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Surgical Outcomes for Upper Lumbar Disc Herniations: A Systematic Review and Meta-analysis

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Abstract

Study Design: Systematic review and meta-analysis.

Objective: To conduct a literature review on outcomes of discectomy for upper lumbar disc herniations (ULDH), estimate pooled rates of satisfactory outcomes, compare open laminectomy/microdiscectomy (OLM) versus minimally invasive surgical (MIS) techniques, and compare results of disc herniations at L1-3 versus L3-4.

Methods: A systematic review of articles reporting outcomes of nonfusion surgical treatment of L1-2, L2-3, and/or L3-4 disc herniations was performed. The inclusion and exclusion of studies was performed according to the latest version of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.

Results: A total of 20 articles were included in the quantitative meta-analysis. Pooled proportion of satisfactory outcome (95% CI) was 0.77 (0.70, 0.83) for MIS and 0.82 (0.78, 0.84) for OLM. There was no significant improvement with MIS techniques compared with standard OLM, odds ratio (OR) = 0.86, 95% CI (0.42, 1.74), $P = .66$. Separating results by levels revealed a trend of higher satisfaction with L3-4 versus L1-3 with OLM surgery, OR = 0.46, 95% CI (0.19, 1.12), $P = .08$.

Conclusion: Our analysis reveals that discectomy for ULDH has an overall success rate of approximately 80% and has not improved with MIS. Discectomy for herniations at L3-4 trends toward better outcomes compared with L1-2 and L2-3, but was not significant.

Keywords

laminectomy, intervertebral disc disease, intervertebral disc displacement, discectomy, intervertebral disc degeneration, odds ratio

Introduction

Upper lumbar disc herniations (ULDH) are uncommon but represent an important, distinct, and complex clinical entity. They were first described as a unique consideration from lower lumbar disc herniations by Graf and Hamby[1] in 1953 for their clinical presentation with paraplegia. Since then, ULDH have been reported in the literature as case reports and case series without any pooled analysis previously performed; possibly due to their relative infrequency of only 1% to 11% of all disc herniations.[2-8] Relatedly, there is no consensus regarding whether disc herniations at the L3-4 level should be included as a ULDH, and case series vary on the reported levels.[9] Although rare, every spine surgeon will eventually treat a patient with a ULDH, and knowledge of the prognosis and description of approaches are essential for management.

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As minimally invasive surgery (MIS) techniques for the lumbar spine continue to evolve and gain popularity, there are several MIS techniques that have been adapted to approach ULDH.[10] Theoretically, the potential benefits to these MIS techniques in the upper lumbar spine are that they avoid disruption of the facets, require less retraction of the thecal sac, and still provide adequate exposure for discectomy.[10-13] However, the adjacent structures to the upper lumbar spine, such as the kidneys and ribs, may limit oblique or lateral approaches.[14] Thus, while MIS techniques are a promising treatment strategy, it remains unseen if they are well suited for the unique challenges of ULDH.

In this present study, we aimed to conduct a systematic literature review and meta-analysis on surgical outcomes of ULDH, to estimate pooled effect sizes, and to compare conventional posterior approach with open laminectomy and microdiscectomy (OLM) versus MIS. We also aimed to compare L3-4 versus L1-3 for OLM to hopefully provide some evidence regarding to the debate whether L3-4 should be considered an upper or lower lumbar disc.

Methods

Study Selection

A systematic review of the English literature available on PubMed was performed, along with a review of the bibliographies of the examined articles. The query utilized in the PubMed search was designed to include as many articles as possible pertaining to the pathology and interventions of interest. The final search string was: "upper lumbar" OR "high lumbar" OR "L1 [AND] disc [OR] disk" OR "L2 [AND] disc [OR] disk" OR "L3 [AND] disc [OR] disk."

Eligibility Criteria

All studies undergoing full-text screening were included if the following criteria were met: (1) the study was published prior to December 1, 2019; (2) the study was peer-reviewed, original, and written in the English language or full-English translation available; (3) the study reported nonfusion surgical treatment of L1-2, L2-3, and/or L3-4 disc herniations, and postoperative results were reported as separate from lower lumbar levels; (4) the study was in the format of a randomized controlled trial, nonrandomized trial, case series ($\geq$2 patients), case-control study, or cohort study.

Data Extraction

Abstracts were screened by 2 reviewers (ME and RH) using the inclusion and exclusion criteria stated above. In cases of disagreement, a third reviewer (RY) was involved to make the final decision. Full-text versions of articles meeting the criteria were gathered and reviewed in full to determine eligibility for inclusion in the final analysis. The inclusion and exclusion of studies was performed according to the latest version of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement (www.prisma-statement.org). The bias of each study was evaluated with the criteria recommended by the Cochrane Back Review Group, and studies were considered to have an overall low risk of bias when at least 6 of the individual criteria were determined to have a low risk of bias.[15]

Studies were divided into conventional OLM or MIS technique. Average age of patients, gender, and follow-up duration were recorded. Reported outcomes were collected and divided into groups by level as provided. Outcome measures varied greatly. In order to perform a combined analysis, outcomes were reassigned into either satisfactory or unsatisfactory. Outcomes that were reported as excellent, good, improved, improvement of symptoms, very satisfied, and satisfied were reassigned to satisfactory. Outcomes that were reported as fair, poor, unchanged, deteriorated, worse, and unreported were considered unsatisfactory. Studies with outcomes that cannot be reassigned to satisfactory versus unsatisfactory were not included in the quantitative meta-analysis. Factors such as length of surgery, blood loss, and hospital length of stay were largely undescribed in the individual studies and thus not available for analysis.

Statistical Analysis

The goal of the analysis was to estimate and compare the pooled effect size for different surgical techniques (MIS vs OLM, different MIS approaches vs OLM) or by level (L1-3 vs L3-4 for OLM). The primary analysis analyzed all eligible studies. A sensitivity analysis was performed on a subsample of studies that included patients after 1990 when magnetic resonance imaging (MRI) became available, as prior to this computed tomography myelograms were the gold standard and may have led to inaccurate diagnoses and exploratory surgeries.[5] First, the pooled proportion of satisfactory outcome was computed across studies for each surgical technique separately using the R statistical computing software (https://cran.r-project.org/) and the R package, meta.[16] Fixed effect models were used because fixed effect estimate is less susceptible to biases from small studies.[17] The models were run with 2 different approaches: the classical inverse variance method with logit transformation and the generalized linear mixed model (GLMM). Only results from the inverse variance method were presented in the forest plots because this method can yield weight for each individual study while GLMM method cannot. Between-study heterogeneity was assessed using the τ^2 statistic, which describes the underlying between-study variability, and the I^2 statistics (range: 0%-100%), which describes the percentage of variability in the effect size estimates attributable to heterogeneity between studies rather than to sampling error. Second, to compare outcomes between surgical outcomes, for example, OLM versus MIS, GLMM was applied using the procedure, glimmix, in the statistical computing software SAS 9.4 (SAS Institute Inc). Other comparisons, for example, different MIS approaches versus OLM, and OLM L1-3 versus L3-4, were

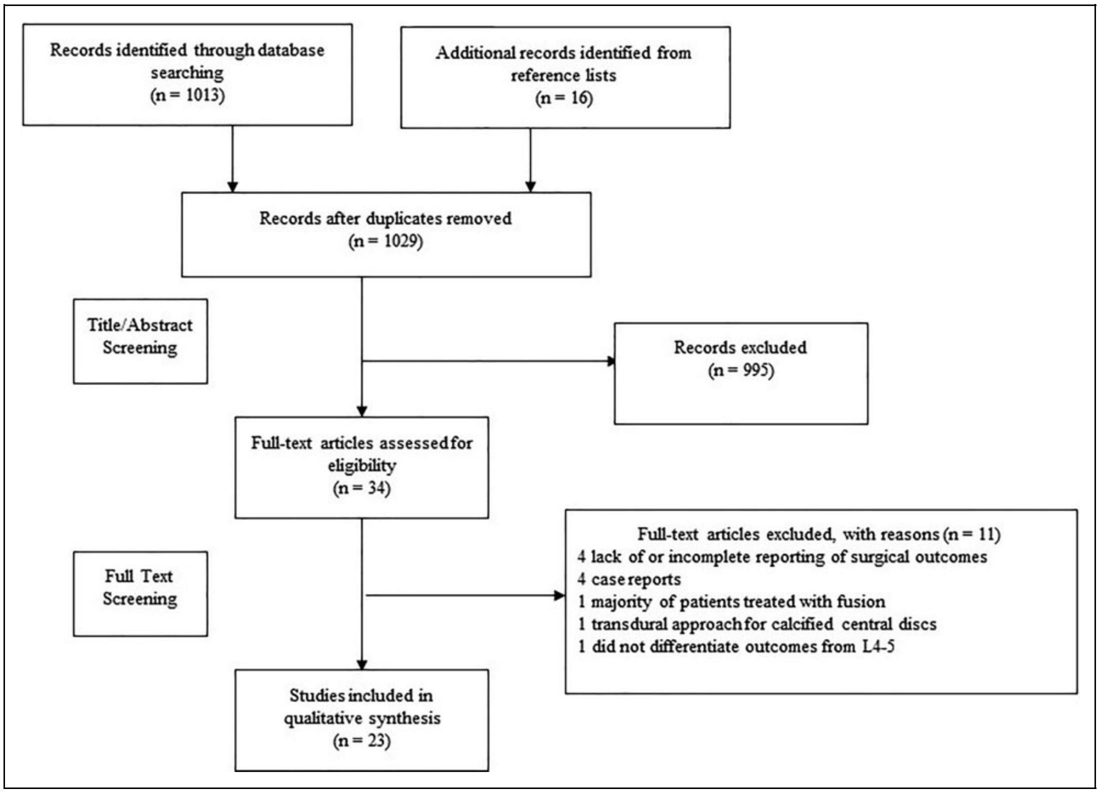

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) diagram.

compared similarly using glimmix. Statistical significance level was set as $P < .05$.

Results

The results of our search are summarized in the PRISMA flow diagram shown in Figure 1. In brief, our search returned 1013 results from the PubMed database; an additional 16 records were identified through review of the bibliographies of the examined articles, which led to a total of 1029 articles without any duplicates. After screening based on title and abstract, 34 full-text versions of the remaining studies were collected and screened for further eligibility. Of these 34 studies, 23 were found to meet inclusion criteria for qualitative analysis. Of the 11 excluded papers, 4 were excluded due to a lack of or incomplete reporting of surgical outcomes, 4 due to case reports rather than case series, 1 due to majority of patients treated with fusion, 1 excluded due to report of transdural approach for calcified central discs felt to be considered neither conventional approach nor MIS technique, and 1 did not separate outcomes of upper lumbar levels from L4-5.

Outcomes of Conventional Posterior Approach

Fourteen studies encompassing 784 patients reported outcomes of conventional OLM (Table 1).[2,4-9,18-24] Number of patients in the included studies ranged from 14 to 141. Albert et al. maintains the largest series with 141 patients operated on between 1980 and 1990 and reports an 80% postoperative improvement rate.[5] Over 80% of the patients in his series were L3-4 with only 24 patients having L1-2 or L2-3 disc herniations. Karaaslan et al[21] hold the largest number of L1-2, L2-3, and concurrent L1-2 and L2-3 disc herniations totaling 78 patients. Nine of the 14 included studies included disc herniations at L3-4 as a ULDH. The average age of patients ranged from 45.7 to 63 years old, and proportion of male gender ranged from 50% to 93%.

Outcomes of MIS Approaches

Nine case series on minimally invasive approaches to ULDH described a total of 5 techniques: percutaneous endoscopic lumbar discectomy (PELD), oblique paraspinal (OP), tubular microdiscectomy (TM), lateral retroperitoneal approach (LRA), and translaminar keyhole laminotomy (Table 1).[10,11,13,14,25-29]

PELD was the most reported with 4 studies that describe experience for a total of 126 patients. Wu et al[13] used the opportunity to explain the differences in approach between L1-2 and L2-3 discs versus L3-4 discs. Oyelese et al[28] described the LRA with transpsoas and direct transforaminal access to central and paracentral disc herniations at L1-2. Using navigation to direct the retroperitoneal dissection toward the neural foramen, minimally invasive dilators were inserted over a guidewire into the posterior disc space allowing access with an expandable retractor. For oblique approaches, Kim et al[26]

Table 1. Study and Patient Characteristics.

First author and year	Study period	Country	Design	Sample size	Levels included	Follow-up average (years)	Average age (years)	Gender (% male)	Surgical technique	Complications
Aronson 1963[2]	1955-1960	USA	R	73	L1-4	NS	55	NS	OLM	NS
Spangfort 1972[22]	1951-1965	Sweden	R	45	L1-4	NS	NS	NS	OLM	NS
Gutterman 1973[8]	NS	USA	R	69	L1-4	1.7	53	73.9	OLM	NS
Pasztor 1981[7]	1955-1973	Hungary	R	134	L1-4	NS	NS	64.9	OLM	3 – 1 pulmonary embolism resulting in death, 2 durotomies
Wei 1989[6]	1978-1987	Taiwan	R	22	L1-4	NS	50	77.2	OLM	NS
Dinakar 1991[23]	NS	India	R	15	L1-4	NS	NS	93	OLM	NS
Albert 1993[5]	1980-1990	USA	R	141	L1-4	2.2	51.6	72.3	OLM	6: 1 durotomy, 2 wrong-level surgery, 1 retained fragments, 1 epidural hematoma, 1 wound infection
Cedoz 1996[24]	1982-1994	France	R	24	L1-3	4.8	52.9	62.5	OLM	1 epidural hematoma
Sanderson 2004[9]	1989-1999	USA	R	26	L1-4	6.75	63	53	OLM	NS
Lee 2005[10]	2001-2003	Korea	R	30	L1-2	1.6	52.5	70	PELD, LRA, and OLM	4: 1 durotomy, 1 pelvic bone fracture, 2 sexual dysfunction (both after PELD)
Moon 2006[14]	2005	Korea	R	4	L1-3	1	42.5	25	OP	NS
Saberi 2007[18]	NS	Iran	R	50	L1-4	1	45.7	50	OLM	No significant postoperative complication was observed.
Lurie 2008[4]	2000-2005	USA	P	41	L2-4	2	50.9	61	OLM	6: 1 durotomy, 1 epidural hematoma, 1 superficial wound infection, 3 "other"
Ahn 2009[25]	2001-2003	Korea	R	45	L1-3	3.2	NS	73.3	PELD	4: 1 durotomy converted to open, 2 reoperations for incomplete decompression, 1 fusion surgery for reherniation
Kim 2009[26]	2005-2008	Korea	R	17	L1-3	2.3	54.6	42.1	OP	No disc reherniations and no approach-related complications, including durotomy and infection
Kim 2010[19]	1998-2007	Korea	R	41	L1-3	1.4	55.5	61	OLM	No major complications related to the surgery, including CSF leak or nerve root injury
Lee 2013[20]	2008-2012	Korea	R	15	L1-3	NS	56.9	53.3	OLM	NS
Wu 2016[13]	2008-2014	China	R	55	L1-4	2.5	NS	49.1	PELD	No complications occurred, including infection, deep vein thrombosis, or dural tear
Jha 2017[11]	NS	USA	R	3	L1-3	0.8	74.7	66.7	TM	No complications
Karaaslan 2017[21]	2005-2013	Turkey	R	78	L1-3	NS	59.9	50	OLM	13: 3 durotomies, 5 wound infections, 4 reherniations, and 1 motor deficit
Xin 2017[27]	2014-2015	China	R	11	L1-4	1.4	48.1	36.4	PELD	NS
Oyelese 2018[28]	NS	USA	R	3	L1-2	1	52.7	100	LRA	3: Transient anterior thigh pain and numbness
Son 2018[29]	2005-2014	Korea	R	48	L1-3	3.5	57	56.3	Keyhole laminotomy and TM	2: 1 durotomy and 1 revision surgery

Abbreviations: NS, not specified; R, retrospective; P, prospective; OLM, open laminectomy/laminotomy and microdiscectomy; PELD, percutaneous endoscopic lumbar discectomy; LRA, lateral retroperitoneal approach; CSF, cerebrospinal fluid; OP, oblique paraspinal; TM, tubular microdiscectomy.

described a paraspinal approach for ULDH. Using a skin incision ~30 mm lateral from the midline, the lateral portion of the pars interarticularis and facet joint are able to be drilled away allowing access to the disc space. Jha et al1[1] reported their results on ULDH directing the tubular retractor from the contralateral side. They described the contralateral technique as better able to preserve the integrity of the facet joints.

Comparison of Outcomes Between Standard OLM and MIS Techniques

Table 2 contains the clinical outcome reassignments for the studies in order to have the same outcome measures. Three studies did not report outcomes that may be reassigned into a binary outcome (satisfactory vs not) and therefore were excluded from the subsequent analyses.[4,18,20]

In Figure 2, results with all 20 studies published between 1963 and 2018 comparing standard OLM versus all MIS techniques are shown using the fixed effect model with the inverse variance method and logit transformation, yielding weights. Among standard OLM (12 studies) the heterogeneity test shows that the between-study variation was significant ($P <$ .01) with a pooled estimate of 82% (95% CI 0.78-0.84) having a satisfactory surgical outcome. Including all MIS techniques, between-study variation was not significant ($P = .13$) and the pooled estimate of the proportion having a satisfactory result was 77% (95% CI 0.70-0.83). The fixed-effect model with the GLMM approach yielded very similar pooled estimates of the proportions (95% CI) of satisfactory outcomes: 83% (0.80-0.86) vs. 80% (0.74-0.85) in OLM versus MIS, respectively. Comparing between MIS and OLM, we found the odds ratio (OR) = 0.86, 95% CI (0.42-1.74), $P = .66$, indicating that the likelihood of having a satisfactory outcome was not significantly different between MIS and OLM.

As a sensitivity analysis to analyze a subsample of studies from the time point that studies self-reported routine use of MRI, from 2004 to 2018 with our data, still 82% of patients (95% CI 0.75-0.88), undergoing OLM reported satisfactory outcomes but without significant between-study variation ($P = .14$), Supplemental Figure 1. Results were similar with the GLMM method with 83% satisfactory outcomes (95% CI 0.77-0.88). All MIS studies were carried out with routine use of MRI. Comparing MIS versus updated OLM (studies from 2004 and beyond) yielded OR = 0.79 (95% CI 0.30-2.10), $P = .60$, again demonstrating that the likelihood of having a satisfactory outcome is not significantly different.

Pooled estimates for each of MIS subtypes: PELD, LRA, OP, TM, and translaminar are summarized in Figure 3. The pooled proportions (95% CI) were estimated as 0.72 (0.63-0.79) for PELD, 0.90 (0.53-0.99) for LRA, 0.79 (0.57-0.91) for OP, and 0.89 (0.73-0.96) for TM. There was only 1 study, Son et al,[29] that reported on translaminar keyhole, with 100% satisfactory rate (20 out of 20 patients). Outcomes of PELD versus OLM yielded slight trend toward significance favoring OLM with an OR = 0.50 (95% CI0.21-1.16), $P = .10$. The results for OP and TM versus OLM were not significant: OP versus OLM OR = 1.04 (95% CI 0.20-5.25), and $P = .96$; and TM versus OLM OR = 2.15 (95% CI 0.38-12.38), $P = .36$. Models comparing LRA and translaminar keyhole versus OLM could not converge as all surgeries were reported as 100% satisfactory for LRA and translaminar keyhole.

Comparison of Outcomes With OLM for Disc Herniations at L1-3 Versus L3-4

There were 3 studies that had data on outcomes of L3-4 separately and 7 studies with data on L1-2 and L2-3 (Figure 4). Using the inverse variance method with logit transformation, yielding weights, 80% of patients (95% CI 0.72-0.87), with disc herniations at L3-4 had a favorable outcome with standard OLM. For disc herniations at L1-3, 74% of patients (95% CI 0.67-0.81), had a favorable outcome. Comparing results by levels revealed a trend toward significance of higher satisfaction for L3-4 vs. L1-3 disc herniations treated with standard OLM surgery; OR = 0.46 (95% CI 0.19-1.12), and $P = .08$.

Discussion

Surgical Outcomes of ULDH

In this study, ULDH were shown to have an overall favorable prognosis. Our meta-analysis demonstrated 82% having a satisfactory outcome with standard OLM, which remained the same when excluding studies prior to routine use of MRI. Among all reported MIS techniques, the proportion of satisfied patients did not significantly improve. These results were closely comparable to outcomes seen in the largest case series by Albert et al[5] with 80% excellent or good patient reported results reported nearly 3 decades ago in 1993.

Only one of the included studies reported prospectively collected data using a surgical and a control cohort of conservative management. Lurie et al[4] described this sub-group analysis of outcomes by level from the SPORT study in which they compared L2-3 and L3-4 disc herniations against L4-5 and L5-S1 herniations. Of the 1244 patients enrolled, 88 (7%) were classified as ULDH with 41 undergoing surgery and 47 conservatively managed. They found that the ULDH had the largest effects of surgery compared with nonoperative management with the smallest treatment effects at L5-S1 and intermediate effects at L4-L5. This difference in treatment effect was mainly a result of a significantly lower rate of improvement in patients with ULDH after conservative treatment. Thus, ULDH may have a lower rate of favorable outcomes when compared with reports of 88% to 97% success rate reported in L4-5 and L5-S1 microdiscectomies,[30-32] but when compared with conservative measures surgical outcomes have a greater effect. However, it should be noted that Lurie et al[4] did not report results by level, which makes it possible that the increased operative treatment effect was seen because a majority of the disc herniations were at L3-4, only a small number at L2-3, and none at L1-2.

Table 2. Surgical Outcomes.

First author and year	Technique	Levels	Sample size	Reported outcomes	Clinical outcome reassignment	
					Satisfactory	Unsatisfactory
Aronson 1963[2]	OLM	L1-4	73	80% (59) improved, 10% (7) good, 10% (7) unchanged	66	7
Spangfort 1972[22]	OLM	L1-3	5	100% (5) complete relief of sciatic pain	5	0
		L3-4	40	75% (30) complete relief of sciatic pain	30	10
Gutterman 1973[8]	OLM	L1-2	4	25% (1) excellent, 50% (2) good, 25% (1) fair, 0% (0) poor	3	1
		L2-3	17	18% (3) excellent, 35% (6) good, 41% (7) fair, 6% (1) poor	9	8
		L3-4	48	44% (21) excellent, 40% (19) good, 8% (4) fair, 8% (4) poor	40	8
Pasztor 1981[7]	OLM	L1-4	134	69% (93) excellent, 23% (31) good, 1% (2) fair, 4% (6) unchanged, 0.7% (1) deteriorated, 0.7% (1) died	124	10
Wei 1989[6]	OLM	L1-4	22	91% (20) of patients reported excellent or good results	20	2
Dinakar 1991[23]	OLM	L1-4	15	73.3% (11) of patients reported excellent or good results	11	4
Albert 1993[5]	OLM	L1-4	141	80% (113) excellent or good patient-reported results	113	28
Cedoz 1996[24]	OLM	L1-2	7	71.4% (5) very satisfied and satisfied patients	5	2
		L2-3	17	52.9% (9) very satisfied and satisfied patients	9	8
Sanderson 2004[9]	OLM	L1-3	9	33% (3) improved, 56% (5) unchanged, 11% (1) worse	3	6
		L3-4	17	88% (15) improved, 12% (2) unchanged, 0% (0) worse	15	2
Lee 2005[10]	PELD	L1-2	14	14.3% (2) excellent, 28.6% (4) good, 14.3% (2) fair, and 42.9% (6) poor	6	8
	LRA		5	20% (1) excellent, 80% (4) good, and 0% (0) fair or poor	5	0
	OLM		11	36.4% (4) excellent, 54.5% (6), good, 9.09% (1) fair, and 0% (0) poor	10	1
Moon 2006[14]	OP	L1-3	4	100% (4) improvement in symptoms Mean 23.5 improvement in ODI	4	0
Saberi 2007[18]	OLM	L1-4	50	Mean 28 improvement in ODI	N/A	N/A
Lurie 2008[4]	OLM	L2-4	41	24.6-point mean improvement in SF-36 bodily pain, 23.4-point mean improvement in SF-36 physical functioning, and 19-point mean improvement in ODI treatment effect compared with nonoperative management	N/A	N/A
Ahn 2009[25]	PELD	L1-3	45	46.7% (21) excellent, 31.1% (14) good, 13.3% (6) fair, and 8.9% (4) poor	35	10
Kim 2009[26]	OP	L1-3	17	Overall patient satisfaction: 78.1%	13	4
Kim 2010[19]	OLM	L1-2	14	Excellent 57% (8), good 21% (3), fair 14% (2), poor 7% (1)	11	3
		L2-3	27	Excellent 56% (15), good 26% (7), fair 18% (5), poor 0% (0)	22	5
Lee 2013[20]	OLM	L1-3	15	Mean 14.5 improvement in ODI Mean 4.8-point improvement in leg pain VAS Mean 1.2-point improvement in back pain VAS	N/A	N/A
Wu 2016[13]	PELD	L1-3	13	30.8% (4) excellent, 46.2% (6) good, 7.7% (1) fair, 7.7% (1) poor, and 7.7% (1) unreported	10	3
		L3-4	42	31.0% (13) excellent, 40.5% (17) good, 11.9% (5) fair, 4.8% (2) poor, and 11.9% (5) unreported	30	12
Jha 2017[11]	TM	L1-3	3	100% (3) improvement in back and/or leg pain	3	0
Karaaslan 2017[21]	OLM	L1-2	21	85.7% (18) postoperative improvement	18	3
		L2-3	45	93.3% (42) postoperative improvement	42	3
		L1-2 + L2-3	12	75% (9) postoperative improvement	9	3
Xin 2017[27]	PELD	L1-4	11	Modified MacNab criteria: 81.8% (9) excellent, 9.1% (1) good, and 9.1% (1) fair	10	1
Oyelese 2018[28]	LRA	L1-2	3	100% (3) improvement in back and/or leg pain	3	0
Son 2018[29]	Translaminar (keyhole laminotomy)	L1-3	20	75% (15) excellent and 25% (5) good by Odom's criteria	20	0
	TM		28	39.3% (11) excellent, 57.1% (14) good, and 10.7% (3) fair by Odom's criteria	25	3

Abbreviations: OLM, open laminectomy/laminotomy and microdiscectomy; PELD, percutaneous endoscopic lumbar discectomy; LRA, lateral retroperitoneal approach; OP, oblique paraspinal; TM, tubular microdiscectomy; ODI, Oswestry Disability Index; SF-36, Short Form–36; VAS, visual analog scale. N/A= not applicable.

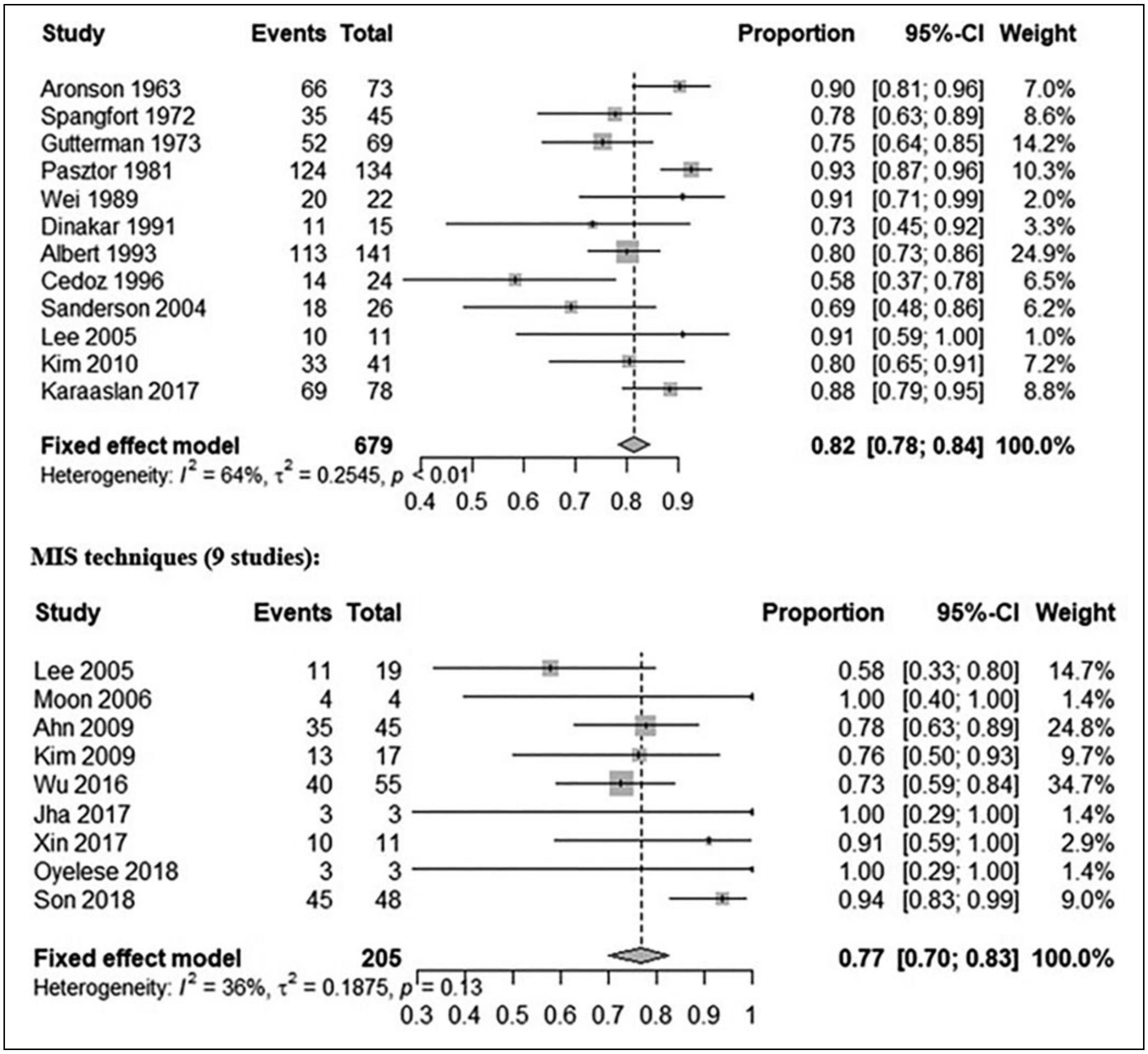

Figure 2. OLM vs. MIS, all 20 studies published between 1963 and 2018.[a] OLM, open laminectomy/laminotomy and microdiscectomy; MIS, minimally invasive surgery. [a] Pooled proportion across the studies was estimated with the inverse variance method with logit transformation, yielding weights.

MIS Versus Open Techniques

Despite the theoretical benefits of MIS techniques, the literature does not support improved results over standard OLM for ULDH. It remains unclear if the adjacent structures to the upper lumbar spine, such as the kidneys and ribs, are the most limiting factor for approaches that utilize an alternative plane.[14] Or perhaps there is a ceiling effect for achieving higher rates of satisfactory outcomes for patients with ULDH. An obvious third explanation would be the low frequency of ULDH to allow for surgeons to overcome the initial learning curve to adapt these relatively new MIS techniques.

Likewise, despite being the most popular MIS technique reported for ULDH with a total of 126 patient outcomes reported, PELD is relatively new and has a steep learning curve.[33-35] Our meta-analysis shows that this evolving technique may appear to have inferior outcomes compared with conventional posterior approach with a slight trend toward significance favoring OLM with an OR of 0.50 (95% CI 0.21-1.16), and $P = .10$. One possibility is that the majority of reported endoscopic discectomies were at L1-3. Wu et al[13] reported a trend toward a higher rate of symptom recurrence requiring reoperation in the L1-3 group compared with the L3-4 group (16.7% vs 5.4%; $P > .05$), but this did not reach statistical significance.

Lee et al[10] directly compared PELD, LRA, and standard open laminotomy/laminectomy approaches for L1-2 disc herniations. The PELD group showed the worst outcomes with only 6 of their 14 patients (42.9%) having excellent or good results. This is compared with 100% of the LRA group and 90.9% of the conventional group with excellent or good results (Fisher's exact test, $P = .04$). They owed the poor outcomes with PELD to the kidneys restricting an ample lateral entry point.

The authors of the PELD approaches for the ULDH may have failed to exclude less accessible midline disc

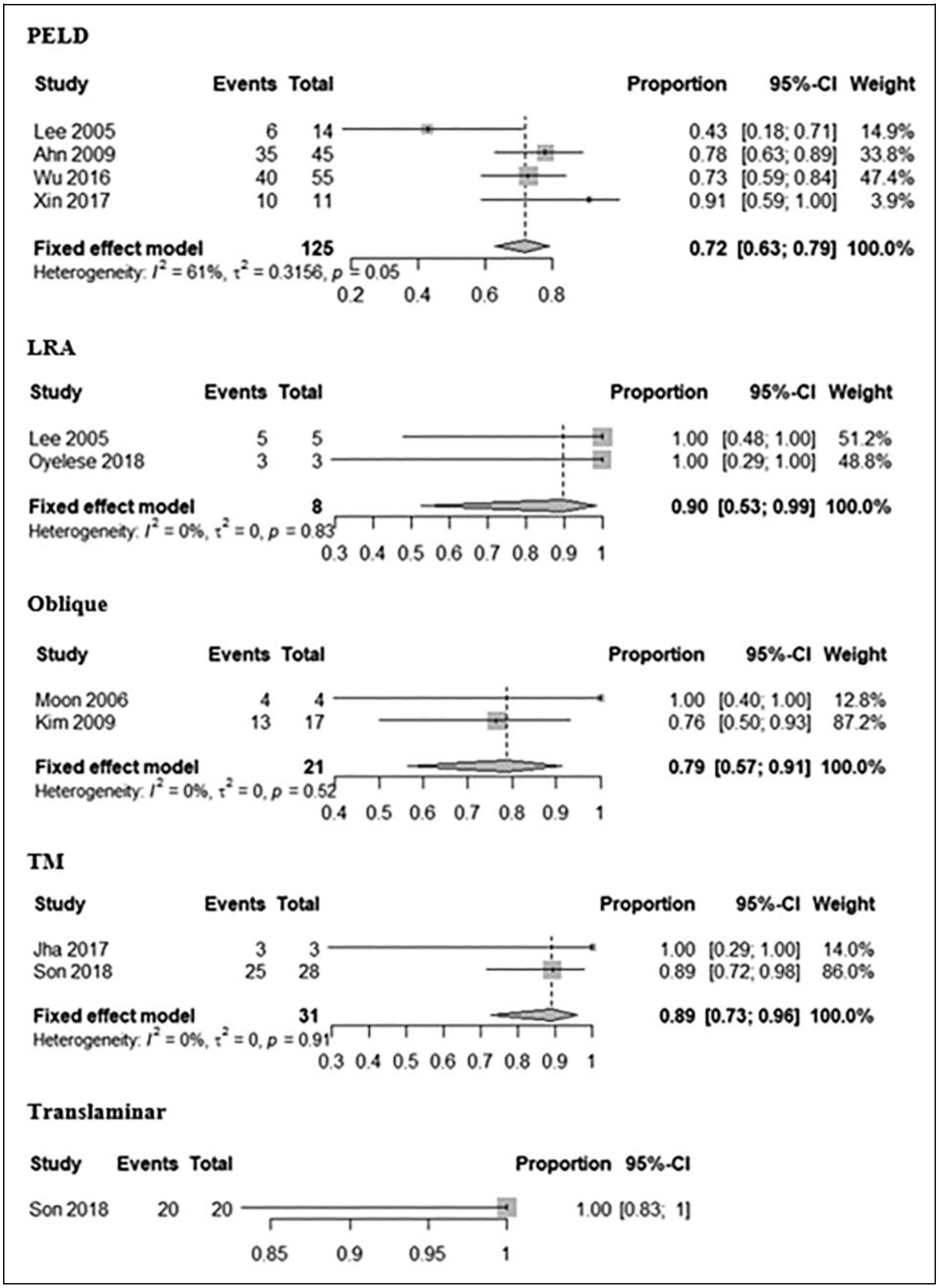

Figure 3. Subtypes of minimally invasive surgery (MIS) techniques.[a] PELD, percutaneous endoscopic lumbar discectomy; LRA, lateral retroperitoneal approach; Oblique, oblique paraspinal; TM, tubular microdiscectomy. [a] Pooled proportion across the studies was estimated with the inverse variance method with logit.

herniations, which can result in worse results. Ahn et al[25] demonstrated that a central disc herniation was significantly related to a poor outcome (OR = 12.7, 95% CI 1.24-130.35, $P = .032$). Telfeian et al[36] showed success with patients undergoing transforaminal PELD approach at the thoracolumbar junction (T12-L1) by carefully selecting only foraminal and paracentral disc herniations. With regard to the other MIS techniques, oblique paraspinal, tubular microdiscectomy, lateral retroperitoneal approach, and translaminar keyhole laminotomy, the sample sizes were small and subject to high risk of bias restricting conclusions from this analysis.

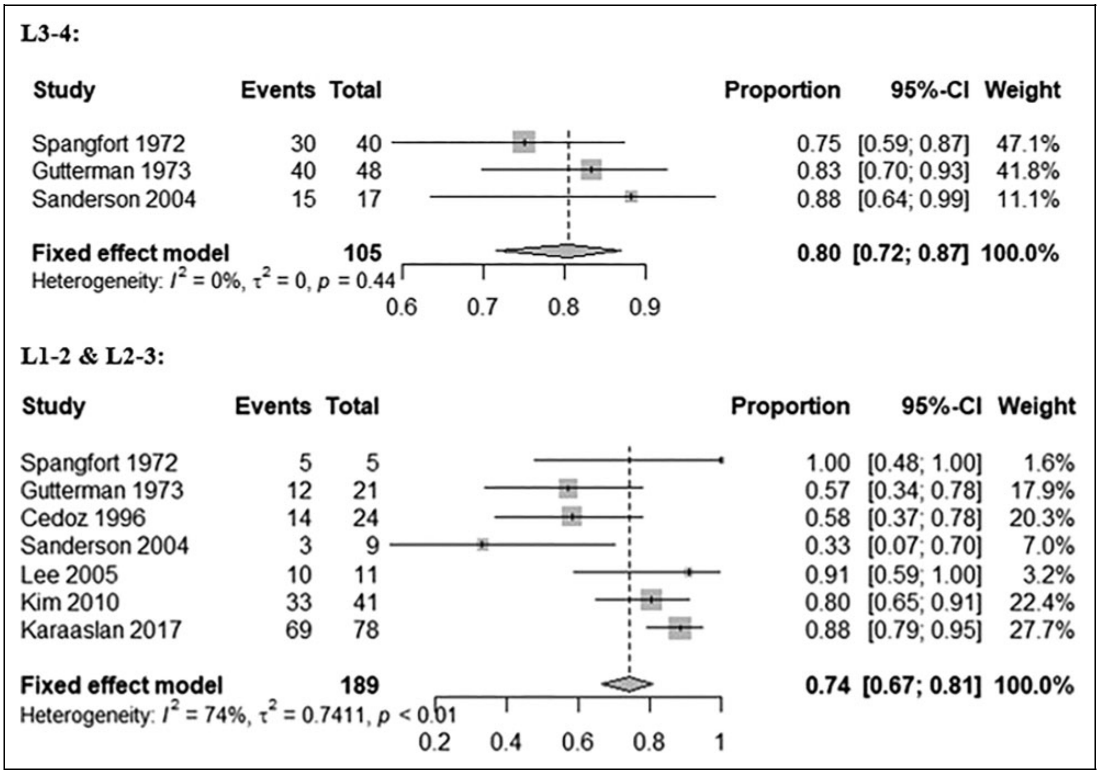

Figure 4. OLM alone: L3-4 versus L1-2 and L2-3.[a] OLM, open laminectomy/laminotomy and microdiscectomy. [a] Pooled proportion across the studies was estimated with the inverse variance method with logit transformation, yielding weights.

Consensus on L3-4

ULDH are universally agreed to include levels of L1-2 and L2-3; however, there is no current consensus on L3-4 as part of the group of ULDH. Only 11 of the 23 (48%) studies collected in our systematic review of the literature included L3-4 disc herniations as a ULDH. We report a trend toward significance of better outcomes of disc herniations at L3-4 versus L1-3 with standard OLM surgery. In contrast, Sanderson et al[9] reported that the characteristics and clinical outcomes for L1-2 and L2-3 were exceedingly poor, and that L3-4 disc herniation patients matched much more closely to those of L4-5 and L5-S1. However, they included a high proportion of patients with prior surgery as well as performed a greater number of fusions in the L1-3 that likely contributed.[9] Additionally, they only included 9 patients in the L1-3 group in their final analysis making it difficult to draw conclusions. Lee et al[20] also found that patients with L1-2 and L2-3 disc herniations had lesser improvement of their back pain compared with lower lumbar disc herniations. Unfortunately, they grouped L3-4 outcomes with lower lumbar levels precluding direct comparisons between L1-3 and L3-4.

In several cadaveric and computed topographic imaging morphometric studies, L3-4 frequently marks an inflection point in the linear graph models describing facet orientation, laminar thickness, width of the PLL, and range of motion in flexion-extension.[37-39] Correspondingly, the rate of disc herniations at L3-4 is also seen as an inflection point as it occurs significantly more frequently than at L1-3 but significantly less than the much more common lower lumbar disc herniations at L4-5 and L5-S1.[3,22,40,41] Based on the comparative anatomy, one may say that L3-4 acts as a transitional level between L1-3 and L4-S1. We suggest that L3-4 disc herniations more closely matches with disc herniations at L1-2 and L2-3 because of the related pathophysiology and pattern of herniation distinct from L4-5 and L5-S1 disc herniations.

Review of Comparative Anatomy and Pathophysiology

The changes in lordosis, pedicle height, pedicle width, and transverse pedicle angle are common knowledge to spine surgeons since pedicle screw fixation and restoration of spinopelvic alignment is standard practice.[42-44] Also familiar is that the size of the vertebral body increases steadily from L1 to L5, indicative of the increasing loads that each lower lumbar vertebra absorbs.[45-49] The disc heights and spinal canal dimensions likewise increase in the cranial-caudal direction, and the width of the vertebral body and the mean transverse diameter of the spinal canal remains a steady ratio.[47] Smaller sagittal and cross-sectional spinal canal dimensions are significant factors in predicting outcomes of surgery for symptomatic disc herniations.[50-52]

Although the vertebral body and spinal canal are correspondingly smaller at higher levels, the laminar thickness is increased in the upper lumbar spine of L1-3 compared with L4 and L5.[53] In addition to the narrower spinal canal and thicker lamina at the upper lumbar levels, there is a higher number of nerve roots and often the conus medullaris behind L1. This facilitates compression of the conus or multiple nerve roots, which leads to polyneuropathies and a higher rate of preoperative urinary disturbance.[19,22,23,54,55] In turn, increased presence of preoperative urinary incontinence, multiple nerve root involvement, and possibly paraplegia clearly leads to worse reported outcomes.[1,2,8,23]

In the upper lumbar spine from L1 to L3, the facets are oriented significantly more parallel to the midsagittal plane with a sharp decrease in their facet angles compared with the thoracic spine facets and then a steady increase seen in superior and inferior L4 and L5 facets.[56] As the facet complex is oriented more vertical, it becomes much more difficult to perform only a partial medial facetectomy as well as a narrower corridor of approach to the intervertebral disc space.[57] This may explain a higher rate of worse back pain after conventional posterior OLM for ULDH,[20] as instability is related with a larger degree of the facetectomy performed.[58] Additionally, the cross-sectional area of the pars interarticularis gradually decreases moving from L5 to L1 making an iatrogenic pars defect at the upper lumbar levels more likely.[59]

The location of the herniated disc fragment also has a unique pattern due to the variations in the ligamentous complexes. The posterior longitudinal ligament morphometry thins from an average width of 7.8 mm at L1 to 1.9 mm at L5 with a sharp progressive decrease seen from L4.[38] Consequently, ULDH are more likely to be foraminal or far lateral rather than central or paracentral, which is seen in disc herniations from L1-3 as well as L3-4.[4,60] Lurie et al[4] found in their series that 24% of ULDH versus 2% to 3% of L4-L5 and L5-S1 herniations to be foraminal ($P < .001$), and only 44% of ULDH versus 76% to 83% of L4-L5 and L5-S1 herniations to be paracentral ($P < .001$). In addition to being more likely foraminal or far lateral, ULDH also has an increased incidence of posteriorly migrated disc fragments.[7,61-64]

Biomechanically, the range of motion in flexion-extension is significantly less at the upper lumbar levels. Cook et al[65] quantified the range of motion by level and determined that flexion-extension at L3-4 was significantly greater than L1-2, but significantly less than L4-5 and L5-S1. In asymptomatic individuals, flexion-extension x-rays have shown decreased angular motion at the upper lumbar levels with an increasing trend in the cranial-caudal direction.[39] Thus, it has been postulated that this decreased movement shields these levels from disc degeneration and facet-ligamentous hypertrophy.[3,66]

Thus, pathogenesis of ULDH differ significantly from disc herniations at L4-5 and L5-S1. Concurrent levels of disc degeneration are more common in ULDH than L4-5 and L5-S1.[3] Accordingly, patients with ULDH are older and often demonstrate an ascending pattern of disc degeneration with increasing stiffness of the lower lumbar levels.[3,4,20,41,64] The presence of multiple levels of involvement should not be overlooked as the potential number of pain generators does not portend a favorable outcome for axial back pain.[22] Isolated herniation at the upper lumbar levels does occur rarely and has an association with vertebral body fractures and compression deformities, both of which are common in older patients and more prevalent at the thoraco-lumbar junction.[3,67] Endplate fractures or deformities create wedge-shaped vertebrae and an abnormal distribution of stress in the adjacent intervertebral disc, which may accelerate the process of degeneration.[68,69] Concordantly, the likelihood of preoperative back pain and the probability of persisting or worsening after surgery are high in both scenarios, and the patient needs to be counseled appropriately.

Limitations

The main limitation to this analysis is the level of evidence in all the included studies. The reported case series are susceptible to bias in their results. It is also difficult to draw final conclusions from small sample sizes which was made more complex by heterogeneity of levels and no standard reported outcome measures. Prospective data collection with standardized patient questionnaires and larger case series will help. Unfortunately, a multicenter randomized control trial to determine if there is benefit of MIS for ULDH is unlikely given the rarity of the pathology and diverse presenting symptoms.

Strengths

The strength of our analysis is that it provides the first systematic review and meta-analysis on surgical outcomes of discectomy for ULDH. Our study highlights the history and evolution of surgical treatment of this rare clinical entity that has never previously received a full appraisal of the current literature. Despite decades of advancement in technology and minimally invasive techniques our results demonstrate little improvement in the care of ULDH. These results will help guide surgeons' preoperative counseling of patients, as well as serve as a call to improve results of a neglected condition.

Conclusions

Our analysis supports that ULDH have an overall prognosis slightly greater than 80% satisfactory results and has not improved with MIS techniques. Discectomy for herniations at L3-4 trends toward better outcomes compared with disc herniations at L1-2 and L2-3, but was not significant. Future studies may include more detailed post-operative imaging, including 3-dimensional computed tomography and flexion/extension films, to determine degrees of facetectomy and if there are signs of instability. For prospective cohorts, authors should strive to separate all results of discectomy by level to help determine what nuances in outcomes may exist.

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Supplemental Material

Supplemental material for this article is available online.

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