the assessed outcomes and potentially contributed to generate bias. According to the GRADE framework, the differences reported in terms of reherniation, LBP severity, leg pain severity, complications, satisfaction, and operative time are flawed by a very low certainty of the evidence. Studies with a more rigorous design are needed to enhance the reliability of reported results. Second, the level of evidence of included studies was generally low, with only 1 RCT included and most of the available data coming from retrospective observational cohort studies. Larger, prospective, randomized comparative studies with longer follow-up periods are needed to validate these findings in the future. Third, some of the investigated outcomes were compromised by a significant level of heterogeneity, potentially impacting the interpretation of our results. These include early postoperative LBP and leg pain intensity, as well as LBP severity at 1 year. Given the subjective nature of PROMs and the diverse populations, baseline values, and treatment modalities in the included studies, the presence of heterogeneous pain values was not unexpected. Concerning operative time, the heterogeneity observed may be attributed to the use of different calculation methods for assessing surgical time (e.g., starting from anesthesia vs. from incision), which were not disclosed in the included studies. In addition, while sequestration represents by definition an extruded disc with no connections between the displaced portion and the disc of origin [45], several authors adopted the term "sequestrectomy" when referring to the removal of contained LDHs. Joint international efforts are needed to standardize surgical terminology and improve the quality and reproducibility of related studies.

Conclusions

This systematic review and meta-analysis demonstrated that discectomy and sequestrectomy do not significantly differ in terms of risk of reherniation, reoperation rate, and postoperative complications. Patients treated with sequestrectomy may benefit from a marginally higher pain improvement, better satisfaction outcomes, and shorter operative time, although the clinical relevance of these differences needs to be validated in larger RCTs.

Declaration of competing interest

One or more of the authors declare financial or professional relationships on ICMJE-TSJ disclosure forms.

CRediT authorship contribution statement

Luca Ambrosio: Writing − review & editing, Writing − original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Gianluca Vadalà:** Writing − review & editing, Visualization, Validation, Supervision, Conceptualization. **Elisabetta de Rinaldis:** Methodology, Investigation, Formal analysis, Data curation. **Sathish Muthu:** Writing − review & editing, Visualization. **Stipe Ćorluka:** Writing − review & editing, Visualization. **Zorica Buser:** Writing − review & editing, Visualization. **Hans-Jörg Meisel:** Writing − review & editing, Visualization. **S. Tim Yoon:** Writing − review & editing, Supervision. **Vincenzo Denaro:** Supervision.

Author disclosures

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Supplementary materials

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