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Posted Date: 4 November 2025

doi: 10.20944/preprints202511.0264.v1

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Article

Early Pain Trajectories and Their Predictive Value in Lumbar Disc Herniation Treated with Transforaminal Full-Endoscopic Discectomy

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Abstract

Background: Transforaminal endoscopic lumbar discectomy (TELDD) is a minimally invasive procedure that enables rapid recovery for symptomatic lumbar disc herniations. However, early postoperative pain trajectories and their prognostic value remain insufficiently characterized. **Methods:** A multicenter retrospective cohort study was conducted in 97 patients (104 levels) who underwent TELDD between 2021 - 2024 at 11 spine-specialized centers. Patient-reported outcomes (Visual Analog Scale [VAS] for low back and leg pain; Oswestry Disability Index [ODI]) were collected preoperatively and serially through postoperative day (POD) 180 using a validated mobile platform (SPINEhealthie). A $\geq 30\%$ ODI improvement at final follow-up defined a good outcome. Comparisons were performed using repeated-measures ANOVA and receiver operating characteristic (ROC) analyses. **Results:** Mean age was 54.1 ± 1.5 years; 55.7% were male. Overall, 69.1% of our patients achieved good outcomes. LBP and leg pain improved significantly by POD1 (VAS-LBP: 6.0; 3.8, respectively. $p < 0.001$; VAS-leg: 6.7; 2.9, respectively. $p < 0.001$), while ODI improved gradually through POD90 ($p < 0.001$). Foraminal herniations showed worse outcomes (46.1% good) compared to central/paracentral lesions (84.2%, $p < 0.001$). Early reduction in leg pain correlated with short-term success (AUC=0.717; cutoff -2.75 , sensitivity 70.0%, specificity 68.2%). In foraminal LDH, both leg pain and ODI improvements at POD1 predicted good outcomes (AUC=0.726 and 0.700, respectively). **Conclusions:** TELDD provides rapid relief of pain and functional improvement. Early postoperative reduction in leg pain, particularly within the first 24 hours, is a fair predictor of mid-term recovery. Mobile app-based outcome tracking enables early identification of patients at risk for poor recovery and may inform timely postoperative interventions.

Keywords: transforaminal endoscopic discectomy; lumbar disc herniation; early outcomes; leg pain; Oswestry Disability Index; prognostic factors; remote patient monitoring

1. Introduction

Lumbar disc herniation (LDH) is a common spinal disorder characterized by low back pain (LBP), radiating leg pain, or both and the condition often leads to significant limitations in activities of daily living. [1] When conservative treatment fails to provide sufficient relief, surgical intervention is considered. [2] Although traditional open surgery was once the standard approach, recent advancements in minimally invasive techniques have led to improved patient satisfaction and earlier return to work and daily life. [3–6] Among these, full-endoscopic spine surgery has garnered attention for its ability to be performed under local anesthesia, its minimal invasiveness to surrounding soft tissues, and its rapid postoperative recovery. [7–10] In particular, the transforaminal approach allows access to the herniated disc via the intervertebral foramen, preserving structures such as the lamina and ligamentum flavum, and contributing to the growing practice of 1-day surgeries in the field of orthopedic spine surgery.

Moreover, since the onset of the COVID-19 pandemic, there has been a societal shift toward improved accessibility to healthcare services, including the widespread adoption of remote consultations and mobile applications for postoperative pain assessment and follow-up. [11–16] These tools have enabled more continuous and quantitative monitoring of postoperative recovery from an earlier stage, thereby increasing the importance of evaluating outcomes and predicting prognosis during the acute postoperative period.

However, postoperative trajectories of low back pain, leg pain, and functional recovery after LDH surgery vary substantially among individuals. Prior studies have identified factors such as patient age, herniation morphology, and anesthesia type as potential determinants of outcome. Nevertheless, the relationship between acute postoperative changes in pain and disability and subsequent short-term recovery remains poorly defined, and the specific predictors of suboptimal outcomes, particularly in foraminal herniations, have not been fully elucidated.

In this study, we retrospectively analyzed cases of transforaminal endoscopic lumbar discectomies (TELD) to evaluate the progression of low back and leg pain, and lumbar function from the preoperative period through the acute and early postoperative phases. We aimed to determine the correlation between acute postoperative trends and short-term clinical outcomes, and to identify clinical characteristics associated with poor surgical outcomes.

2. Materials and Methods

2.1. Patient Enrollment and Data Acquisition

This multicenter retrospective study included patients aged 18 years or older who underwent TELD between March 2021 and June 2024 for LDH. Ethical approval was obtained from the Institutional Review Boards of all participating centers. Informed consent was secured from each patient after thorough explanation of the procedure, associated risks and benefits, and the option to withdraw at any time. All surgeries were carried out at 11 surgeons proficient in TELD in multi spine-specialized institutions by. The procedure was defined as uniportal endoscopic discectomy employing an integrated system consisting of a light source, camera, and irrigation. Patient-reported outcome measures (PROMs) were collected both preoperatively and postoperatively using the validated SPINEhealthie mobile application.

2.2. Surgical Indications and Preoperative Management

Patients presented with LBP and radicular symptoms including leg pain, paresthesia, or muscle weakness attributed to nerve root compression by herniated intervertebral discs. In the absence of acute neurologic deficits, patients were required to complete a minimum 3-month course of conservative therapy, which included non-steroidal anti-inflammatory drugs (NSAIDs), oral analgesics, and physical rehabilitation. For cases with ambiguous clinical or imaging findings, selective nerve root blocks were administered for diagnostic clarification. Exclusion criteria included interlaminar endoscopic procedures, and cases where detailed PROMs could not be collected via smartphone application.

2.3. Radiological Assessment and Classification

LDHs were subtyped into 3 groups according to the location of herniated disc by magnetic resonance imaging (MRI) in central disc herniation, paracentral disc herniation, and foraminal disc herniation.

2.4. Surgical Technique

All TELD procedures were performed following established protocols. Patients were positioned either prone under general anesthesia or in the lateral decubitus position under conscious sedation. The trajectory was planned using anteroposterior fluoroscopy at a 15° angle, with a skin entry point 8–10 cm off midline, adjusted to the spinous process projection in lateral view. After an 8-mm skin incision, a Jamshidi needle was advanced to the lateral aspect of the superior articular process (SAP) under fluoroscopic guidance. Serial dilation and trephine use allowed partial resection of the SAP to create the working channel. The ligamentum flavum was dissected from its ventromedial insertion on the SAP to expose the lateral recess. For ventral lesions, the nerve root was gently retracted, and compressive disc fragment were resected with a punch. All patients were discharged on the day of surgery and encouraged to resume daily activities as tolerated.

2.5. Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics version 26.0. Continuous data were expressed as mean ± standard error of the mean (SEM), while categorical variables were presented as frequencies and percentages. Depending on the distribution, comparisons of continuous variables were performed using either the Student’s t-test or the Mann–Whitney U test. Categorical data were compared using the χ^2 test or Fisher’s exact test. Repeated measures were analyzed using one-way ANOVA. A p-value < 0.05 was considered statistically significant. Patients who completed VAS assessments within 14 days and at either 3 or 6 months postoperatively were included in this study. A good outcome was defined as a ≥30% improvement in the Oswestry Disability Index (ODI) from baseline, while cases with <30% improvement were classified as poor outcomes.

3. Results

3.1. Patient Demographics in the Entire Cohort (Table 1)

A total of 97 patients were included in this study. The mean age was 54.1 ± 1.5 years, with 54 male patients (55.7%) and 43 female patients (44.3%). The mean BMI was 31.0 ± 0.8 kg/m². A total of 104 discs were treated, including seven cases (7.2%) involving two intervertebral levels. The most frequently affected level was L4/5 (57 discs, 54.8%), followed by L5/S1 (24 discs, 23.1%) and L3/4 (14 discs, 13.5%). The most common type of herniation was paracentral (51 cases, 52.6%), followed by foraminal (39 cases, 40.2%) and central (6 cases, 6.2%); in one case (1.0%), the herniation could not be classified. No segmental instability was observed. The mean duration of symptoms before surgery was 14.2 ± 1.7 months. There were 27 revision surgeries (27.8%). General anesthesia was used in 61 cases (62.9%), and local anesthesia in 36 cases (37.2%). The average operative time was 73.7 ± 5.4 minutes, and the mean blood loss was 5.5 ± 0.7 ml. No intraoperative complications such as dural tears, postoperative CSF leakage, or nerve root injuries were observed. The average follow-up period was 5.0 ± 1.0 months.

Table 1. Demographic and surgical characteristics of patients who underwent transforaminal endoscopic lumbar discectomy (TELD).

Number of cases	Total	Good outcome	Poor outcome	p-value
	97	67 (69.1 %)	30 (30.1 %)	
Age (years)	54.1 ± 1.5	53.4 ± 1.9	55.5 ± 2.3	0.526

Gender				0.757
Male	54 (55.7 %)	38 (56.7 %)	16 (53.3 %)	
Female	43 (44.3 %)	29 (43.3 %)	14 (46.7 %)	
BMI (kg/m²)	31.0 ± 0.8	30.6 ± 1.0	31.8 ± 1.6	0.510
Level				
L1/2	2 (1.9 %)	2 (2.8 %)	0 (0 %)	1.000
L2/3	7 (6.7 %)	4 (5.6 %)	3 (9.4 %)	0.673
L3/4	14 (13.5 %)	10 (13.9 %)	4 (12.5 %)	1.000
L4/5	57 (54.8 %)	42 (58.3 %)	15 (46.9 %)	0.241
L5/S1	24 (23.1 %)	14 (19.4 %)	10 (31.3 %)	0.189
Total number	104	72	32	
More than 2 levels	7 (7.2 %)	5 (7.5 %)	2 (6.7 %)	1.000
Location of disc herniation				
Central	6 (6.2 %)	5 (7.5 %)	1 (3.3 %)	0.663
Paracentral	51 (52.6 %)	43 (64.1 %)	8 (26.7 %)	0.001
Foraminal	39 (40.2 %)	18 (26.9 %)	21 (70.0 %)	<0.001
Missing	1 (1.0 %)	1 (1.5 %)	0 (0 %)	1.000
Intervertebral Instability	0	0	0	
Duration of symptoms (months)	14.2 ± 1.7	14.3 ± 2.2	13.9 ± 2.3	0.909
Revision surgery	27 (27.8 %)	16 (23.9 %)	11 (36.7 %)	0.194
Anesthesia				0.008
General	61 (62.9 %)	48 (71.6 %)	13 (43.3 %)	
Local	36 (37.2 %)	19 (28.4 %)	17 (56.7 %)	
OP time (min)	73.7 ± 5.4	79.5 ± 6.5	60.8 ± 9.6	0.112
Blood loss (g)	5.5 ± 0.7	6.2 ± 0.9	4.0 ± 0.9	0.146
Perioperative complication	0	0	0	
Duration of follow-up (months)	5.0 ± 0.1	5.0 ± 0.2	4.9 ± 0.3	0.826

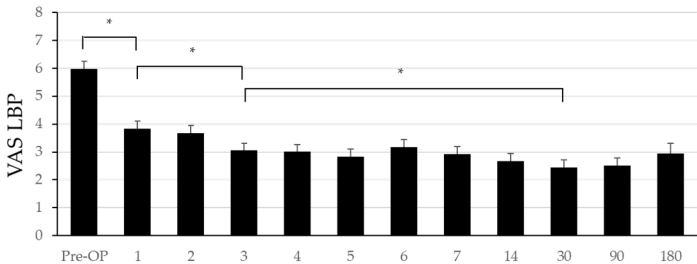
3.2. Postoperative Course in the Entire Cohort (Table 2 and Figure 1)

Preoperative VAS scores for LBP, leg pain, and ODI were 6.0 ± 0.3, 6.7 ± 0.2, and 23.0 ± 1.0, respectively. All significantly decreased by postoperative day 1 (3.8 ± 0.3, p<0.001; 2.9 ± 0.3, p<0.001; 18.7 ± 1.0, p=0.001), and the improvement was maintained until the final follow-up. VAS for LBP continued to improve significantly through postoperative day 3 and day 30 (p=0.004 and p<0.001, respectively) and remained stable thereafter. Leg pain VAS showed a marked improvement on day 1 and remained stable up to day 180, with no significant difference between day 1 and day 180 (p=0.697). ODI showed gradual and significant improvement on days 14, 30, and 90 (p=0.036, p=0.002, p<0.001), with no further significant difference between day 90 and day 180 (p=0.222).

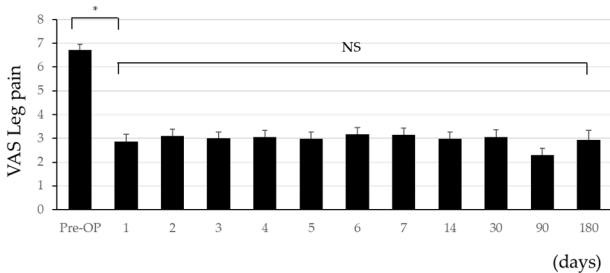
Table 2. Postoperative Course after TELD in the Entire Cohort.

Days post-surgery	Pre-OP	1	2	3	4	5	6	7	14	30	90	180
n	97	97	97	97	97	97	97	97	97	85	96	66

VAS LBP	Mean ± SEM	6.0 ± 0.3	3.8 ± 0.3	3.7 ± 0.3	3.0 ± 0.3	3.0 ± 0.2	2.8 ± 0.3	3.2 ± 0.3	2.9 ± 0.3	2.7 ± 0.3	2.4 ± 0.3	2.5 ± 0.3	2.9 ± 0.4
	p-Value for Pre-OP	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	p-Value for 1 day before			0.509	0.006	0.831	0.256	0.104	0.137	0.137	0.168	0.472	0.103
	n	97	97	97	97	97	97	97	97	97	85	96	66
VAS Leg pain	Mean ± SEM	6.7 ± 0.2	2.9 ± 0.3	3.1 ± 0.3	3.0 ± 0.3	3.0 ± 0.3	3.0 ± 0.3	3.2 ± 0.3	3.2 ± 0.3	3.0 ± 0.3	3.1 ± 0.3	2.3 ± 0.3	2.9 ± 0.4
	p-Value for Pre-OP	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	p-Value for 1 day before			0.284	0.686	0.727	0.644	0.333	0.866	0.291	0.381	0.046	0.033
	n	97	96	96	95	95	96	94	96	96	84	95	63
ODI	Mean ± SEM	23.0 ± 1.0	18.7 ± 1.0	19.6 ± 1.1	18.6 ± 1.0	19.7 ± 1.0	18.9 ± 1.0	18.7 ± 1.0	18.0 ± 1.0	17.0 ± 1.0	14.9 ± 1.1	11.1 ± 1.0	11.3 ± 1.3
	p-Value for Pre-OP	0.001	0.005	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	p-Value for 1 day before			0.225	0.112	0.121	0.081	0.785	0.187	0.077	0.002	<0.001	0.222
	n	97	96	96	95	95	96	94	96	96	84	95	63



(a)



(b)

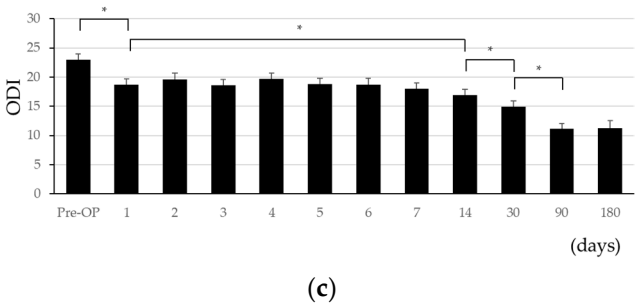


Figure 1. Postoperative Evolution of VAS and ODI Scores After TELD (a) VAS Low Back Pain Over the Operative Course (b) VAS Low Leg Pain Over the Operative Course (c) ODI Scores Over the Operative Course

3.3. Comparison of Patient Demographics Between Good and Poor Outcome Groups (Table 1)

Of the 97 patients, 67 (69.1%) were classified as having a good outcome group (G group), defined as >30% improvement in ODI at final follow-up. No significant differences in age, sex, or BMI were observed between the good and poor outcome (P group) groups (53.4 ± 1.9 vs. 55.5 ± 2.3 years, $p=0.526$; 56.7% vs. 53.3% male, $p=0.757$; 30.6 ± 1.0 vs. 31.8 ± 1.6 kg/m², $p=0.510$). The affected disc level distribution did not differ significantly. However, paracentral LDH were significantly more common in the G group (64.1% vs. 26.7%, $p=0.001$), while foraminal herniations were more frequent in the P group (26.9% vs. 70.0%, $p<0.001$). No significant differences were observed in symptom duration or prior lumbar surgery. General anesthesia was more commonly used in the G group (71.6% vs. 43.3%, $p=0.008$). No differences in operative time, blood loss, or follow-up period were noted.

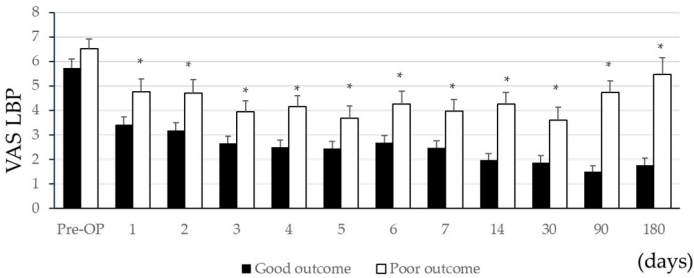
3.4. Comparison of Postoperative Course Between Good and Poor Groups (Table 3 and Figure 2, 3)

No significant differences were observed in preoperative VAS or ODI scores between groups. However, on postoperative day 1, both VAS scores were significantly lower in the G group compared in the P group (back pain: 3.4 ± 0.3 vs. 4.8 ± 0.5 , $p=0.027$; leg pain: 2.2 ± 0.4 vs. 4.3 ± 0.5 , $p=0.001$), with the differences persisting through day 180. ODI differences became significant at day 14 (15.2 ± 1.2 vs. 20.7 ± 1.6 , $p=0.008$). ROC analysis showed AUC values of 0.534 (LBP), 0.717 (leg pain), and 0.605 (ODI), indicating a fair correlation only for leg pain VAS. The cutoff for leg pain VAS was -2.75 (sensitivity 70.0%, specificity 68.2%).

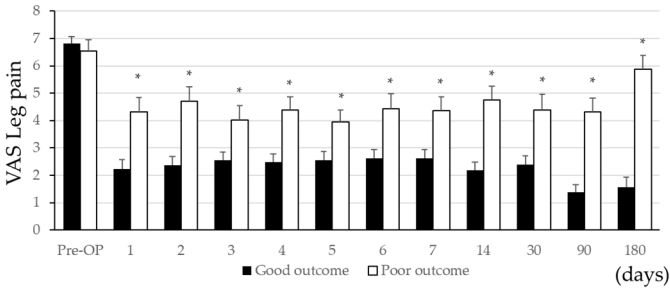
Table 3. Postoperative Course after TELD in Good and Poor outcome groups.

		Days post-surgery	Pre-OP	1	2	3	4	5	6	7	14	30	90	180
VAS LBP	G	n	67	67	67	67	67	67	67	67	67	57	66	45
		Mean ± SEM	5.7 ± 0.4	3.4 ± 0.3	3.2 ± 0.3	2.7 ± 0.3	2.5 ± 0.3	2.5 ± 0.3	2.7 ± 0.3	2.5 ± 0.3	2.0 ± 0.3	1.9 ± 0.3	1.5 ± 0.2	1.8 ± 0.3
		p-Value	0.217	0.027	0.010	0.017	0.002	0.028	0.007	0.007	<0.001	0.002	<0.001	<0.001
	P	n	30	30	30	30	30	30	30	30	30	28	30	21
		Mean ± SEM	6.5 ± 0.4	4.8 ± 0.5	4.7 ± 0.6	3.9 ± 0.5	4.2 ± 0.5	3.7 ± 0.5	4.3 ± 0.5	4.0 ± 0.5	4.3 ± 0.5	3.6 ± 0.5	4.7 ± 0.5	5.5 ± 0.7
		p-Value	0.217	0.027	0.010	0.017	0.002	0.028	0.007	0.007	<0.001	0.002	<0.001	<0.001
			n	67	67	67	67	67	67	67	67	57	66	45
			Mean ± SEM	5.7 ± 0.4	3.4 ± 0.3	3.2 ± 0.3	2.7 ± 0.3	2.5 ± 0.3	2.7 ± 0.3	2.5 ± 0.3	2.0 ± 0.3	1.9 ± 0.3	1.5 ± 0.2	1.8 ± 0.3
			p-Value	0.217	0.027	0.010	0.017	0.002	0.028	0.007	0.007	<0.001	0.002	<0.001
			n	67	67	67	67	67	67	67	67	57	66	45

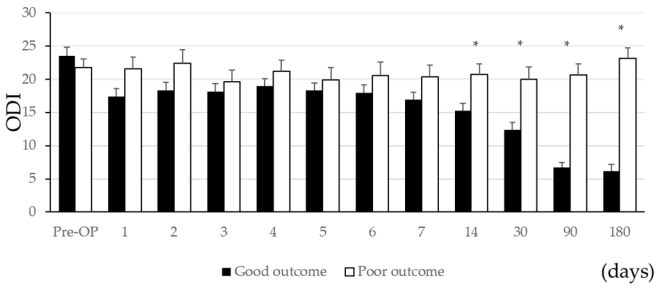
VAS Leg pain	G oo d	Mean ± SEM	6.8± 0.3	2.2 ± 0.4	2.4 ± 0.3	2.6 ± 0.3	2.5 ± 0.3	2.6 ± 0.3	2.6 ± 0.3	2.6 ± 0.3	2.2 ± 0.3	2.4 ± 0.3	1.4 ± 0.3	1.6 ± 0.4
	P oo r	n	30	30	30	30	30	30	30	30	30	28	30	21
		Mean ± SEM	6.5 ± 0.4	4.3 ± 0.5	4.7 ± 0.5	4.0 ± 0.5	4.4 ± 0.5	4.0 ± 0.5	4.4 ± 0.6	4.4 ± 0.5	4.8 ±0.5	4.4 ± 0.6	4.3 ±0.5	5.9 ± 0.5
		p-Value	0.57 9	0.00 1	<0.0 01	0.01 0	0.00 1	0.01 5	0.00 3	0.00 4	<0.0 01	0.00 2	<0.0 01	<0.0 01
ODI	G oo d	n	67	66	66	66	65	66	66	66	66	56	65	44
		Mean ± SEM	23.5 ± 1.3	17.4 ± 1.2	18.3 ± 1.3	18.2 ± 1.2	19.0 ± 1.2	18.4 ± 1.1	17.9 ± 1.2	16.9 ± 1.2	15.2 ± 1.2	12.4 ± 1.1	6.7 ± 0.7	6.2 ± 1.0
	P oo r	n	30	30	30	30	30	30	28	30	30	28	30	19
		Mean ± SEM	21.8 ± 1.3	21.6 ± 1.8	22.4 ± 2.1	19.6 ± 1.9	21.2 ± 1.7	19.9 ± 1.8	20.6 ± 2.0	20.4 ± 1.8	20.7 ± 1.6	20.0 ± 1.9	20.7 ± 1.7	23.2 ± 1.6
		p-Value	0.39 7	0.06 3	0.08 2	0.52 0	0.28 6	0.45 1	0.24 9	0.11 0	0.00 8	<0.0 01	<0.0 01	<0.0 01



(a)



(b)



(c)

Figure 2. (a) Comparison of VAS Low Back Pain Over the Operative Course Between Good and Poor Outcomes (b) Comparison of VAS Low Leg Pain Over the Operative Course Between Good and Poor Outcomes (c) Comparison of ODI Scores Over the Operative Course Between Good and Poor Outcomes

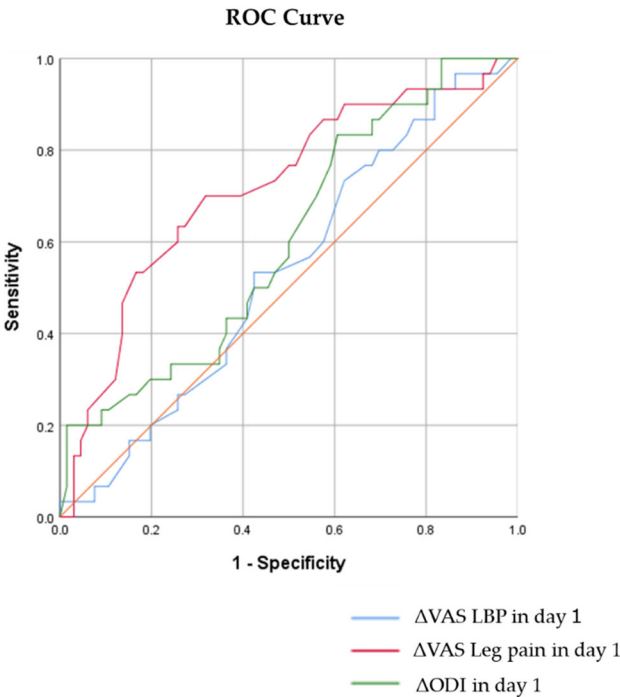


Figure 3. ROC Curves for VAS (LBP & Leg Pain) and ODI on Day 1 After TELD.

3.5. Comparison of Patient Demographics and Postoperative Course by Herniation Location (Table 4, 5 and Figure 4)

Patients were grouped into central/paracentral LDH (CP group, n=57) and foraminal LDH (F group, n=39) based on herniation type. F group patients were older (60.6 ± 1.8 vs. 49.6 ± 2.0 , $p<0.001$) and had lower BMI (28.6 ± 1.1 vs. 32.6 ± 1.2 , $p=0.015$). CP group had more L4/5 herniations (63.3% vs. 42.9%, $p=0.045$), and general anesthesia was more frequently used in CP group (71.9% vs. 51.3%). Other background factors were not significantly different.

VAS and ODI scores preoperatively were not significantly different between CP and F groups. However, LBP VAS at day 90 was significantly lower in CP group (2.1 ± 0.3 vs. 3.2 ± 0.4 , $p=0.037$), though no difference remained at day 180. Leg pain VAS was significantly lower in CP group from day 1 through day 30 but not beyond. ODI did not differ significantly at any time point.

Table 4. Demographic and surgical characteristics of patients between Central/Paracentral LDH and Foraminal Lumbar disc herniation (LDH).

Number of cases	Central/Paracentral (CP) LDH			P-value	Foraminal (F) LDH			P-value	p-value
	Total	Good outcome	Poor outcome		Total	Good outcome	Poor outcome		
	57 (59.4 %)	48 (84.2 %)	9 (15.8 %)		39 (40.6 %)	18 (46.1 %)	21 (53.9 %)		<0.001
Age	49.6 ± 2.0	48.6 ± 2.3	50.3 ± 4.1	0.762	60.6 ± 1.8	63.9 ± 2.0	57.7 ± 2.8	0.081	<0.001
Gender				0.717				0.232	0.979
Male	32 (56.1 %)	26 (54.2 %)	6 (66.7 %)		22 (56.4 %)	12 (66.7 %)	10 (47.6 %)		
Female	25 (43.9 %)	22 (45.8 %)	3 (33.3 %)		17 (43.6 %)	6 (33.3 %)	11 (52.4 %)		
BMI (kg/m²)	32.6 ± 1.2	32.2 ± 1.3	35.0 ± 3.4	0.394	28.6 ± 1.1	26.4 ± 1.1	30.4 ± 1.7	0.069	0.015
Level									
L1/2	2 (3.3 %)	2 (3.9 %)	0 (0 %)	1.000	0 (0 %)	0 (0 %)	0 (0 %)		0.512
L2/3	3 (5.0 %)	2 (3.9 %)	1 (11.1 %)	0.409	4 (9.5 %)	2 (10.5 %)	2 (8.7 %)	1.000	0.437
L3/4	7 (11.7 %)	6 (11.8 %)	1 (11.1 %)	1.000	7 (16.6 %)	4 (21.1 %)	3 (13.0 %)	0.682	0.558
L4/5	38 (63.3 %)	33 (64.7 %)	5 (55.6 %)	0.463	18 (42.9 %)	8 (42.1 %)	10 (43.4 %)	0.843	0.045
L5/S1	10 (16.7 %)	8 (15.7 %)	2 (22.2 %)	0.650	13 (31.0 %)	5 (26.3 %)	8 (34.8 %)	0.496	0.075
Total number	60	51	9		42	19	23		
More than 2 levels	3 (5.2 %)	3 (6.3 %)	0 (0 %)	1.000	3 (7.7 %)	1 (5.6 %)	2 (9.5 %)	1.000	0.684
Intervertebral Instability	0 (0 %)	0 (0 %)	0 (0 %)		0 (0 %)	0 (0 %)	0 (0 %)		
Duration of symptoms	12.7 ± 2.0	13.2 ± 2.3	10.0 ± 2.0	0.307	16.3 ± 3.0	17.2 ± 5.4	15.5 ± 3.2	0.781	0.297
Revision surgery	14 (24.6 %)	12 (25.0 %)	2 (22.2 %)	1.000	13 (33.3 %)	4 (21.0 %)	9 (42.9 %)	0.173	0.348
Anesthesia				0.250				0.075	0.039
General	41 (71.9 %)	36 (75.0 %)	5 (55.6 %)		20 (51.3 %)	12 (66.7 %)	8 (38.1 %)		
Local	16 (28.1 %)	12 (25.0 %)	4 (44.4 %)		19 (48.7 %)	6 (33.3 %)	13 (61.9 %)		
OP time (min)	82.4 ± 7.5	83.0 ± 8.1	84.8 ± 22.0	0.931	61.0 ± 7.3	73.1 ± 10.8	50.6 ± 9.6	0.125	0.053
Blood loss (g)	6.8 ± 1.1	6.8 ± 1.2	7.2 ± 0.9	0.890	3.6 ± 0.6	4.8 ± 1.0	2.6 ± 0.5	0.049	0.026

Perioperative complication	0 (0 %)	0 (0 %)	0 (0 %)		0 (0 %)	0 (0 %)	0 (0 %)		
Duration of follow-up (months)	4.9 ± 0.2	4.8 ± 0.2	5.3 ± 0.4	0.309	5.0 ± 0.2	5.3 ± 0.3	4.7 ± 0.3	0.182	0.774

Table 5. Postoperative Course after TELD in Central/Paracentral LDH and Foraminal LDH.

	Type of LDH	Days post surgery	Pre-OP	1	2	3	4	5	6	7	14	30	90	180
VAS LBP	Central/Paracentral	n	57	57	57	57	57	57	57	57	57	47	56	37
		Mean ± SEM	6.2 ± 0.4	3.7 ± 0.4	3.7 ± 0.3	3.2 ± 0.3	2.8 ± 0.3	2.8 ± 0.3	2.8 ± 0.3	2.8 ± 0.3	2.3 ± 0.3	2.2 ± 0.3	2.1 ± 0.3	2.7 ± 0.5
	Foraminal	n	39	39	39	39	39	39	39	39	39	39	39	28
		Mean ± SEM	5.7 ± 0.5	4.1 ± 0.5	3.7 ± 0.5	2.9 ± 0.4	3.4 ± 0.4	3.0 ± 0.4	3.8 ± 0.5	3.2 ± 0.4	3.3 ± 0.4	2.8 ± 0.4	3.2 ± 0.4	3.4 ± 0.6
		p-Value	0.378	0.450	0.907	0.519	0.232	0.753	0.075	0.442	0.064	0.304	0.037	0.345
VAS Leg pain	Central/Paracentral	n	57	57	57	57	57	57	57	57	57	47	56	37
		Mean ± SEM	6.6 ± 0.3	2.3 ± 0.4	2.6 ± 0.4	2.5 ± 0.3	2.4 ± 0.3	2.6 ± 0.4	2.7 ± 0.3	2.6 ± 0.3	2.2 ± 0.3	2.1 ± 0.3	1.9 ± 0.3	2.5 ± 0.5
	Foraminal	n	39	39	39	39	39	39	39	39	39	39	39	28
		Mean ± SEM	6.9 ± 0.3	3.8 ± 0.5	3.9 ± 0.5	3.9 ± 0.5	4.0 ± 0.5	3.6 ± 0.4	4.0 ± 0.5	4.0 ± 0.5	4.2 ± 0.5	4.2 ± 0.5	3.0 ± 0.5	3.6 ± 0.6
		p-Value	0.393	0.017	0.034	0.015	0.004	0.065	0.037	0.019	0.001	0.001	0.070	0.171
ODI	Central/Paracentral	n	57	56	57	57	57	57	57	57	57	47	56	36
		Mean ± SEM	24.6 ± 1.1	20.4 ± 1.3	21.0 ± 1.3	20.2 ± 1.2	20.6 ± 1.2	20.0 ± 1.1	19.3 ± 1.2	18.1 ± 1.2	16.4 ± 1.2	13.7 ± 1.3	10.2 ± 1.2	10.3 ± 1.5
	Foraminal	n	39	38	38	38	38	38	37	38	38	37	38	26
		Mean ± SEM	21.1 ± 1.7	16.6 ± 1.6	17.9 ± 1.9	16.7 ± 1.7	18.8 ± 1.7	17.6 ± 1.6	18.4 ± 1.9	18.2 ± 1.7	18.2 ± 1.6	16.4 ± 1.7	12.8 ± 1.7	13.0 ± 2.3

p-Value 0.077 0.073 0.159 0.090 0.380 0.225 0.662 0.951 0.371 0.210 0.208 0.301

Table 6. Postoperative Course after TELD in Good and Poor outcome groups in Central/Paracentral LDH.

		Days post surgery	Pre-OP	1	2	3	4	5	6	7	14	30	90	180	
VAS LBP	Good	n	48	48	48	48	48	48	48	48	48	39	47	30	
		Mean ± SEM	6.1 ± 0.4	3.6 ± 0.4	3.6 ± 0.4	3.0 ± 0.4	3.0 ± 0.3	2.6 ± 0.3	2.7 ± 0.3	2.7 ± 0.3	2.7 ± 0.3	2.2 ± 0.3	2.1 ± 0.4	1.5 ± 0.3	2.0 ± 0.4
	Poor	n	9	9	9	9	9	9	9	9	9	9	8	9	7
		Mean ± SEM	6.6 ± 0.8	4.0 ± 0.9	4.2 ± 1.1	4.3 ± 0.9	3.6 ± 0.8	3.1 ± 0.9	3.2 ± 0.9	3.1 ± 0.9	2.6 ± 0.8	2.4 ± 0.8	5.1 ± 1.1	5.5 ± 1.2	
	p-Value	0.657	0.746	0.549	0.140	0.260	0.677	0.619	0.673	0.675	0.736	0.012	0.002		
VAS Leg pain	Good	n	48	48	48	48	48	48	48	48	48	39	47	30	
		Mean ± SEM	6.7 ± 0.3	2.1 ± 0.4	2.3 ± 0.4	2.3 ± 0.3	2.2 ± 0.3	2.5 ± 0.4	2.6 ± 0.4	2.6 ± 0.4	2.1 ± 0.4	2.2 ± 0.4	1.5 ± 0.4	1.8 ± 0.5	
	Poor	n	9	9	9	9	9	9	9	9	9	8	9	7	
		Mean ± SEM	5.8 ± 0.9	3.1 ± 1.0	4.4 ± 1.0	3.3 ± 0.8	3.6 ± 0.8	3.2 ± 0.8	3.4 ± 0.9	3.0 ± 0.8	2.8 ± 0.8	1.9 ± 0.6	4.0 ± 0.8	5.8 ± 1.0	
	p-Value	0.310	0.393	0.032	0.231	0.117	0.467	0.337	0.625	0.418	0.763	0.007	0.001		
ODI	Good	n	48	47	48	48	48	48	48	48	48	39	47	29	
		Mean ± SEM	24.8 ± 1.2	19.9 ± 1.4	20.7 ± 1.4	20.1 ± 1.4	20.5 ± 1.3	20.1 ± 1.3	19.6 ± 1.3	18.1 ± 1.3	16.2 ± 1.3	13.2 ± 1.4	7.4 ± 0.8	6.9 ± 1.1	
	Poor	n	9	9	9	9	9	9	9	9	9	8	9	7	
		Mean ± SEM	23.5 ± 2.1	22.9 ± 3.6	23.0 ± 3.8	20.6 ± 3.4	21.1 ± 2.7	19.4 ± 3.1	17.9 ± 3.2	18.3 ± 3.2	17.3 ± 2.9	16.4 ± 3.8	24.9 ± 2.7	24.1 ± 2.8	
	p-Value	0.672	0.426	0.529	0.891	0.863	0.823	0.618	0.954	0.757	0.371	<0.001	<0.001		

Table 7. Postoperative Course after TELD in Good and Poor outcome groups in Central/Paracentral LDH.

		Days post-surgery	Pre-OP	1	2	3	4	5	6	7	14	30	90	180
VAS LBP	Good	n	18	18	18	18	18	18	18	18	18	18	18	14
		Mean ± SEM	4.8 ± 0.8	3.0 ± 0.6	2.2 ± 0.5	1.9 ± 0.4	2.3 ± 0.4	1.8 ± 0.6	2.7 ± 0.6	1.9 ± 0.5	1.3 ± 0.4	1.3 ± 0.4	1.6 ± 0.5	1.3 ± 0.3
	Poor	n	21	21	21	21	21	21	21	21	21	21	21	14
		Mean ± SEM	6.5 ± 0.5	5.1 ± 0.6	4.9 ± 0.7	3.8 ± 0.6	4.4 ± 0.6	3.9 ± 0.6	4.7 ± 0.7	4.3 ± 0.6	5.0 ± 0.5	4.1 ± 0.7	4.6 ± 0.5	5.5 ± 0.9
	p-Value		0.094	0.022	0.002	0.011	0.007	0.016	0.032	0.004	<0.001	0.001	<0.001	<0.001
VAS Leg pain	Good	n	18	18	18	18	18	18	18	18	18	18	18	14
		Mean ± SEM	7.1 ± 0.5	2.6 ± 0.7	2.7 ± 0.6	3.3 ± 0.6	3.3 ± 0.7	2.9 ± 0.5	2.9 ± 0.7	2.9 ± 0.7	2.5 ± 0.6	2.9 ± 0.6	1.2 ± 0.4	1.3 ± 0.5
	Poor	n	21	21	21	21	21	21	21	21	21	21	21	14
		Mean ± SEM	6.8 ± 0.5	4.9 ± 0.6	4.9 ± 0.6	4.3 ± 0.6	4.7 ± 0.6	4.3 ± 0.6	4.9 ± 0.7	4.9 ± 0.6	5.6 ± 0.6	5.4 ± 0.7	4.5 ± 0.7	5.9 ± 0.6
	p-Value		0.739	0.018	0.021	0.279	0.121	0.079	0.054	0.027	0.001	0.012	<0.001	<0.001
ODI	Good	n	18	17	17	17	17	17	17	17	17	17	17	14
		Mean ± SEM	21.2 ± 3.1	11.5 ± 1.7	12.6 ± 2.1	13.6 ± 2.2	15.8 ± 2.4	14.4 ± 2.2	14.4 ± 2.4	14.4 ± 2.4	13.1 ± 2.4	10.5 ± 1.9	5.2 ± 1.5	4.9 ± 2.0
	Poor	n	21	21	21	21	21	21	20	21	21	20	21	12
		Mean ± SEM	21.0 ± 1.6	21.0 ± 2.2	22.2 ± 2.6	19.2 ± 2.3	21.3 ± 2.2	20.2 ± 2.3	21.9 ± 2.6	21.3 ± 2.3	22.2 ± 1.8	21.4 ± 2.2	18.9 ± 2.0	22.6 ± 2.1
	p-Value		0.961	0.002	0.008	0.094	0.098	0.080	0.045	0.047	0.004	0.001	<0.001	<0.001

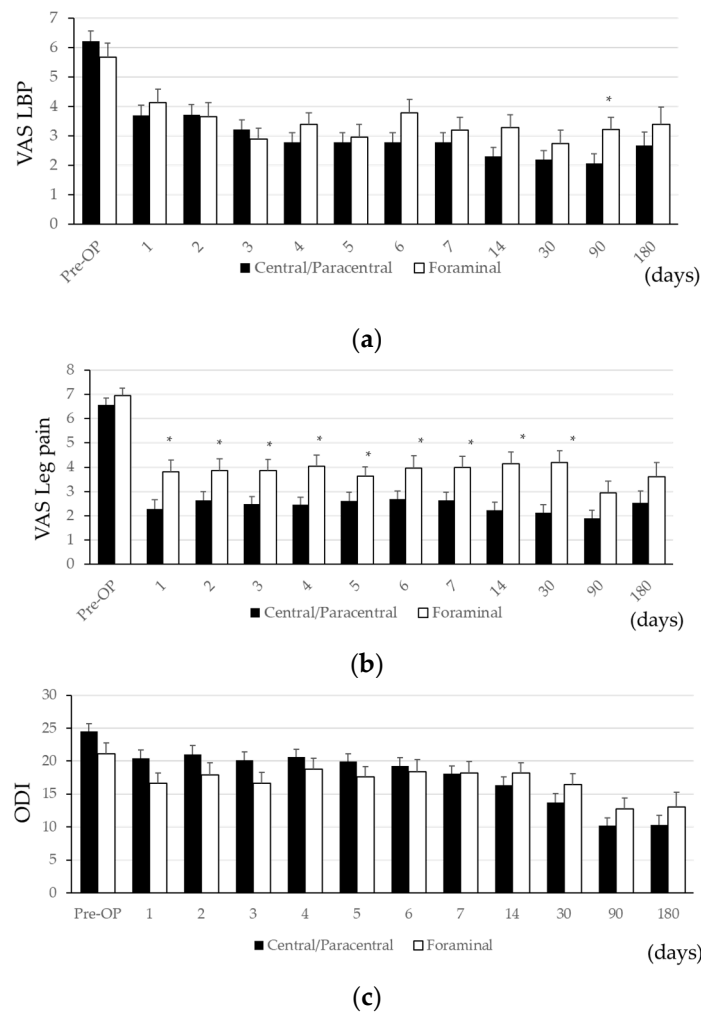
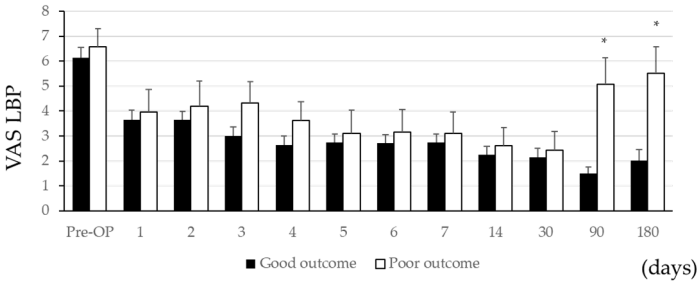


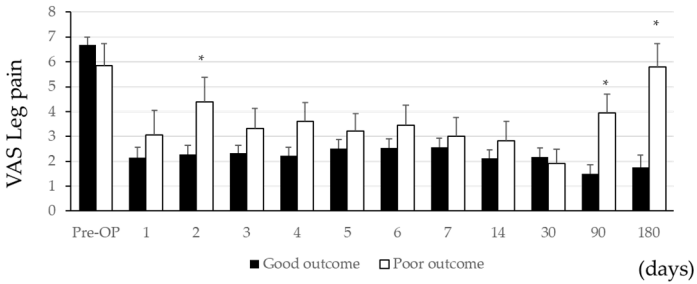
Figure 4. (a) Comparison of VAS Low Back Pain Over the Operative Course Between Central/Paracentral and Foraminal Disc Herniations (b) Comparison of VAS Low Leg Pain Over the Operative Course Between Central/Paracentral and Foraminal Disc Herniations (c) Comparison of ODI Scores Over the Operative Course Between Central/Paracentral and Foraminal Disc Herniations

3.6. Comparison of Patient Demographics and Postoperative Course between Good and Poor Outcomes Groups in Central/Paracentral LDH (Table 4, 6 and Figure 5)

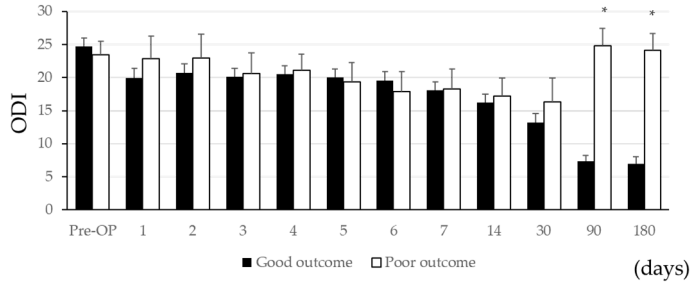
Among the CP group, 48 of 57 patients (84.2%) achieved good outcomes. No significant differences were found in demographics or preoperative scores. LBP VAS did not differ significantly until day 90 and 180, when the G group showed lower scores. Similarly, leg pain VAS differed at day 2 and again from day 90 onward. ODI differences followed the same trend, with significant differences appearing only from day 90 onward, suggesting recurrence of symptoms and possible disc herniation recurrence in the P group.



(a)



(b)



(c)

Figure 5. Of those with central/paracentral LDH: (a) Comparison of VAS Low Back Pain Over the Operative Course Between Good and Poor Outcomes (b) Comparison of VAS Low Leg Pain Over the Operative Course Between Good and Poor Outcomes (c) Comparison of ODI Scores Over the Operative Course Between Good and Poor Outcomes

3.7. Comparison of Patient Demographics and Postoperative Course between Good and Poor Outcomes Groups in Foraminal LDH (Table 4, 7 and Figure 6, 7)

In contrast, only 18 of 39 F group patients (46.1%) had good outcomes, significantly lower than the CP group ($p<0.001$). No significant demographic or preoperative differences were observed. LBP VAS and leg pain VAS were significantly lower in the G group from day 1 onward, with persistent differences through day 180. ODI scores also followed this pattern. ROC analysis showed fair correlation for leg pain VAS (AUC 0.726) and ODI (AUC 0.700), with cutoff values of -3.25 (sensitivity

71.4%, specificity 72.2%) and -5.5 (sensitivity 76.2%, specificity 55.6%), respectively. These findings suggest residual symptoms in poor outcome cases, possibly reflecting surgical failure.

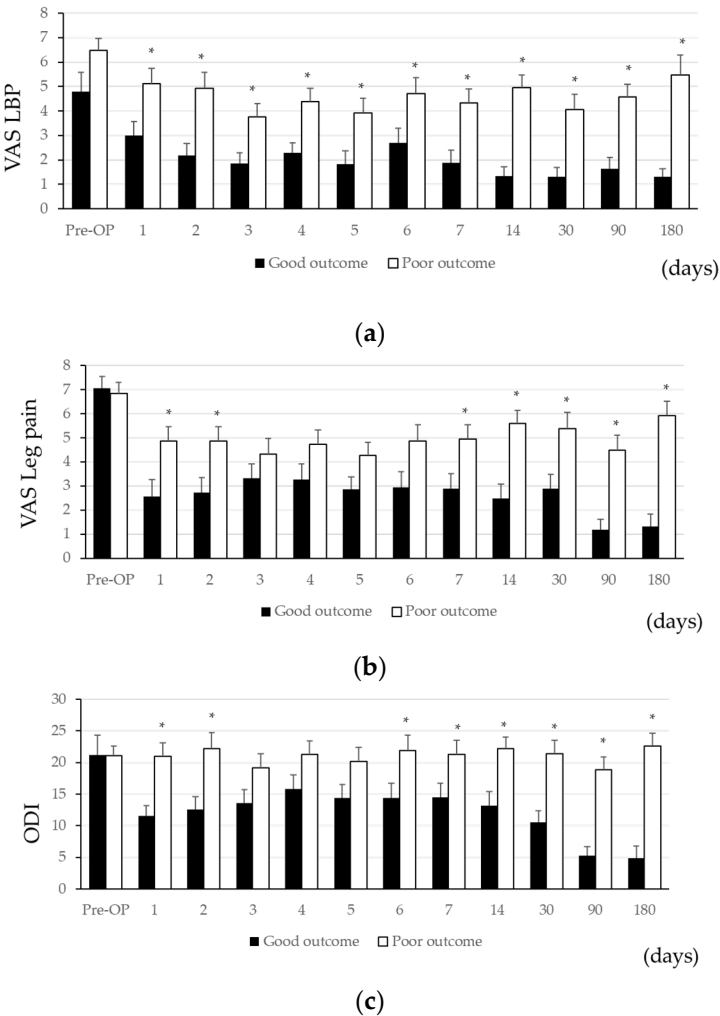


Figure 6. Of those with foraminal LDH: (a) Comparison of VAS Low Back Pain Over the Operative Course Between Good and Poor Outcomes (b) Comparison of VAS Low Leg Pain Over the Operative Course Between Good and Poor Outcomes (c) Comparison of ODI Scores Over the Operative Course Between Good and Poor Outcomes

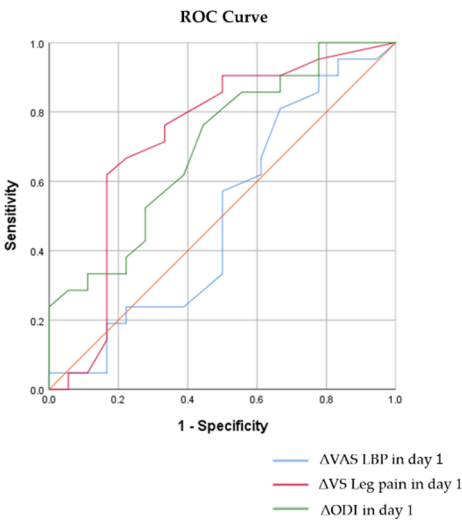


Figure 7. ROC Curves for VAS (LBP & Leg Pain) and ODI on Day 1 After TELD

4. Discussion

In this study, we analyzed short-term clinical outcomes following TELD. LBP VAS scores improved to levels statistically indistinguishable from final follow-up within the first postoperative week, and leg pain VAS improved significantly by postoperative day 1. However, ODI scores showed gradual improvement, reaching significant changes over a 90-day period. Importantly, patients with foraminal LDH demonstrated significantly poorer outcomes compared to those with central or paracentral LDH. Additionally, in foraminal LDH cases, the degree of improvement in leg pain VAS and ODI on postoperative day 1 showed fair correlation with short-term outcomes. The cutoff values for predicting good outcomes were -3.25 for leg pain VAS (sensitivity: 71.4%, specificity: 72.2%) and -5.5 for ODI (sensitivity: 76.2%, specificity: 55.6%).

Previous studies have reported favorable outcomes of minimally invasive surgery (MIS) for central and paracentral LDH using interlaminar or transforaminal approaches. [17] While MIS has also been applied to foraminal LDH with reportedly good results, outcome variability remains. [18–20] Foraminal herniation frequently exerts pressure near the dorsal root ganglion, causing intense preoperative pain. Additionally, due to its location in the narrow, immobile foraminal space and often on the ventrocaudal side of the nerve root, visualizing and completely decompressing the herniation intraoperatively is technically challenging.

Several studies have identified poor prognostic factors including older age, prolonged symptom duration before surgery, smoking, obesity, and psychological stress. [21–23] Anatomically, vertically collapsed foramina due to advanced disc degeneration, multi-level disease, and segmental instability are implicated [24]. In our study, 57 central and paracentral LDH and 39 foraminal LDH cases were analyzed, with 84.2% and 46.1% achieving good short-term outcomes, respectively ($p < 0.001$). Patients with foraminal LDH were significantly older (60.6 ± 1.8 vs. 48.6 ± 2.3 years, $p < 0.001$), indicating a higher baseline risk. Interestingly, BMI was lower in the foraminal LDH cases (28.6 ± 1.1 vs. 32.3 ± 1.3 , $p = 0.015$), suggesting that high BMI did not negatively influence outcomes in this subset.

No cases demonstrated segmental instability, and prior lumbar surgery did not correlate with poor outcomes. While we did not assess disc degeneration or foraminal narrowing, such structural limitations likely constrained decompression effectiveness, particularly in foraminal herniation. The use of local anesthesia was more common in foraminal cases (48.7% vs. 28.1%, $p = 0.075$), and across all 97 cases, poor outcome patients had significantly more frequent local anesthesia than good outcome patients (56.7% vs. 28.4%, $p = 0.039$). Although previous reports suggest comparable efficacy between local and general anesthesia for transforaminal discectomy, some have noted superior short-term outcomes with general anesthesia in older adults, while others suggest long-term disadvantages for procedures performed under local anesthesia.

TELD is associated with minimal invasion of paraspinal muscles, potentially contributing to faster pain relief and functional recovery. Multiple studies have highlighted that short-term outcomes often correlate with long-term prognosis [25,26]. While some patients experience recurrence despite early improvements, and others achieve success through diligent rehabilitation, in general, favorable short-term outcomes predict favorable long-term results.

In our cohort of 97 patients, leg pain VAS reduction on postoperative day 1 showed a fair correlation with 3-to-6-month outcomes. Stratifying by herniation type revealed distinct patterns: central and paracentral LDH cases showed no correlation between postoperative outcomes at acute phase and final results, with poor outcomes attributed to symptom recurrence at 3 to 6 months. In contrast, foraminal LDH patients in the good outcome group demonstrated significantly better scores in all three measures (LBP VAS, leg pain VAS, ODI) from day 1 onward. Both leg pain VAS and ODI improvements showed fair correlations with short-term results.

Previous studies have also suggested correlations between early postoperative improvement and later outcomes [25,27–29]. In our analysis, the cutoff value for leg pain VAS on postoperative day 1 was -3.25 (sensitivity: 71.4%, specificity: 72.2%) and for ODI was -5.5 (sensitivity: 76.2%, specificity: 55.6%), indicating the potential to predict outcomes early. These results suggest that leg pain and lumbar function changes on the first postoperative day may serve as useful early indicators,

particularly for evaluating the need for re-assessment or additional interventions in foraminal LDH cases.

Limitations in our study include not assessing smoking status, psychological factors, or anatomical characteristics such as herniation size, degree of disc degeneration, or spinal alignment. These unmeasured variables may have influenced outcomes. Moreover, postoperative MRI was not analyzed in this study, limiting the ability to differentiate between recurrent herniation and residual fragments in poor outcome cases.

5. Conclusions

Future studies should integrate detailed intraoperative assessments, advanced pre- and postoperative imaging, and quantitative morphological evaluation of disc pathology influencing outcomes. Incorporating procedural details from intraoperative videos and app-based monitoring of postoperative pain trajectories may further enable personalized postoperative management and early identification of patients at risk for suboptimal recovery.

Author Contributions: Conceptualization, K.S. and C.H; methodology, K.S. and C.H; validation, J.O., J.L., M.M., P.D., R.G., S.K., A.T. and O.K.; formal analysis, K.S.; i writing—original draft preparation, K.S. C.P.; data curation – K.S.; writing—review and editing, C.H., J.O., M.M., P.D., R.G., S.K., A.T., A.A., N.T., and O.K.; visualization, K.S.; supervision, C.H.; project administration, C.H.; funding acquisition, C.H.; All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the Raisbeck family foundation.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and individually approved by the Institutional Review Board of each participating university.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets generated and/or analyzed during the current study contain protected health information (PHI) and are therefore not publicly available. Access to these data may be granted upon reasonable request and with appropriate permissions, in accordance with institutional and ethical guidelines.

Acknowledgments: The research team would like to extend thanks to the Endoscopic Spine Research Group (ESRG), of which Peter B. Derman, Christoph P. Hofstetter, Osama N. Kashlan, Sanjay Konakondla, and Albert E. Telfeian, Anubhav Amin, John Ogunlade, Mark Mahan, Meng Huang, Raymond Joseph Gardocki, are members. We also thank Cathryn Payne and Nguyen Tran (University of Washington) for coordination between institutions. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: Christoph Hofstetter is a consultant for Joimax, Globus, and Kuros; and reports teaching for Joimax and AOSpine. John Ogunlade serves as a consultant for Arthrex. Peter Derman is a consultant for Arthrex, Joimax, and received royalties from DeGen Medicaland Accelus. The other authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article

Abbreviations

The following abbreviations are used in this manuscript:

TELD	Transforaminal Endoscopic Lumbar Discectomy
LDH	Lumbar Disc Herniation
LBP	Low Back Pain
VAS	Visual Analogue Scale
ODI	Oswestry Disability Index
POD	Postoperative Day
ROC	Receiver Operating Characteristic
AUC	Area Under the Curve
PROMs	Patient-Reported Outcome Measures

NSAIDs	Non-Steroidal Anti-Inflammatory Drugs
MRI	Magnetic Resonance Imaging
SAP	Superior Articular Process

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