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Surgical Outcomes of Lumbar Disc Herniation: A Retrospective Analysis

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Annotation: Background: Lumbar disc herniation (LDH) represents one of the most common spinal disorders requiring surgical intervention. Despite various surgical approaches available, there remains a lack of consensus regarding optimal techniques and their long-term outcomes.

Objective: To evaluate the clinical outcomes, complications, and prognostic factors associated with surgical management of LDH in a large, single-center cohort.

Methods: This retrospective analysis examined 425 consecutive patients who underwent surgical treatment for symptomatic lumbar disc herniation (LDH) between January 2018 and December 2022. Surgical approaches included microdiscectomy, endoscopic discectomy, and open discectomy. The primary outcomes were pain reduction (measured by the Visual Analog Scale), functional improvement (as assessed by the Oswestry Disability Index), and return to work or activities. Secondary outcomes included reoperation rates, complications, and patient satisfaction scores.

Results: At a mean follow-up of 36.7 months, significant improvements were observed in pain scores (mean reduction, 4.2 ± 1.6 points; $p < 0.001$) and functional capacity (mean ODI improvement, 28.7 ± 11.3 points; $p < 0.001$) across all surgical modalities. Microdiscectomy demonstrated superior outcomes for selected parameters, including shorter hospital stay, faster return to activities, and lower complication rates compared to open procedures. Recurrent herniation occurred in 7.3% of patients, with higher rates in those with larger disc herniations, obesity, and smoking history. Multiple regression analysis identified younger age, shorter symptom duration, and absence of comorbidities as positive prognostic factors.

Conclusion: Surgical intervention for LDH provides significant and sustained clinical improvement across multiple outcome domains. Minimally invasive approaches appear to offer advantages in terms of early recovery metrics, although long-term functional outcomes were comparable across techniques. Patient selection and consideration of identified prognostic factors may optimize surgical decision-making and outcomes.

Keywords: Lumbar disc herniation; microdiscectomy; endoscopic discectomy; surgical outcomes; prognostic factors.

Introduction

Lumbar disc herniation (LDH) is among the most common spinal pathologies, affecting 1-3% of the population, leading to the highest incidence of pathology in the fourth or fifth decade of life [1,2]. It is an essential source of global healthcare costs, work disability, and loss of quality of life [3]. LDH typically presents as a syndrome of low back pain, radiculopathy, sensory symptoms, and motor weakness, depending on which neural structure is disrupted. The pathophysiology is the displacement of nucleus pulposus material outside of the confines of the annulus fibrosus, which may lead to both mechanical compression and chemical irritation of surrounding neural elements [4].

The natural history of LDH is favorable in as many as 70-80% of cases, with spontaneous symptom resolution via conservative management options, including physical therapy, analgesics, and activity

modification [4,5]. Nonetheless, many patients will have persistent or escalating neurological symptoms, intractable pain, or functional impairment that ultimately require surgical management. The decision-making process surrounding surgical management is certainly complicated and multifactorial, involving clinical, imaging, and patient-specific data [6].

The transformations in procedures for lumbar disc herniation (LDH) have gone on for decades. The shift from traditional open laminectomy and discectomy to a minimally invasive approach is a great example. Mixter and Barr performed the first open discectomy in 1934 [11], laying the groundwork for surgical decompression of herniated disc material. Open discectomy underwent continuous refinement and evolved to microdiscectomy, which Yasargil and Caspar developed in the 1970s. Microdiscectomy introduced microscopic viewing with specialized instruments to minimize trauma while providing adequate surgical exposure. In more recent years, endoscopic techniques were developed, with a promise of further reduced surgical trauma, postoperative pain, and recovery time [7,13].

Despite the proliferation of surgical options and technical innovations, comparative evidence regarding their relative efficacy, safety profiles, and long-term outcomes remains incomplete [7,8]. Systematic reviews and meta-analyses have yielded inconsistent conclusions, often limited by heterogeneous study designs, variable outcome measures, and insufficient follow-up durations. Furthermore, the identification of reliable prognostic factors that predict surgical success remains elusive, complicating patient selection and individualized treatment planning [14].

Several patient-specific characteristics have been proposed as potential determinants of surgical outcomes, including age, symptom duration, comorbidity burden, psychosocial factors, and specific radiological features [14,15]. Disc herniation morphology (protrusion, extrusion, or sequestration), location (central, paracentral, foraminal, or extraforaminal), and size have been variably associated with surgical success rates. Additionally, the presence of modifiable risk factors such as obesity, smoking status, and occupational factors may influence both immediate postoperative recovery and long-term functional outcomes [8,16].

Complications following LDH surgery, while relatively infrequent, encompass a spectrum of adverse events ranging from minor wound issues to devastating neurological injuries [5,10]. The reported incidence of surgical site infections varies from 0.5% to 3%, depending on institutional protocols, surgical approach, and patient risk factors. Dural tears occur in approximately 1-7% of cases, potentially resulting in cerebrospinal fluid leakage, pseudomeningocele formation, or subsequent meningitis if inadequately managed. Perhaps most significantly, recurrent disc herniation represents a challenging complication, affecting 5-15% of patients within the first five years postoperatively and often necessitating revision surgery [10,16].

The economic implications of LDH extend beyond direct healthcare costs to encompass productivity losses, disability claims, and diminished workforce participation [3]. Cost-effectiveness analyses have generally supported surgical intervention for appropriate candidates, particularly when considering quality-adjusted life years and return-to-employment metrics. However, the relative cost-utility of different surgical techniques remains incompletely characterized, especially when accounting for reoperations, complications, and long-term functional outcomes [3,9].

Outcome assessment following LDH surgery has evolved substantially, moving beyond surgeon-centered measures such as radiological resolution or absence of complications toward patient-reported outcomes that capture pain severity, functional status, and quality of life dimensions [12]. Validated instruments, including the Visual Analog Scale (VAS), Oswestry Disability Index (ODI), EQ-5D, and SF-36, have become standard components of comprehensive outcome evaluation. Additionally, objective performance measures, such as return to work, analgesic consumption, and healthcare utilization, provide complementary perspectives on surgical effectiveness [9, 12].

Despite methodological advancements in outcomes research, existing literature on LDH surgical outcomes exhibits several limitations. Many studies feature relatively small sample sizes, limited follow-up durations, or single-surgeon experiences that may not generalize to broader practice settings

[9,18]. Selection bias frequently confounds comparative analyses, as patients with specific clinical or radiological characteristics may be preferentially directed toward particular surgical approaches. Furthermore, the multifactorial nature of pain and disability complicates attribution of outcomes solely to surgical intervention, particularly in patients with psychological comorbidities, compensation claims, or concurrent degenerative conditions [21].

The increasing emphasis on value-based healthcare has heightened scrutiny of appropriate indications for LDH surgery and optimization of patient selection. Practice guidelines from major spine societies generally recommend surgical consideration for patients with persistent radicular symptoms corresponding to imaging findings, neurological deficits, or cauda equina syndrome [8]. However, substantial practice variation persists regarding the timing of intervention, the selection of surgical approach, and perioperative management protocols.

Many new technologies, including sophisticated intraoperative navigation, robotic assistance in surgery, and augmented reality visualization, have recently entered the field of surgery for LDH, with anticipated advantages related to emphasizing surgical safety and precision [22]. New ERAS practices also recently incorporated spinal surgical procedures with a focus on multimodal analgesia, earlier mobilization, and reduction of postoperative opioid exposure. Evaluating these evaluations as part of our routine clinical practice is vital to understanding how they are contributing to improved clinical performance, use of medical resources, and satisfaction from the perspective of the patient [23].

This study was designed to reduce the gaps in our knowledge related to the surgical treatment of LDH that persist in the literature. By evaluating a large, consecutive cohort of patients that underwent surgery for symptomatic LDH all using varying surgical techniques, we aimed to provide meaningful data on clinical outcomes, complication rates, and prognostic factors with long-term follow-up. The use of a single, academic center allowed for a consistent surgical approach; and similar perioperative processes; and a similar approach to outcome assessment, meaning that most variations in practice were controlled for within each category. Importantly, the differences in the welcoming approach of surgical training and surgical style for each surgeon lends greater generalizability of the data to different practice environments.

There were three main aims of this research. First, to quantify values for pain, function, and quality of life improvements following surgery for lumbar disc herniation (LDH); second, to compare outcomes across different types of surgical approach; microdiscectomy, endoscopic discectomy, and open; and third, identify specific patient, radiographic, and surgical factors for good or poor outcomes. Secondary aims were to characterize complication rates, reoperation rates, and develop a predictive model for surgical outcomes to support evidence based decision making.

Methodology

Study Design and Patient Population

This study employed a retrospective cohort design to examine consecutive patients who underwent surgical intervention for symptomatic lumbar disc herniation at a private hospital in Baghdad between January 1, 2018, and December 31, 2022. All patient data were anonymized and stored on secure, encrypted institutional servers.

Inclusion criteria encompassed: (1) adult patients aged 18-75 years; (2) primary diagnosis of lumbar disc herniation confirmed by magnetic resonance imaging; (3) concordant radicular symptoms and/or neurological deficits; (4) failure of conservative management for at least 6 weeks (except in cases of progressive neurological deficit or cauda equina syndrome); (5) surgical intervention via microdiscectomy, endoscopic discectomy, or open discectomy; and (6) minimum follow-up of 12 months.

Exclusion criteria comprised: (1) previous lumbar spine surgery at the affected level; (2) concomitant lumbar pathology requiring additional procedures (fusion, instrumentation, or decompression of stenosis); (3) spondylolisthesis > grade I; (4) spinal deformity requiring correction; (5) active infection

or malignancy; (6) traumatic disc herniation; and (7) incomplete medical records or inadequate follow-up data.

Data Collection

A standardized data extraction form was utilized to collect demographic, clinical, radiological, surgical, and outcome parameters from electronic medical records. Demographic variables included age, sex, body mass index (BMI), smoking status, comorbidities (quantified using the Charlson Comorbidity Index), educational level, employment status, and workers' compensation involvement. Clinical data encompassed symptom duration, previous conservative treatments, preoperative pain scores, neurological examination findings, and medication usage.

Radiological assessment involved review of preoperative magnetic resonance imaging by two independent observers (a fellowship-trained spine surgeon and a neuroradiologist), who were blinded to clinical outcomes. Disc herniation characteristics were classified according to: (1) level (L3-4, L4-5, L5-S1, or multilevel); (2) location (central, paracentral, foraminal, or extraforaminal); (3) morphology (protrusion, extrusion, or sequestration); (4) size (measured in mm in both cranio-caudal and medio-lateral dimensions); and (5) presence of additional findings (Modic changes, facet arthropathy, or canal stenosis).

Operative variables were extracted from surgical reports and included: surgical approach (microdiscectomy, endoscopic discectomy, or open discectomy), operating surgeon, operative time, estimated blood loss, extent of disc removal (partial or subtotal), intraoperative complications, and length of hospital stay.

Outcome Measures

Primary outcome measures included:

1. Pain intensity, measured using the Visual Analog Scale (VAS, 0-10) for both back and leg pain, was assessed preoperatively and at 1, 3, 6, 12, and 24 months postoperatively.
2. Functional status, evaluated using the Oswestry Disability Index (ODI, 0-100%), collected at the same time intervals.
3. Return to work or previous activity level, including the time required to return and the capacity (full or limited).
4. Patient satisfaction, assessed using a 5-point Likert scale (very satisfied, satisfied, neutral, dissatisfied, very dissatisfied).

Secondary outcome measures comprised:

1. Complications, categorized as surgical (dural tear, nerve injury, infection, hematoma, wound issues) or medical (venous thromboembolism, urinary retention, adverse medication reactions).
2. Reoperation rate and indications, including recurrent herniation, residual symptoms, or new pathology.
3. Analgesic consumption, particularly opioid usage beyond 3 months postoperatively.
4. Healthcare utilization, including emergency department visits, unplanned readmissions, and additional interventional procedures.

Statistical Analysis

A sample size calculation determined that 400 patients would provide 90% power ($\alpha = 0.05$) to detect a clinically meaningful difference of 2 points on the VAS and 10 points on the ODI between surgical techniques, accounting for an anticipated 15% loss to follow-up [9, 12].

Descriptive statistics were calculated for demographic, clinical, and outcome variables. Continuous data were presented as means with standard deviations or medians with interquartile ranges, depending on the distribution's normality. Categorical variables were expressed as frequencies and percentages.

Comparative analyses between surgical techniques utilized analysis of variance (ANOVA) with post-hoc Bonferroni correction for continuous variables and chi-square or Fisher's exact tests for categorical outcomes. Mixed-effects models were employed to evaluate longitudinal changes in VAS and ODI scores, accounting for repeated measures and adjusting for potential confounders including age, sex, BMI, symptom duration, and herniation characteristics.

Univariate and multivariate logistic regression analyses were conducted to identify factors associated with favorable outcomes (defined as ≥50% reduction in VAS, ≥30% improvement in ODI, and return to work) and complications. Variables with a p-value of less than 0.20 in the univariate analysis were included in the multivariate models. Kaplan-Meier survival analysis was utilized to evaluate time to recurrent herniation, with log-rank tests comparing differences between surgical approaches.

A predictive model for surgical success was developed using variables significantly associated with favorable outcomes in multivariate analysis, with internal validation through bootstrap resampling. Model performance was assessed using the area under the receiver operating characteristic curve (AUC), calibration plots, and the Hosmer-Lemeshow goodness-of-fit test.

All statistical analyses were performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA), with $p<0.05$ considered statistically significant.

Results

Demographic and Clinical Characteristics

A total of 425 patients met the inclusion criteria and were included in the final analysis. Table 1 summarizes the baseline demographic and clinical characteristics of the study population, stratified by surgical technique. The mean age was 47.3 ± 13.2 years, with a slight male predominance (56.5%). The most commonly performed procedure was microdiscectomy (n = 248, 58.4%), followed by endoscopic discectomy (n = 102, 24.0%), and open discectomy (n = 75, 17.6%).

Table 1: Baseline Demographic and Clinical Characteristics by Surgical Technique

Characteristic	Overall (n=425)	Microdiscectomy (n=248)	Endoscopic (n=102)	Open (n=75)	p-value
Age, years (mean±SD)	47.3±13.2	46.1±12.8	44.9±11.7	53.2±14.5	0.003
Sex, male (%)	240 (56.5)	145 (58.5)	56 (54.9)	39 (52.0)	0.541
BMI, kg/m² (mean±SD)	27.8±4.9	27.4±4.7	26.9±4.3	30.1±5.6	0.001
Current smoker (%)	106 (24.9)	59 (23.8)	21 (20.6)	26 (34.7)	0.047
Comorbidity Index (median, IQR)	1 (0-2)	1 (0-2)	1 (0-1)	2 (1-3)	<0.001
Symptom duration, months (median, IQR)	7.5 (3.2-14.3)	6.8 (3.0-12.5)	5.4 (2.8-10.7)	12.3 (6.5-24.1)	<0.001
Preoperative VAS back pain (mean±SD)	6.4±1.9	6.2±1.8	6.1±2.0	7.3±1.7	0.002
Preoperative VAS leg pain (mean±SD)	7.8±1.6	7.9±1.5	7.7±1.6	7.8±1.7	0.683
Preoperative ODI (mean±SD)	58.3±14.7	57.1±14.2	56.9±15.0	63.5±14.6	0.004
Workers' compensation (%)	87 (20.5)	47 (19.0)	18 (17.6)	22 (29.3)	0.087

BMI = Body Mass Index; IQR = Interquartile Range; ODI = Oswestry Disability Index; SD = Standard Deviation; VAS = Visual Analog Scale

Significant differences were observed in several baseline characteristics across surgical groups. Patients undergoing open discectomy were older, had higher BMI, greater comorbidity burden, longer symptom duration, and worse preoperative back pain and functional status compared to the minimally invasive cohorts ($p<0.05$ for all comparisons). No significant differences were noted in preoperative leg pain severity or workers' compensation status.

Radiological Findings

Table 2 presents the radiological characteristics of disc herniations. The L4-5 and L5-S1 levels accounted for 86.8% of cases, with paracentral herniation being the most common location (62.1%). Extrusion was the predominant herniation morphology, accounting for 52.2%, followed by protrusion (31.5%) and sequestration (16.3%).

Table 2: Radiological Characteristics of Disc Herniations

Characteristic	Number (%)
Level	
L3-4	42 (9.9)
L4-5	203 (47.8)
L5-S1	166 (39.0)
Multiple levels	14 (3.3)
Location	
Central	68 (16.0)
Paracentral	264 (62.1)
Foraminal	72 (16.9)
Extraforaminal	21 (5.0)
Morphology	
Protrusion	134 (31.5)
Extrusion	222 (52.2)
Sequestration	69 (16.3)
Size	
Small (<5mm)	87 (20.5)
Medium (5-10mm)	246 (57.9)
Large (>10mm)	92 (21.6)
Additional findings	
Modic changes	156 (36.7)
Facet arthropathy	183 (43.1)
Canal stenosis	94 (22.1)

Clinical Outcomes

Significant improvements in pain and functional outcomes were observed across all surgical techniques at each follow-up time point (Table 3). The mean reduction in leg pain VAS score was 5.7 ± 2.1 points at 12 months postoperatively, representing a 73.1% decrease from baseline. Back pain demonstrated a more modest improvement, with a mean reduction of 3.6 ± 2.4 points (56.3%). Functional status, as measured by the ODI, improved by a mean of 39.2 ± 16.4 points at 12 months, corresponding to a 67.2% reduction in disability.

Table 3: Clinical Outcomes by Surgical Technique (Mean±SD)

Outcome Measure	Time Point	Overall (n=425)	Microdiscectomy (n=248)	Endoscopic (n=102)	Open (n=75)	p-value
VAS Leg Pain	Baseline	7.8±1.6	7.9±1.5	7.7±1.6	7.8±1.7	0.683
	1 month	3.1±1.8	2.8±1.7*	2.7±1.5*	4.2±2.0	<0.001
	3 months	2.5±1.9	2.3±1.8	2.2±1.7	3.4±2.1	0.002
	12 months	2.1±2.0	1.9±1.8	2.0±1.9	2.7±2.2	0.038

	24 months	2.2±2.1	2.0±1.9	2.1±2.0	2.8±2.4	0.046
VAS Back Pain	Baseline	6.4±1.9	6.2±1.8	6.1±2.0	7.3±1.7	0.002
	1 month	3.8±1.7	3.5±1.6*	3.2±1.5*	5.0±1.7	<0.001
	3 months	3.2±1.8	3.0±1.7	2.8±1.6	4.1±1.9	<0.001
	12 months	2.8±1.9	2.6±1.8	2.5±1.7	3.5±2.0	0.005
	24 months	2.9±2.0	2.7±1.9	2.6±1.8	3.7±2.1	0.003
ODI (%)	Baseline	58.3±14.7	57.1±14.2	56.9±15.0	63.5±14.6	0.004
	1 month	33.7±13.5	30.8±12.7*	29.2±11.9*	45.2±12.8	<0.001
	3 months	24.6±13.9	22.5±12.8	21.3±12.1	33.9±14.6	<0.001
	12 months	19.1±14.2	17.4±13.1	16.8±12.6	26.3±16.2	<0.001
	24 months	20.3±15.1	18.6±14.1	17.9±13.7	27.8±17.0	<0.001

*p<0.05 for pairwise comparison between microdiscectomy or endoscopic vs. open discectomy (Bonferroni-corrected) ODI = Oswestry Disability Index; SD = Standard Deviation; VAS = Visual Analog Scale

Comparative analysis revealed significant differences in early recovery parameters, with both microdiscectomy and endoscopic approaches demonstrating superior outcomes at 1-month follow-up compared to open discectomy for all primary measures. These differences persisted throughout the follow-up period for back pain and functional status, though they narrowed over time. At 24 months, the mean ODI scores were 18.6±14.1% for microdiscectomy, 17.9±13.7% for endoscopic discectomy, and 27.8±17.0% for open discectomy (p<0.001).

Return to work was achieved by 352 patients (82.8%) at a median of 8.7 weeks (IQR: 6.2-12.5). Patients who underwent minimally invasive procedures returned to work significantly earlier than those who had open discectomy (microdiscectomy: 7.9 weeks, endoscopic: 7.3 weeks, open: 12.4 weeks; p<0.001). Patient satisfaction was rated as "satisfied" or "very satisfied" by 84.2% of patients at final follow-up, with no significant differences observed between surgical techniques (p=0.192).

Complications and Reoperations

The overall complication rate was 12.5% (53/425), with significant differences observed between surgical techniques (Table 4). Dural tears were the most common surgical complication, occurring in 4.7% of cases, followed by surgical site infections in 2.6%. Minimally invasive techniques were associated with lower complication rates compared to open discectomy, with microdiscectomy (10.5%), endoscopic discectomy (9.8%), and open discectomy (21.3%) showing significant differences (p = 0.023).

Table 4: Complications and Reoperations by Surgical Technique

Outcome	Overall (n=425)	Microdiscectomy (n=248)	Endoscopic (n=102)	Open (n=75)	p-value
Complications, n (%)	53 (12.5)	26 (10.5)	10 (9.8)	16 (21.3)	0.023
Dural tear	20 (4.7)	11 (4.4)	3 (2.9)	6 (8.0)	0.236
Surgical site infection	11 (2.6)	5 (2.0)	2 (2.0)	4 (5.3)	0.241
Nerve root injury	3 (0.7)	1 (0.4)	1 (1.0)	1 (1.3)	0.593
Hematoma	5 (1.2)	2 (0.8)	1 (1.0)	2 (2.7)	0.348
Medical complications	14 (3.3)	7 (2.8)	3 (2.9)	4 (5.3)	0.479
Reoperations, n (%)	37 (8.7)	21 (8.5)	8 (7.8)	8 (10.7)	0.766
Recurrent herniation	31 (7.3)	18 (7.3)	7 (6.9)	6 (8.0)	0.951
Residual symptoms	4 (0.9)	2 (0.8)	1 (1.0)	1 (1.3)	0.916
New pathology	2 (0.5)	1 (0.4)	0 (0.0)	1 (1.3)	0.407
Time to recurrence, months (median, IQR)	11.5 (5.8-24.3)	12.2 (6.1-25.7)	10.8 (5.2-22.4)	9.7 (4.7-21.8)	0.418

IQR = Interquartile Range

Reoperation was required in 37 patients (8.7%) during the follow-up period, primarily due to recurrent disc herniation (7.3%). No significant differences in reoperation rates were observed between surgical techniques (p = 0.766). Kaplan-Meier analysis demonstrated a cumulative recurrent herniation rate of 5.2% at 1 year and 9.7% at 5 years.

Prognostic Factors

Multivariate analysis identified several factors independently associated with favorable outcomes at 12 months (Table 5). Younger age, shorter symptom duration (<6 months), absence of Modic changes, extrusion/sequestration morphology, and non-smoking status were significant predictors of superior pain and functional outcomes. Neither surgical technique nor level of herniation emerged as independent predictors after adjustment for confounding variables.

Table 5: Multivariate Analysis of Factors Associated with Favorable Outcomes at 12 Months

Variable	Adjusted Odds Ratio	95% CI	p-value
Age (per 10-year decrease)	1.47	1.23-1.76	<0.001
Symptom duration			
<3 months	2.86	1.89-4.32	<0.001
3-6 months	1.94	1.28-2.95	0.002
>6 months	Reference		
Smoking status			
Non-smoker	1.78	1.26-2.51	0.001
Smoker	Reference		
Herniation morphology			
Protrusion	Reference		
Extrusion	1.53	1.07-2.19	0.021
Sequestration	1.68	1.13-2.51	0.011
Modic changes			
Absent	1.64	1.18-2.28	0.003
Present	Reference		
Workers' compensation			
No	1.92	1.31-2.81	<0.001
Yes	Reference		
BMI			
<30 kg/m²	1.58	1.12-2.23	0.009
≥30 kg/m²	Reference		
Surgical technique			
Microdiscectomy	1.22	0.78-1.92	0.384
Endoscopic	1.31	0.79-2.17	0.292
Open	Reference		

BMI = Body Mass Index; CI = Confidence Interval

The predictive model developed from these factors demonstrated good discriminative ability (AUC = 0.79, 95% CI: 0.74-0.84) and calibration (Hosmer-Lemeshow test, p = 0.412) for identifying patients likely to achieve favorable outcomes following surgical intervention.

Discussion

This retrospective analysis of 425 patients who underwent surgical treatment for lumbar disc herniation provides valuable insights into clinical outcomes, complications, and prognostic factors associated with various surgical techniques. The results demonstrate significant improvements in pain, function, and quality of life following surgical intervention, with sustained benefits throughout the

nearly three-year follow-up period. At the same time, minimally invasive approaches, including microdiscectomy and endoscopic discectomy, exhibited advantages in early recovery parameters, and all techniques achieved clinically meaningful improvements in primary outcome measures.

The demographic profile of our cohort aligns with previous epidemiological studies of LDH, with peak incidence in the fourth and fifth decades and slight male predominance. The observed distribution of disc herniation levels also corresponds with established patterns, with L4-5 and L5-S1 accounting for the vast majority of cases. This concentration at the lower lumbar levels reflects the biomechanical stresses experienced at these segments, which bear greater loads and undergo more extensive motion than the upper lumbar regions.

Our findings regarding clinical outcomes support the existing literature, which demonstrates the efficacy of surgical intervention for appropriately selected patients with LDH [1,9,17]. The magnitude of improvement in leg pain (mean VAS reduction of 5.7 points) exceeds the minimally clinically significant difference (MCID) of 1.6-2.2 points established for radicular symptoms. Similarly, the observed improvement in ODI scores (mean reduction of 39.2 points) substantially surpasses the MCID threshold of 12.8 points. These results compare favorably with those reported in landmark randomized controlled trials such as the Spine Patient Outcomes Research Trial (SPORT) [17], which demonstrated superior outcomes with surgical management compared to non-operative care for patients with LDH.

The comparative study of surgical methods yielded some significant findings. There were several differences in early recovery outcomes for microdiscectomy and endoscopic approaches versus open discectomy with respect to decreased postoperative pain, improved function, shorter length of stay, and earlier return to work. These differences likely reflect information similar to those in the minimally invasive case - less tissue trauma, less trauma to stabilizing structures, and no or little inflammatory response. However, in the long run these differences were diminished and two years out from surgery most outcomes were similar.

Several factors may explain this convergence of outcomes. First, the initial benefits of reduced surgical trauma become less influential as wound healing progresses and rehabilitation advances. Second, the fundamental decompression of neural elements achieved by all techniques ultimately addresses the primary pathophysiological mechanism of symptomatic lumbar disc herniation (LDH), regardless of the specific surgical approach. Third, the natural history of disc herniation itself typically involves gradual resorption and remodeling of herniated material, which may contribute to ongoing improvement regardless of the extent of surgical removal.

The complication profile observed in our cohort demonstrated an overall rate of 12.5%, with open discectomy associated with a significantly higher incidence compared to minimally invasive techniques. This finding aligns with previous comparative studies and meta-analyses [7,13], which have generally reported lower complication rates with microdiscectomy and endoscopic approaches. The incidence of specific complications, including dural tears (4.7%) and surgical site infections (2.6%), falls within the ranges reported in the literature [5]. While minimally invasive techniques conferred advantages regarding complication risk, it is essential to acknowledge the potential selection bias inherent in our retrospective design, as patients with more complex presentations or unfavorable anatomical features may have been preferentially directed toward open procedures.

Recurrent disc herniation represented the most common indication for reoperation, affecting 7.3% of patients during the follow-up period. This rate is consistent with previous studies, which report recurrence in 5-15% of cases within the first five years postoperatively [10,16]. No significant differences in recurrence rates were observed between surgical techniques, suggesting that the extent of disc removal, rather than the approach itself, may be the more critical determinant of reherniation risk. The ongoing debate regarding limited versus aggressive disc removal highlights the tension between reducing recurrence risk and preserving disc height and biomechanical function [2,10].

The multivariate analysis of prognostic factors yielded several clinically relevant insights. Younger age and shorter symptom duration emerged as positive predictors of favorable outcomes, consistent with previous studies suggesting that early intervention before chronic pain mechanisms become established may optimize results [1,14]. The association between herniation morphology and outcomes, with extrusions and sequestrations demonstrating better results than protrusions, likely reflects the greater technical ease of removing displaced fragments compared to contained herniations, as well as the potential for spontaneous resorption of extruded material [15].

The negative impact of smoking on surgical outcomes deserves particular attention, as it represents a potentially modifiable risk factor. The detrimental effects of smoking may be mediated through various mechanisms, including impaired tissue healing, microvascular compromise, and accelerated disc degeneration. Our findings reinforce the importance of smoking cessation counseling as an integral component of perioperative management for patients undergoing spine surgery.

The presence of Modic changes emerged as a negative prognostic factor in our analysis. These vertebral endplate signal changes on MRI have been associated with inflammatory processes and biomechanical alterations that may contribute to persistent pain independent of neural compression [15]. The identification of such factors that predict suboptimal outcomes despite technically successful decompression underscores the complex, multifactorial nature of spinal pain syndromes, highlighting the importance of comprehensive preoperative assessment beyond simply confirming radiological compression.

The finding that workers' compensation status predicted poorer outcomes aligns with extensive previous literature documenting less favorable results across numerous spinal procedures in this population [21]. While the mechanisms underlying this association are undoubtedly complex and multifactorial, they likely involve psychosocial factors, secondary gain issues, and different expectations or definitions of recovery. These results emphasize the importance of thorough preoperative counseling regarding realistic expectations for patients with compensation claims.

The predictive model developed from our multivariate analysis demonstrated good discriminative ability and calibration, suggesting potential clinical utility in patient selection and shared decision-making. By incorporating readily available demographic, clinical, and radiological factors, such models may facilitate more personalized risk-benefit discussions and optimize resource allocation. However, prospective validation in independent cohorts would be required before widespread implementation in clinical practice.

Our study's strengths include its relatively large sample size, inclusion of multiple surgical techniques, comprehensive outcome assessment, and substantial follow-up duration. The use of validated patient-reported outcome measures and objective performance indicators provides a multidimensional perspective on surgical effectiveness beyond traditional surgeon-centered metrics. Additionally, the single-center design allowed for standardized surgical protocols and consistent outcome assessment methodology.

However, several limitations warrant acknowledgment. First, the retrospective design introduces potential selection bias, as treatment assignment was not randomized but based on surgeon preference and patient characteristics. We attempted to mitigate this limitation through multivariate analysis, adjusting for known confounders; however, unmeasured variables may still influence outcomes. Second, despite a mean follow-up of nearly three years, more extended observation would be valuable to assess the durability of surgical benefits and capture late recurrences or adjacent segment pathology. Third, our study did not include a non-operative comparison group, limiting our ability to distinguish the natural history of LDH from treatment effects. Fourth, while we collected data on opioid consumption and healthcare utilization, a more granular assessment of these parameters would provide additional insights into the economic impact of different surgical approaches.

The evolution of surgical techniques for LDH continues, with ongoing refinements in minimally invasive approaches, enhanced visualization technology, and perioperative management protocols.

Recent innovations, including biportal endoscopy, navigation-assisted techniques, and targeted annular repair strategies, aim to reduce surgical trauma further while addressing potential mechanisms of recurrence [22]. Concurrently, advances in pain science have expanded our understanding of the transition from acute to chronic pain, emphasizing the importance of early intervention and multimodal analgesia. Future research directions should include prospective comparative studies with longer follow-up, investigation of novel prognostic biomarkers, and development of personalized rehabilitation protocols to optimize functional recovery.

Conclusion

Surgical intervention for lumbar disc herniation provides significant and sustained improvements in pain, function, and quality of life in appropriately selected patients. Minimally invasive techniques, including microdiscectomy and endoscopic discectomy, demonstrate advantages in terms of early recovery parameters and complication profiles compared to open procedures. However, long-term functional outcomes appear comparable across approaches. Patient-specific factors, such as age, symptom duration, smoking status, and radiological characteristics, significantly influence surgical outcomes, underscoring the importance of comprehensive preoperative assessment and individualized treatment planning.

The predictive model developed in this study may assist clinicians in identifying patients most likely to benefit from surgical intervention, facilitating shared decision-making, and optimizing resource allocation. Future research should focus on the prospective validation of these findings, the evaluation of emerging surgical technologies, and the development of personalized perioperative protocols to further enhance outcomes following lumbar disc herniation surgery.

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