

Research Article

MRI and Histopathology-Based Predictors of Postoperative Functional Recovery in Patients with Lumbar Disc Herniation: A Retrospective Cohort Study

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ABSTRACT

Background: Functional recovery after lumbar microdiscectomy varies despite adequate decompression. Magnetic resonance imaging (MRI) and histopathological characteristics of excised disc tissue may provide complementary prognostic information.

Objective: To identify MRI- and histopathology-based predictors of postoperative functional recovery in patients with lumbar disc herniation.

Methods: This retrospective cohort study included 100 patients undergoing primary lumbar microdiscectomy at District Headquarters Hospital, Nankana Sahib, and Neurosurgery Unit III, Punjab Institute of Neurosciences, Lahore General Hospital, from March 2025 to March 2026. Preoperative MRI assessed disc morphology, Pfirrmann grade, Modic changes, nerve-root compression, canal compromise, and foraminal stenosis. Histopathology evaluated degeneration, inflammation, neovascularization, fibrosis, and cartilaginous endplate fragments. Functional recovery was assessed using the Oswestry Disability Index (ODI) at 6 months. Poor recovery was defined as <30% improvement in ODI.

Results: Successful recovery occurred in 74% of patients. Poor recovery was independently associated with symptom duration ≥ 6 months (aOR 2.74), Modic type 1 changes (aOR 3.12), severe nerve-root compression (aOR 2.89), and substantial cartilaginous endplate involvement (aOR 3.46). Advanced disc degeneration and foraminal stenosis were associated with poor recovery on univariable analysis but lost significance after multivariable adjustment in the final model. The combined clinical-MRI-histopathological model demonstrated the highest predictive accuracy (AUC 0.87; 95% CI 0.79-0.94), with 84.6% sensitivity and 81.1% specificity.

Conclusion: MRI and histopathological features provide complementary prognostic information after lumbar microdiscectomy. Their combined assessment may improve risk stratification and postoperative management.

Keywords: Lumbar Disc Herniation, Magnetic Resonance Imaging, Histopathology, Microdiscectomy, Modic Changes, Oswestry Disability Index, Functional Recovery.

INTRODUCTION

Lumbar disc herniation (LDH) is a prevalent degenerative spinal disease and a significant contributor to low-back pain, radiculopathy, neurologic dysfunction, and functional disability. Most patients are treated conservatively, but surgery—either decompression or microdiscectomy—is often necessary if the radicular pain does not resolve or if there are increasing neurological deficits or significant nerve-root compression. Symptom

relief is usually achieved with surgery, but the functional outcome after surgery is not equal across all patients^{1,2}.

Magnetic resonance imaging (MRI) is the most important imaging technique for assessing LDH and offers a comprehensive assessment of disc morphology, degeneration, neural compression, spinal canal compromise, and vertebral endplate abnormalities³. Different factors like extrusion, sequestration, Pfirrmann degeneration grade, nerve-root compression,

foraminal stenosis, and Modic changes have been studied as possible predictors of the surgical outcome. Nevertheless, the relationship between individual MRI abnormalities and postoperative recovery remains inconsistent, indicating that structural imaging alone may not fully explain differences in clinical outcome^{4,5}.

Histopathology of tissue removed from the disc provides further data on the biological activity and severity of disc degeneration. Herniated tissue may have disrupted matrix, chondrocyte clustering, fibrosis, granulation tissue, neovascularization, infiltration of inflammatory cells, and fragments of cartilaginous endplate⁶. Macrophage-mediated inflammation is involved in the degradation and spontaneous resorption of herniated nucleus pulposus, while extensive involvement of endplate-cartilage may signify more advanced structural damage. Previous studies examining these histological characteristics as predictors of postoperative outcome have reported variable findings^{7,8}.

Combining MRI findings with the histopathology results, it is thus possible to evaluate both the anatomical and biological aspects of postoperative recovery⁸⁻¹⁰. However, relatively limited evidence has evaluated these parameters simultaneously in patients undergoing surgery for LDH. This study was designed to identify MRI- and histopathology-based predictors of postoperative functional recovery in patients with lumbar disc herniation and to determine whether a combined clinical, radiological, and histopathological model improves postoperative outcome prediction.

MATERIALS AND METHODS

Study Design and Setting

This retrospective cohort study was conducted at the Department of Neurosurgery, District Headquarters Hospital, Nankana Sahib, Punjab, Pakistan, and Neurosurgery Unit III, Punjab Institute of Neurosciences, Lahore General Hospital, Lahore, Punjab, Pakistan, from March 2025 to March 2026. Medical records, preoperative magnetic resonance imaging (MRI), operative findings, histopathology reports, and postoperative follow-up data of patients undergoing surgery for lumbar disc herniation were reviewed.

Study Population

One hundred consecutive adult patients who underwent primary lumbar microdiscectomy (PLMD) for symptomatic lumbar disc herniation (LDH) were included. Patients aged 18–70

years old with an MRI diagnosis of single-level lumbar disc herniation who had failed conservative management and had functional assessment available post-surgery were eligible.

Patients who had a history of lumbar spine surgery, multilevel decompression or fusion, spinal tumors, vertebral fractures, spinal infections, congenital spinal abnormalities, inflammatory spinal disorders, incomplete MRI, histopathological, or follow-up records or recurrent disc herniation were excluded.

Clinical Assessment

Demographic and clinical parameters included age, sex, BMI, smoking history, DM, duration of onset of symptoms, affected spinal level, radicular pain, sensory deficit, motor deficit, and straight-leg-raising findings. Pain intensity at baseline was measured using the visual analogue scale (VAS), and functional disability was measured using the Oswestry Disability Index (ODI).

Functional status was assessed at around 6-months following surgery. Successful functional recovery was defined as a reduction of ODI by $\geq 30\%$ from the pre-op value, and $< 30\%$ was considered poor functional recovery.

MRI Evaluation

The sagittal and axial T1- and T2-weighted sequences of the preoperative lumbar MRI examinations were analyzed. MRI features were assessed as the level of affected discs; morphology of herniation; migration of disc; degree of spinal canal compromise; foraminal or lateral recess stenosis; nerve root compression; disc degeneration; and changes of the vertebral end plates.

The herniated disc was classified as either a protrusion, extrusion, or sequestration. Intervertebral disc degeneration was classified according to the Pfirrmann classification, and classification of IV and V was considered to be in advanced degeneration. Vertebral endplate abnormalities were categorised as Modic type 1, Modic type 2, Modic type 3, and absent. The compression of the nerve root was classified as mild, moderate or severe based on the amount of nerve root displacement and deformation. Canal compromises $> 50\%$ were deemed important.

To reduce assessment bias, MRI findings were analyzed independently of postoperative functional outcomes.

Surgical Procedure and Tissue Collection

Standard lumbar microdiscectomy was performed on all patients under general anesthesia. This was confirmed intraoperatively and decompression of the involved nerve root and removal of herniated disc material were performed. Immediately after excision, the tissue was preserved in 10% neutral buffered formalin and sent for histopathological examination.

Histopathological Assessment

Discs were routinely processed, embedded in paraffin, sectioned, and stained with hematoxylin and eosin. Histopathological features were matrix degeneration, chondrocytes in clusters, fissuring, fibrosis, myxoid degeneration, granulation tissue, new blood vessels, presence of inflammatory cells, and cartilaginous endplate fragments.

The overall disc degeneration was classified according to matrix disruption, fibrosis, cellular abnormalities, and structural disorganization as mild, moderate, or severe. The level of inflammatory-cell infiltration was determined by the amount of infiltrated tissue examined. The proportion of cartilage present in the surgically excised specimen was determined and classified as either absent/minimal or substantial.

Outcome Measures

The main outcome was functional recovery after surgery from a percentage change in ODI at 6 months. Postoperative ODI, changes in leg-pain VAS, persistence of neurological symptoms, and differences in functional recovery in relation to MRI and histopathological characteristics were secondary outcomes.

Statistical Analysis

Analysis of data was done through IBM SPSS Statistics version 26.0. Continuous variables were either expressed as mean $\pm$ standard deviation or a median with interquartile range

(IQR) depending on the distribution of the data. The categorical variables were reported as frequencies and percentages.

Independent-samples t test or Mann–Whitney U test was applied to continuous variables, and chi-square or Fisher's exact test was applied to categorical variables. A multivariable logistic regression model was used to assess variables considered to have $p < 0.10$ on univariable analysis along with clinically relevant variables. Adjusted odds ratios (aORs) with 95% confidence intervals (CIs) are presented.

The predictive performance of clinical, MRI and combined MRI-histopathological models was assessed by receiver operating characteristic analysis. The area under the curve (AUC) was calculated with 95% CIs. A two-sided p -value < 0.05 was considered statistically significant.

Ethical Considerations

The study was performed in compliance with the principles of the Declaration of Helsinki and approved by the appropriate institutional ethics committee. Patient information was anonymized prior to analysis, and confidentiality was ensured during the study.

RESULTS

Patient Characteristics

A total of 100 patients with lumbar disc herniation were included, comprising 61 (61.0%) males and 39 (39.0%) females. The mean age was 44.2 ± 11.3 years. L4–L5 was the most commonly affected level in 53 (53.0%) patients, followed by L5–S1 in 42 (42.0%) and L3–L4 in 5 (5.0%). Thirty-five patients (35.0%) presented with symptoms of ≥ 6 months' duration, and 29 patients (29.0%) had a motor deficit preoperatively. Seventy-four patients (74.0%) had successful functional recovery at 6 months, and 26 (26.0%) had poor functional recovery at 6 months. Older age and longer symptom duration were significant factors associated with poor recovery (Table 1).

Table 1. Baseline Characteristics According to Functional Recovery

Variable	Successful recovery (n=74)	Poor recovery (n=26)	p-value
Age, years	42.8 $\pm$ 10.7	48.1 $\pm$ 12.0	0.039
Male	47 (63.5%)	14 (53.8%)	0.386
Female	27 (36.5%)	12 (46.2%)	0.386
BMI, kg/m ²	26.9 $\pm$ 3.7	28.6 $\pm$ 4.2	0.054
Diabetes mellitus	7 (9.5%)	6 (23.1%)	0.071
Smoking	15 (20.3%)	9 (34.6%)	0.139
Symptoms ≥ 6 months	20 (27.0%)	15 (57.7%)	0.005
Preoperative motor deficit	18 (24.3%)	11 (42.3%)	0.082
Preoperative ODI	58.1 $\pm$ 11.8	60.4 $\pm$ 13.0	0.401

Preoperative VAS	7.5 ± 1.4	7.8 ± 1.3	0.337
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Sex distribution, baseline disability, and preoperative pain scores were comparable between the two groups, whereas symptom duration ≥6 months was significantly more frequent among patients with poor recovery (Table 1).

Functional Outcomes

The mean ODI decreased from 58.7 ± 12.1 preoperatively to 24.6 ± 14.8 at 6 months,

while mean leg-pain VAS decreased from 7.6 ± 1.4 to 2.4 ± 1.8. Patients with successful recovery demonstrated significantly lower postoperative ODI and VAS scores. Residual radicular symptoms were present in 10 (38.5%) patients with poor recovery compared with 7 (9.5%) patients with successful recovery (Table 2).

Table 2. Postoperative Functional Outcomes

Outcome	Successful recovery (n=74)	Poor recovery (n=26)	p-value
Preoperative ODI	58.1 ± 11.8	60.4 ± 13.0	0.401
6-month ODI	18.0 ± 8.7	43.5 ± 11.2	<0.001
ODI reduction, %	69.0 ± 12.8	28.0 ± 8.9	<0.001
Preoperative VAS	7.5 ± 1.4	7.8 ± 1.3	0.337
6-month VAS	1.8 ± 1.2	4.1 ± 1.6	<0.001
Residual radicular symptoms	7 (9.5%)	10 (38.5%)	<0.001

Overall, both disability and radicular pain improved substantially following surgery, although improvement was significantly greater among patients classified as having successful functional recovery (Table 2).

MRI Findings

Disc extrusion was observed in 55 patients (55.0%), sequestration in 21 (21.0%), and protrusion in 24 (24.0%). Advanced disc degeneration corresponding to Pfirrmann grades IV–V was present in 63 patients

(63.0%). Modic changes were identified in 38 (38.0%) patients, including type 1 in 16 (16.0%), type 2 in 20 (20.0%), and type 3 in 2 (2.0%).

Modic type 1 changes, advanced Pfirrmann degeneration, severe nerve-root compression, and moderate-to-severe foraminal stenosis occurred more frequently in patients with poor recovery. Severe nerve-root compression was present in 50.0% of poor-recovery patients compared with 21.6% of successful-recovery patients (Table 3).

Table 3. MRI Characteristics According to Functional Recovery

MRI finding	Successful recovery (n=74)	Poor recovery (n=26)	p-value
Pfirrmann grade IV–V	42 (56.8%)	21 (80.8%)	0.030
Modic type 1 change	7 (9.5%)	9 (34.6%)	0.003
Modic type 2 change	14 (18.9%)	6 (23.1%)	0.646
Extrusion/sequestration	58 (78.4%)	18 (69.2%)	0.344
Severe nerve-root compression	16 (21.6%)	13 (50.0%)	0.006
Canal compromise >50%	20 (27.0%)	12 (46.2%)	0.071
Moderate/severe foraminal stenosis	13 (17.6%)	10 (38.5%)	0.029
Disc migration	29 (39.2%)	9 (34.6%)	0.680

Modic type 1 changes showed a particularly strong unadjusted association with poor recovery, occurring in 34.6% versus 9.5% of patients, respectively (Table 3).

Histopathological Findings

Histopathological examination demonstrated moderate-to-severe degenerative changes in 72 patients (72.0%). Granulation tissue was present in 61 (61.0%), moderate-to-marked inflammatory infiltration in 58 (58.0%), neovascularization in 48 (48.0%), and

substantial cartilaginous endplate fragments in 39 (39.0%). Severe disc degeneration and substantial cartilaginous endplate involvement were significantly associated with poor recovery.

Substantial endplate cartilage was present in 69.2% of poor-recovery patients compared with 28.4% of patients with successful recovery (Table 4).

Table 4. Histopathological Characteristics According to Functional Recovery

Histopathological finding	Successful recovery (n=74)	Poor recovery (n=26)	p-value
Severe disc degeneration	20 (27.0%)	13 (50.0%)	0.032
Chondrocyte clustering	35 (47.3%)	15 (57.7%)	0.362
Granulation tissue	47 (63.5%)	14 (53.8%)	0.386
Moderate/marked inflammation	41 (55.4%)	17 (65.4%)	0.376
Neovascularization	37 (50.0%)	11 (42.3%)	0.501
Substantial endplate cartilage	21 (28.4%)	18 (69.2%)	<0.001
Marked fibrosis	17 (23.0%)	11 (42.3%)	0.059

Inflammatory infiltration and neovascularization alone were not significantly associated with outcome, whereas structural endplate involvement demonstrated the strongest histopathological relationship with postoperative recovery (Table 4).

Multivariable Predictors of Poor Functional Recovery

Variables with clinical relevance or significant univariable associations were entered into multivariable logistic regression. After

adjustment, symptom duration ≥ 6 months, Modic type 1 changes, severe nerve-root compression, and substantial cartilaginous endplate involvement remained independently associated with poor recovery.

Substantial endplate-cartilage involvement demonstrated the strongest association (aOR 3.46; 95% CI 1.31–9.15; $p=0.012$), followed by Modic type 1 changes (aOR 3.12; 95% CI 1.06–9.18; $p=0.039$) and severe nerve-root compression (aOR 2.89; 95% CI 1.08–7.75; $p=0.035$) (Table 5).

Table 5. Multivariable Logistic Regression for Poor Functional Recovery

Predictor	Adjusted OR	95% CI	p-value
Age per 10-year increase	1.26	0.91–1.74	0.163
Symptoms ≥ 6 months	2.74	1.08–6.96	0.034
Pfirrmann grade IV–V	1.67	0.60–4.65	0.326
Modic type 1 change	3.12	1.06–9.18	0.039
Severe nerve-root compression	2.89	1.08–7.75	0.035
Moderate/severe foraminal stenosis	1.61	0.59–4.39	0.349
Severe histological degeneration	1.72	0.64–4.65	0.283
Substantial endplate cartilage	3.46	1.31–9.15	0.012

Advanced Pfirrmann degeneration and severe histological degeneration lost statistical significance after adjustment, suggesting that Modic type 1 changes, nerve-root compression, symptom duration, and endplate-cartilage involvement provided stronger independent prognostic information (Table 5).

Predictive Performance

The clinical model incorporating age, symptom duration, diabetes mellitus, and preoperative neurological deficit demonstrated an AUC of 0.72 (95% CI 0.62–0.82). Addition of MRI characteristics increased the AUC to 0.81 (95% CI 0.72–0.89). The combined clinical, MRI, and histopathological model demonstrated the highest discrimination, with an AUC of 0.87 (95% CI 0.79–0.94), sensitivity of 84.6%, and specificity of 81.1% (Table 6).

Table 6. Predictive Performance of Models for Poor Functional Recovery

Prediction model	AUC	95% CI	Sensitivity	Specificity
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Clinical model	0.72	0.62–0.82	69.2%	67.6%
Clinical + MRI model	0.81	0.72–0.89	76.9%	75.7%
Clinical + MRI + histopathology model	0.87	0.79–0.94	84.6%	81.1%

The progressive increase in AUC from the clinical model to the combined model indicated that incorporating MRI and histopathological characteristics improved discrimination of patients at risk of poor postoperative functional recovery (Table 6).

DISCUSSION

This study demonstrated that postoperative functional recovery after lumbar microdiscectomy was influenced by a combination of clinical, MRI, and histopathological factors¹. Around 75% were successfully recovered at 6 months and longer symptom duration, Modic type 1 changes, severe nerve-root compression, and significant cartilaginous endplate involvement were independent predictors of poor functional outcome. The clinical-MRI-histopathological model also discriminated better than the clinical and MRI models alone^{2,3}.

There was an independent association between long duration of symptoms and poor recovery. Chronic nerve-root compression can lead to chronic inflammation, demyelination, microvascular dysfunction, and permanent nerve damage, despite a good surgical decompression, which will limit functional improvement⁴. This discovery suggests that early surgical treatment may be beneficial in properly selected patients with ongoing neurological or radicular symptoms⁵.

Modic type 1 changes were significantly linked to poor functional recovery among the MRI characteristics. These changes are active in the vertebral endplate and surrounding bone marrow and could reflect a more biologically active degenerative process. Continuing endplate-related pain and inflammation could therefore explain why some patients continue to be disabled even if they have a successful removal of the compressive disc fragment⁶⁻⁸.

Uncontrolled compression of the nerve root was also an independent negative predictor of postoperative recovery. More mechanical compression can also result in more extensive neural damage before surgery, and decompression may not fully reverse established axonal or microvascular damage⁹. However, morphology of the disc herniation itself did not significantly differ among the groups, suggesting that the severity of the neural compromise may be more important

than the distinction of the kind of disc herniation, whether protruded, extruded, or sequestered¹⁰.

Histopathological evaluation also gave supplemental prognostic information. The greatest independent association with poor recovery was poor involvement of substantial cartilaginous endplate involvement. The endplate cartilage in the excised sample may signal that the disruption of the disc-endplate complex is more extensive and the structural degenerative process is more advanced^{11,12}.

Functional outcome was not significantly related to inflammatory-cell infiltration or neovascularization. This may be due to the complex biological role of inflammation in herniated disc tissue¹³. Inflammatory activity may be the source of radicular pain, and macrophage-mediated tissue degradation may also help to remove and resorb herniated material. The results of this study indicate that the inflammatory alterations should be considered in combination with the structural and radiological features and not as stand-alone factors¹⁴.

Combination of clinical, MRI, and histopathological models demonstrated an AUC of 0.87, which was higher than clinical assessment alone and clinical-MRI model¹⁵. This means that, in addition to routine imaging, the histopathological characteristics give extra prognostic information. This holistic strategy could lead to better preoperative counselling, post-operative monitoring and identification of those patients who need more intensive rehab¹⁶.

Several limitations should be considered. Retrospective study design can lead to selection and information bias and the sample size was relatively small. Histopathological evaluation was limited to the tissue that was resected and may not have been a complete section of the intervertebral disc or endplate complex¹⁷. Functional recovery was evaluated at 6 months, and longer follow-up might reveal other differences in outcome. The psychosocial factors, the occupational demands, the adherence to rehabilitation, and the imaging findings after surgery were also not evaluated in a detailed manner. These findings need to be confirmed in larger prospective, multicenter studies¹⁸⁻²⁰.

CONCLUSION

The MRI and the histopathological features were found to be associated with postoperative functional recovery after surgery for lumbar disc herniation. Symptom duration ≥ 6 months, Modic type 1 changes, severe nerve-root compression, and substantial cartilaginous endplate involvement independently predicted poorer functional recovery. The combined clinical, MRI, and histopathological model had better predictive performance than clinical assessment or imaging assessment alone. Combining MRI with pathological analysis might be useful for better prognostic stratification and post-surgical management of patients undergoing lumbar microdiscectomy.

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Data Availability: Data are available from the corresponding author upon reasonable request.

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