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Postoperative MRI Findings Following PELD and Their Correlations with Clinical Prognosis are Investigated by Injecting Contrast into Annulus Fibrosus Intraoperatively

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Objective: To validate whether a residual mass demonstrated on early postoperative MR after percutaneous endoscopic lumbar discectomy (PELD) is indeed an intraoperatively retained annulus fibrosus, and explore the correlation between imaging changes in the residual mass and clinical prognosis of patients.

Methods: A prospective study of 118 patients were included. During surgery, a contrast medium, Gadopentetate Dimeglumine, was injected around the ruptured annulus fibrosus. The intensity of the T2 signal, the size of the remaining mass (SR), and the cross-sectional area of the spinal canal (SCSA), VAS, and ODI were assessed at preoperative, 1-h (7-day), 6-month, and 12-month postoperative intervals. Based on VAS at 7 days post-surgery, patients were classified into either a non-remission group (Group A, VAS > 3) or a remission group (Group B, VAS ≤ 3).

Results: Six patients who developed recurrent LDH were excluded. A residual mass was detected on MRI 1 h after surgery in 94.6% (106/112). During one year of follow-up, 90.1% (101/112) of the patients displayed fibrous annulus remodeling, although 68.7% (77/112) still exhibited herniation. Significant differences were found in the ODI between Groups A and B one week after surgery ($p < 0.001$). However, no significant differences were observed in T2 signal intensity, SR, and SCSA at 1-h, 6-month and 12-month post-surgery ($p > 0.05$) between the two groups. In a multiple linear regression analysis, early postoperative ODI changes were associated with T2 signal (B = −10.22, sig < 0.05), long-term changes were associated with alterations in SR (B = 5.63, sig < 0.05) and SCSA (B = −0.13, sig < 0.05).

Conclusion: The residual mass observed in early postoperative MR images after PELD was the retained annulus fibrosus intraoperatively. Short-term changes in clinical symptoms after PELD were linked to T2 signal intensity, while long-term changes were associated with changes in SR and SCSA.

Keywords: spinal endoscopy, residual mass, remodeling of fibrous annulus, contrast medium

Introduction

Lumbar disc herniation (LDH) is a prevalent degenerative disease of the spine that frequently occurs in older individuals and those engaged in heavy manual labor.[1] This condition is generally caused by degeneration of the lumbar disc or a tear in the annulus fibrosus, which allows the nucleus pulposus to protrude and exert pressure on the dural sac or nerve roots, resulting in clinical symptoms such as lower back pain and sciatica.[2] The frequency of cases of lumbar disc herniation is on the rise, and patients who have not experienced symptom relief after three months of nonsurgical interventions such as physical therapy and medication typically require surgical treatment.[3] Since Kambin et al[4] proposed and first used percutaneous spinal endoscopic lumbar discectomy (PELD) in 1973, this procedure has become increasingly advanced

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for treating LDH. The operator removes the hypertrophic ligamentum flavum and the protruding nucleus pulposus using miniature surgical instruments under direct endoscopic guidance, effectively alleviating pressure on the dural sac or nerve roots. The ruptured annulus fibrosus is preserved and repaired. Compared to traditional open lumbar discectomy and lumbar microdiscectomy, PELD offers benefits such as reduced tissue trauma, shorter hospital stays, and a lower infection rate.[3,5]

The utility of early post-surgical spinal MRI has proven to be limited, showing a poor correlation with the clinical outcomes of patients.[6,7] Studies have indicated that nearly 90% of patients depict a residual mass and ipsilateral nerve root compression on immediate postoperative MRI scans following PELD. These imaging reports often describe phenomena such as "in a spinal protrusion", "T2 high or intermediate signal", "T1 intermediate signal", and "mixed signal shadows", which are considered to reflect epidural soft tissue edema and changes in spinal canal anatomy, such as residual annulus fibrosus or epidural hematoma.[7,8] Postoperative imaging findings may be misinterpreted by some patients who do not experience symptomatic relief after PELD, assuming that the intraoperative retained annulus fibrosus was a protrusion that had not been completely removed during the initial procedure. Consequently, they may opt for additional, unnecessary surgeries, increasing the medical burden.[9,10]

Consequently, we used PELD as a treatment for LDH. We monitored the alterations in the residual mass within the spinal canal and evaluated its correlation with clinical outcomes. This was achieved by injecting a gadolinium-based contrast medium into the annulus fibrosus left in place during surgery. We then conducted MRI scans of the lumbar spine within 1 h post-surgery and compared these results with lumbar MRI scans taken at 6 and 12 months postoperatively.

Data and Methods

General Information

In the cohort of patients with lumbar disc herniation at the Department of Spine Surgery at our hospital between January 2021 and June 2022, 118 individuals met the predefined inclusion criteria and were subsequently enrolled in the study. This study was approved by the Biomedical Research Ethics Review Committee of our hospital. Inclusion criteria included the following: (1) low back pain with sciatica, (2) preoperative lumbar MRI can clearly display the site of single-segment disc herniation, (3) after three months of strict conservative treatment (medication, and physical therapy), (4) receive PELD surgery, (5) signed informed consent. The exclusion criteria were as follows: (1) with lumbar spinal stenosis, (2) asymptomatic LDH, (3) extremely lateral LDH, (4) active infection, (5) lumbar spondylolisthesis, (6) trauma; and (7) renal hypofunction.[11] Clinical and imaging data were collected from all patients, such as age, gender, disease duration, surgical segment, surgical complications, laboratory values of renal function (BUN and Scr) before and within 24–48h after surgery, and MRI images of the lumbar spine (preoperatively, 1 h, 6 months, and 12 months postoperatively). The clinical indices (VAS and ODI) were assessed and recorded before the operation and at 1 week, 6 months, and 12 months postoperatively, and the clinical efficacy was assessed using the modified MacNab at the final follow-up. The patients were classified into a non-remission group (Group A, VAS > 3) and a remission group (Group B, VAS > 3) based on their VAS scores seven days postoperatively.

Qualitative and quantitative analyses of each patient's MRI images were performed by two spine surgeons, such as T2 signal intensity and the size of the residual mass, and the cross-sectional area of the spinal canal. The predominant signal intensity of the residual mass on the T2-weighted image was compared with that of the paraspinal muscular tissue in the same image, if the signal intensity was higher than, equal to, or lower than the latter, the signal was rated as high, medium, or low, respectively (Figure 1A–C). The size of the residual mass (SR) was measured by drawing a line at the base of the disc at the protrusion, then drawing a vertical line from the first line to the most prominent point and measuring this distance (Figure 1D). Spinal canal cross-sectional area (SCSA): Spinal canal boundary measurements were performed in the plane of the residual mass, anteriorly by the posterior edge of the residual mass, posteriorly by the anterior edge of the ligamentum flavum, and bilaterally by the inner edge of the pedicle root, if the image of the spinal canal demonstrated opening at the sides, bilaterally by the outer edges of nerve roots (Figure 1D).

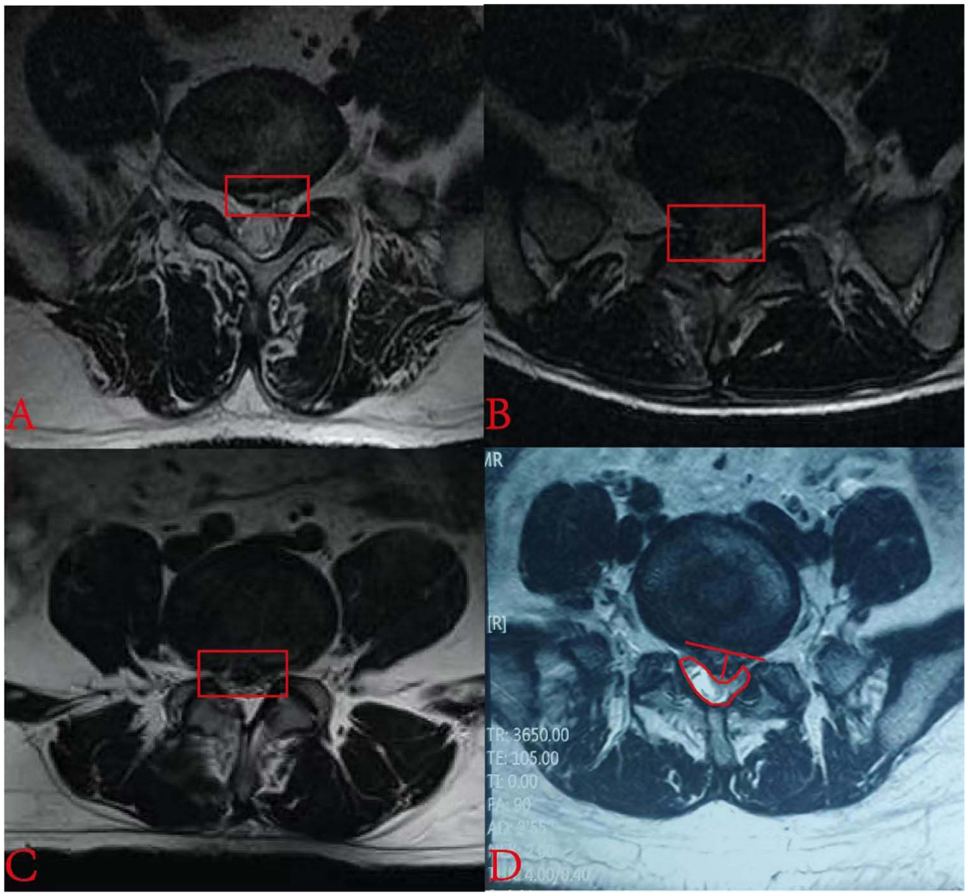

Figure 1 Imaging measurements. (**A**–**C**) High, medium, and low signals on the T2 weighted image (compared with the tissue of the paraspinal muscle in the same image) and the residual mass in the red box. (**D**) The vertical line depicts the size of the residual mass (SR), and the red circle is the cross-sectional area of the spinal canal (SCSA).

Surgery Procedure

The gadopentetate dimeglumine contrast solution (0.02 g/mL) was prepared by taking 1 mL of gadopentetate dimeglumine contrast medium (Magnevist; specification: 15 mL: 7.035 g) and 20 mL of sterile saline, mixing them uniformly, and placing them on the intraoperative sterile table for backup.

In this study, the patient was positioned prone, and the surgical site was subsequently exposed, sterilized, and draped in accordance with the standard surgical protocols. Local anesthesia was administered via injection of 0.5% lidocaine at the segment targeted for surgery. Under fluoroscopic guidance from a C-arm device, a guide needle was precisely inserted at the inferior margin of the lamina space and medial of the inferior articular process on the side of the herniated disc to the ligamentum flavum of the corresponding segment. An incision measuring approximately 0.8 cm was made on the skin. After confirming the appropriate depth and spacing via fluoroscopy, dilating, and working cannulas were inserted through the guide needle, followed by placing a spinal endoscope (Figure 2A). Subsequently, portions of the ligamentum flavum and extradural adipose tissue that obstructed the visual field were excised. Surgical instruments were carefully introduced into the vertebral canal, revealing the dural sac and nerve roots, which were gently displaced to the contralateral side for protection. Endoscopic surgical tools were then employed to excise the pathological nucleus pulposus, thereby fully decompressing the affected nerve root (Figure 2B and C). Once satisfactory pulsation of the nerve root was observed, bipolar radiofrequency ablation was performed to achieve hemostasis. Concurrently, potential nerve endings on the posterior annulus fibrosus surface were ablated using the same modality.

Under direct endoscopic surveillance, the working cannula was rotated in situ, the dural sac and nerve root were placed outside the cannula for protection, and the cannula was gently pressed down to adequately display annulus fibrosus breach and its periphery, when a long microscopic puncture needle pierced the periphery of the ruptured annulus

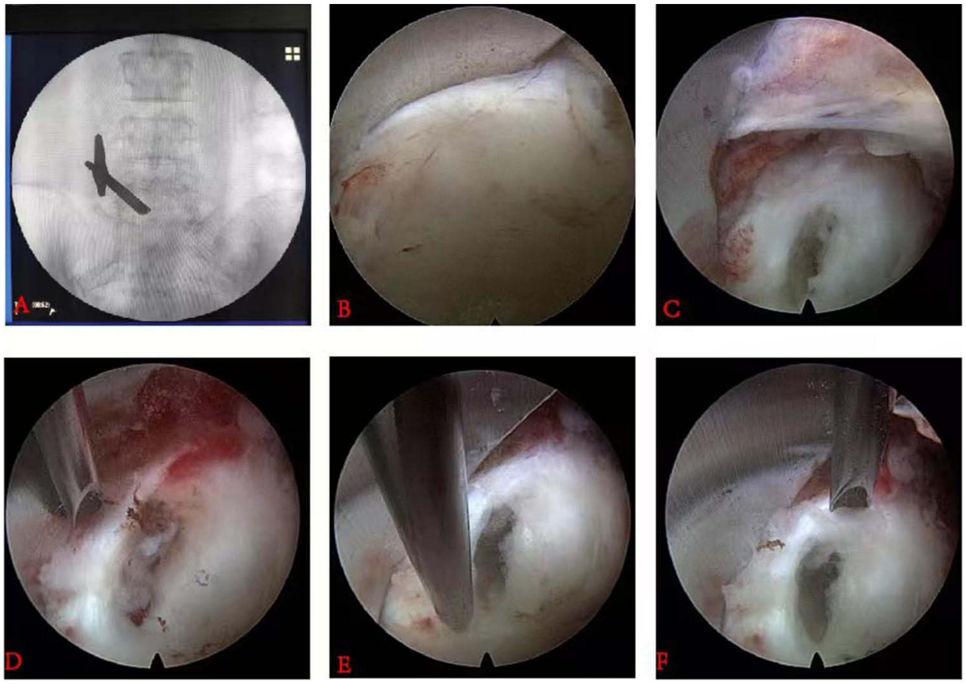

Figure 2 Surgical Procedure. (**A**) The intraoperative positioning of the spinal endoscopic working cannula; (**B**) The protruding annulus fibrosus; (**C**) The complete removal of the nucleus pulposus and the state of decompression of nerve root; (**D**–**F**) Contrast-medium, gadopentetate dimeglumine, is injected into the periphery of annulus fibrosus rupture through a long, microscopic puncture needle.

fibrosus. A slight resistance was felt, the gadopentetate dimeglumine contrast solution was slowly pushed in, and the endoscopic display saw liquid outflow from the injection site, and the injection was stopped in time. The above maneuver was repeated, 3–5 mL of gadopentetate dextran contrast solution was administered into the annulus fibrosus periphery uniformly (Figure 2D–F). After continuous rinsing with sterile saline for 5–7 min, the working cannula was subsequently removed, and the surgical incision was closed with a single suture, followed by the insertion of a drainage tube.

Within 1h after surgery, the patient underwent lumbar MRI scan to show the distribution of gadolinium in the annulus fibrosus, compared with the preoperative MR (Figures 3 and 4).

Data Analysis

Data were statistically analyzed using SPSS statistical software (IBMSPSS 25.0, Chicago, USA). Measurement data were reported as the mean ± standard deviation. Counting data were reported as frequency number (%). Measurement information was tested using a paired *t*-test, an independent sample *t*-test, and repeated ANOVA. The Kruskal–Wallis *H*-test was used to test the counting data. The Pearson test was used for the correlation of parametric data. The Spearman test was used for correlation of non-parametric data. Multiple linear regression was utilized to analyze the correlation between short- and long-term postoperative changes in clinical indicators (ODI) and changes in imaging parameters (T2 signal intensity, SR, and SCSA). Statistical significance was set at $P < 0.05$.

Results

The study cohort consisted of 118 patients, including 50 females and 68 males, with a mean age of 52 years (range 27–77 years). Six patients who developed recurrent lumbar disc herniation at the 1-year postoperative follow-up and were excluded from the study. No significant abnormalities in BUN and Scr levels were observed in all patients before and after surgery (Table 1). MRI scans taken 1 h postoperatively revealed a residual mass in 94.6% (106/112) of the cases. The patients were classified into a non-remission group (Group A, 31 patients, 27.7%) and a remission group (Group B, 81 patients, 72.3%) based on their VAS scores at seven days postoperatively. There were no statistical differences between the two groups in terms of age, gender, disease duration, and surgical segments (Table 2). In both groups, no

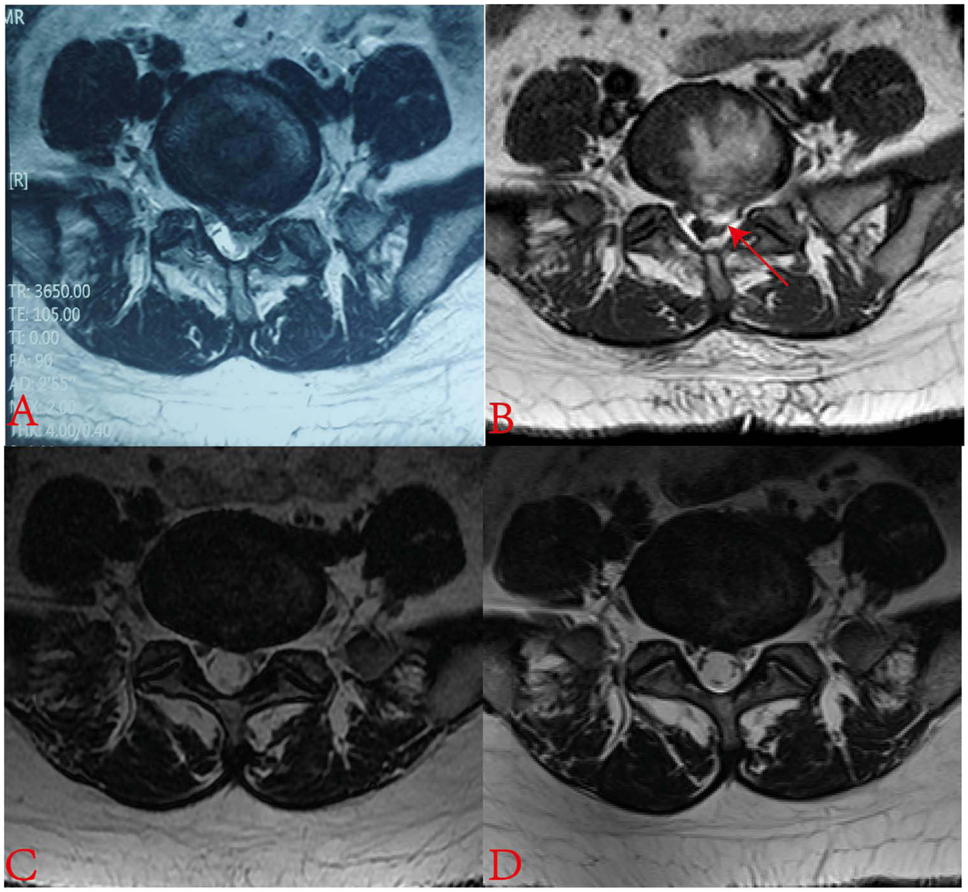

Figure 3 Preoperative, 1 h, 6-month, and 12-month postoperative MRI scans of patient 1. (**A**) Preoperative T2 weight scan depicts a central disc herniation in L5-S1. (**B**) The postoperative T1 weight scan with the red arrow pointing to the annulus fibrosus rupture. (**C** and **D**) Postoperative T2 weight scans at 6 and 12 months, respectively, display that the annulus fibrosus has occurred in the operated segment, but the annulus fibrosus remains protruded.

intraoperative adverse events were observed, including nerve damage or cerebrospinal fluid leakage. The patients in both groups displayed significant improvements in VAS, ODI, SR, and SCSA at 12 months after surgery compared with the preoperative period, and the difference was statistically significant ($p < 0.001$, Table 3, Figure 5A–D). There was a significant difference between patients in groups A and B regarding ODI at one week postoperatively, and the difference was statistically significant ($p < 0.001$, Table 3, Figure 5A and B). However, no statistical difference existed between the two groups in terms of SR and SCSA at 1 h postoperatively and in terms of VAS, ODI, SR, and SCSA at 6 and 12 months postoperatively ($p > 0.05$, Table 3, Figure 5A–D). There were no statistically significant differences between the T2 signal intensity of the residual mass in the two groups at 1 h, 6 months, and 12 months postoperatively ($p > 0.05$, Table 4). In the correlation analysis between clinical indicators and imaging parameters, a short change in ODI was correlated with the T2 signal of the residual mass, and a long change in ODI was linked to the T2 signal of the residual mass, changes in SR, and changes in SCSA (Table 5). In a multiple linear regression analysis with changes in ODI changes (one week postoperatively and one year after surgery) as a dependent variable, early postoperative ODI changes were associated with the T2 signal of the residual mass (B = –10.22, sig < 0.05), and long-term postoperative ODI changes were connected to changes in SR (B = 5.63, sig < 0.05, Table 6) and SCSA (B = –0.13, sig < 0.05, Table 7). About 83.0% (93/112) of the patients demonstrated excellent clinical outcomes, with an excellent rate of 80.6% (25/31) in Group A and 83.9% (68/81) in Group B. Furthermore, 90.1% (101/112) of the cohort exhibited fibrous annulus remodeling, although 68.7% (77/112) continued to exhibit herniation of the fibrous annulus (23 patients in Group A and 54 patients in Group B) (Figures 3A, C, D, 4A, C, and D).

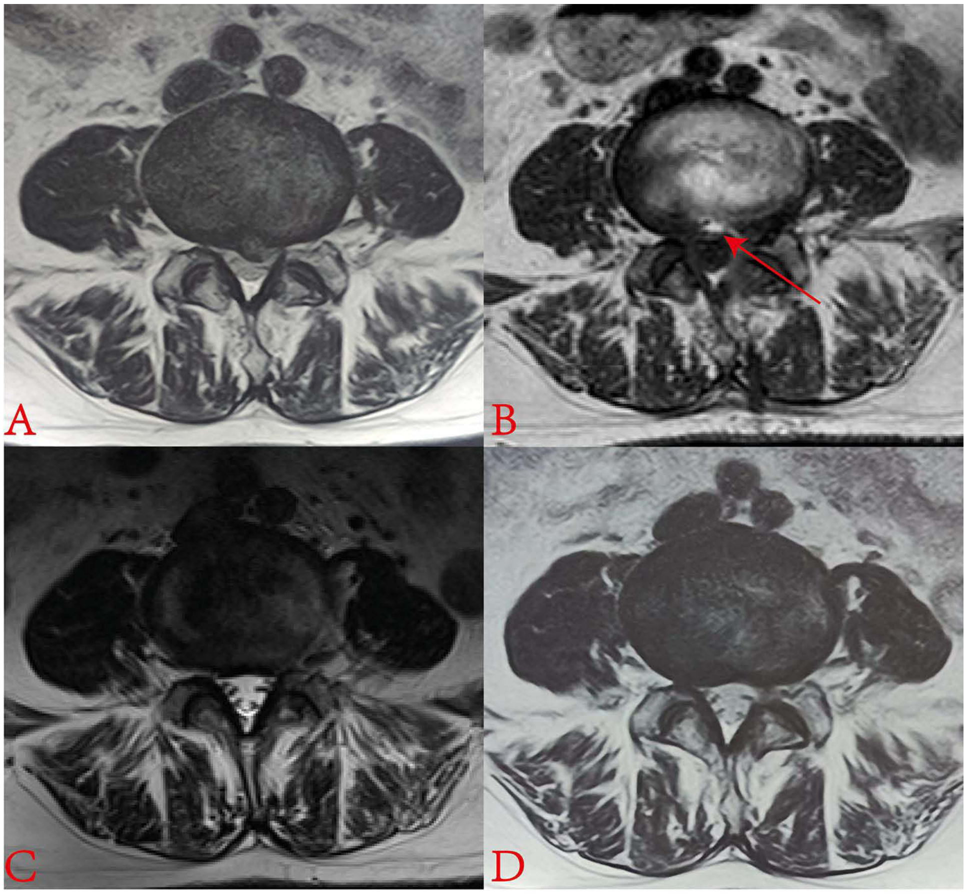

Figure 4 Preoperative, 1 h, 6-month, and 12-month postoperative MRI scans of patient 2. (**A**) Preoperative T2 weight scan displays a paramedian disc herniation in L4-L5. (**B**) The postoperative T1 weight scan with the red arrow pointing to the annulus fibrosus rupture. (**C** and **D**) Postoperative T2 weight scans at 6 months and 12 months, respectively, show that the remodeling of annulus fibrosus has occurred in the operated segment.

Discussion

This study aimed to illustrate that "the residual mass in the operated segment shown on early MRI after PELD is indeed the intraoperatively retained annulus fibrosus". Due to the inherent complexities and steep learning curve associated with PELD,[12] spinal surgeons with limited experience can use the findings of this study to pre-emptively inform patients about postoperative MRI results and possible symptoms, such as lower limb numbness, acidic swelling, and aching.[10] This proactive communication can alleviate patient anxiety concerning disease recurrence and minimize the likelihood of unwarranted reoperations.

PELD is a common minimally invasive technique for LDH treatment. Compared to open lumbar discectomy with fusion internal fixation or lumbar microdiscectomy, PELD offers distinct advantages. It circumvents extensive trauma, significant

Table 1 Comparison of Laboratory Values of Renal Function (BUN, Scr) in All Patients Preoperatively and 24–48 h Postoperatively

Time	Number	BUN (mmol/L)	Scr (μmol/L)
Pre-surgical	118	5.73±2.41	82.32±36.38
Post-surgical	118	5.76±2.36	81.98±34.56
T value		−0.11	0.08
P value		0.90	0.93

Note: p<0.05 indicates statistical significance.

Table 2 Clinical Data of Groups A and B (Age, Gender, Disease Duration, and Surgical Segment)

		Group A	Group B	T value	P value
Age (years, mean±SD)		51.2±13.6	50.6±15.1	0.20	0.83
Gender	Male	19	45	/	0.58
	Female	12	36		
Disease duration (months)		11 (0.4–36)	12 (0.2–48)	/	0.13
Surgical level	L1-L2	1	3	/	0.93
	L2-L3	2	6		
	L3-L4	6	11		
	L4-L5	10	33		
	L5-S1	12	28		

Table 3 Clinical Parameters VAS and ODI and Imaging Parameters SR and SCSA in Groups A and B at Preoperative and 1 h, 6 Months, 12 Months Postoperative

		Group A	Group B	T value	P value
VAS	Preop	5.8±1.5	6.2±1.4	−1.21	0.23
	Postop 7 d	4.8±0.8	1.5±0.5	25.40	<0.001
	Postop 6 m	0.6±0.7	0.5±0.6	0.83	0.41
	Postop 12 m	0.4±0.6	0.4±0.5	0.22	0.82
	F value	293.1	2293.9		
	P value	<0.001	<0.001		
ODI (%)	Preop	67.0±15.3	63.9±15.2	1.11	0.27
	Postop 7 d	17.8±10.7	10.2±2.9	5.78	<0.001
	Postop 6 m	8.0±2.3	8.1±2.3	−0.22	0.82
	Postop 12 m	6.5±2.9	6.4±3.3	0.10	0.92
	F value	310.9	1750.2		
	P value	<0.001	<0.001		
SR (mm)	Preop	5.2±1.2	5.2±1.7	−0.21	0.83
	Postop 1h	5.5±1.1	5.4±1.7	0.93	0.92
	Postop 6 m	2.3±0.7	2.2±0.3	1.85	0.07
	Postop 12 m	1.2±0.4	1.1±0.3	1.22	0.22
	F value	221.9	432.6		
	P value	<0.001	<0.001		
SCSA (mm2)	Preop	118.4±23.1	123.3±24.4	−0.98	0.32
	Postop 1 h	109.9±22.0	115.9±26.5	−1.11	0.27
	Postop 6 m	159.7±23.1	169.3±25.9	−1.80	0.07
	Postop 12 m	178.2±21.1	179.5±23.7	−0.26	0.79
	F value	225.5	494.6		
	P value	<0.001	<0.001		

Note: $p < 0.05$ is statistically significant.

blood loss, post-surgical chronic lumbar pain, and diminished lumbar mobility. Furthermore, it preserves the height of the intervertebral disc, minimizes lamina and ligamentous complex damage, prevents posterior shift of axial loads, delays vertebral joint degeneration and modic changes, and reduces the surgical and hospitalization durations for patients.[13–15] However, PELD is not devoid of potential complications, including dural injury, residual mass, recurrence, and harm to the cauda equina and spinal nerve roots.[16] Notably, recurrent lumbar disc herniation following PELD has a reported incidence of 5.7%–15%, with the majority manifesting within six months post-surgery.[17] Li et al[18] indicated correlations between the severity of disc degeneration, the magnitude of post-surgical fibrous annulus ruptures, and herniation sites with early PELD recurrence. Expansive fibrous annulus ruptures and defects accelerate disc degeneration. In turn, this can lead to nerve root

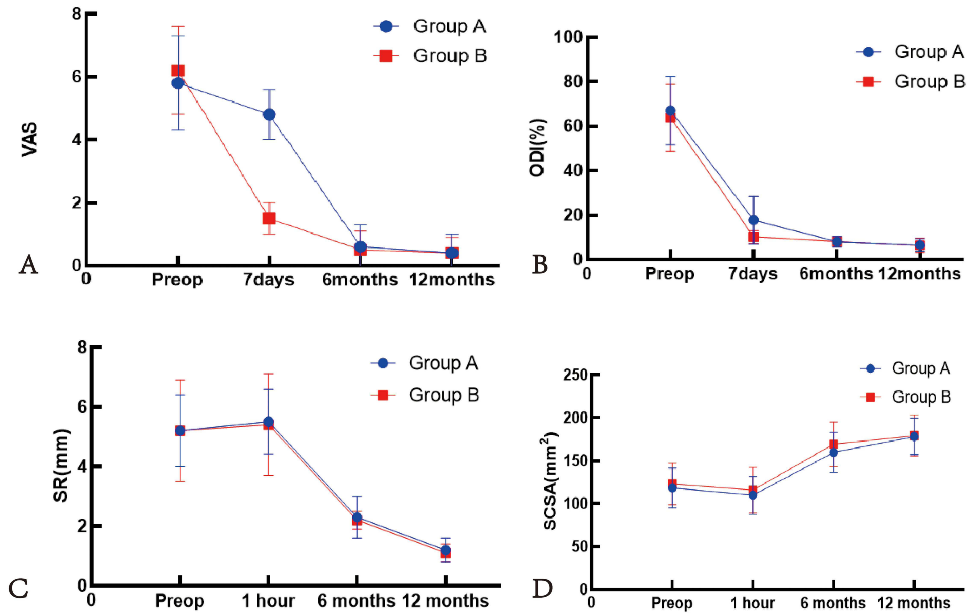

Figure 5 Changes in VAS, ODI, SR, and SCSA in groups A and B preoperatively and 1 h (7 days), 6 months, and 12 months postoperatively. Group A is a non-remission group, and Group B is a remission group. Sub-figure (**A–D**) shows the trends at each time point in terms of VAS, ODI, SR, SCSA for groups A and B respectively.

adhesion, aseptic inflammation, and subsequent chronic lumbar pain after PELD. To mitigate the annulus fibrosus defect and reduce the disc herniation recurrence rate, Mahatthanatrakul et al[7] recommended that surgeons ablate granulation tissue inside the annulus fibrosus fissure and reduce the fissure with bipolar radiofrequency following the decompression of nerve roots or dural sac, while preserving the annulus fibrosus in the herniated disc.

Table 4 The Number of the Residual Mass and the Intensity of the T2 Signal of the Residual Mass at 1 h, 6 Months, and 12 Months After Surgery in Groups A and B

		Group A	Group B	P value
Residual mass T2 signal intensity (high/intermediate/low)	Postop 1 h	15/10/3	52/20/6	0.22
	Postop 6 m	2/8/20	3/8/46	0.16
	Postop 12 m	1/5/17	3/7/44	0.49

Note: p < 0.05 is statistically significant.

Table 5 Correlation Analysis of ODI Changes (One Week Postoperatively and One Year Postoperatively) with Changes in Imaging Parameters

	r	sig
ODI changes at 1 week postoperatively		
SR change (SR1 h after surgery-SRPreoperative)	0.12	0.18
SCSA change (SCSA1 h after surgery-SCSAPreoperative)	−0.03	0.75
Residual mass signal intensity (1h after surgery)	−0.53	<0.001
ODI changes at 1 year postoperatively		
SR change (SR1 year after surgery-SR Preoperative)	0.71	<0.001
SCSA change (SCSA1 year after surgery-SCSAPreoperative)	−0.34	<0.001
Residual mass T2 signal intensity (1 year after surgery)	0.25	0.008

Note: sig< 0.05 is considered statistically significant.

Table 6 Multiple Linear Regression Analysis of MRI Parameters with ODI Changes at One Week Postoperatively as a Dependent Variable

	B	SE	Sig	95% CI
SR change (SR1 h after surgery-SR Preoperative)	3.08	1.79	0.09	(−0.46, 6.62)
SCSA change (SCSA1 h after surgery-SCSAPreoperative)	−0.09	0.14	0.50	(−0.36, 0.17)
Residual mass T2 signal intensity (1h after surgery)	−10.22	1.49	<0.001	(−13.17, −7.2)

Note: sig< 0.05 is considered statistically significant.
Abbreviations: B, unstandardized coefficient; SE, standard error; CI, confidence interval.

Table 7 Multiple Linear Regression Analysis of MRI Parameters with ODI Changes at One Year Postoperatively as a Dependent Variable

	B	SE	Sig	95% CI
SR change (SR1 year after surgery-SR Preoperative)	5.63	0.55	<0.001	(4.54, 6.72)
SCSA change (SCSA1 year after surgery-SCSAPreoperative)	−0.13	0.04	<0.001	(−0.25, −0.05)
Residual mass T2 signal intensity (1 year after surgery)	1.59	1.14	0.18	(−0.65, 3.84)

Note: sig< 0.05 is considered statistically significant.
Abbreviations: B, unstandardized coefficient; SE, standard error; CI, confidence interval.

MRI is a widely utilized diagnostic tool for LDH, renowned for its non-invasive nature, high-resolution imaging, and ability to differentiate tissue signals based on varying scanning sequences.[19] This effectively delineates the relationship between the intervertebral disc, dural sac, and epidural soft tissue. Early postoperative MRIs in LDH patients frequently depict ipsilateral nerve roots compressed by residual masses and unusual disc signals in the operated segment.[6,7,19] Weber et al[6] conducted lumbar microdiscectomy on 30 patients, followed by 3.0 T MRI scans 24 h post-surgery. Interestingly, 80% of patients displayed epidural soft tissue modifications and intra-spinal protrusions reminiscent of preoperative images at the surgical site. In a study involving 31 PELD patients, Mahatthanatrakul et al[7] revealed that all of them had intra-spinal protrusions in the operated segment on MRIs taken within 24 h post-surgery. The aforementioned protrusions demonstrated high and intermediate mixed signal shadows with nerve root compression and thickening on T2-weighted images. In this study, with moderate inter-rater consistency across all variables, 94.6% (106/112) of cases demonstrated a residual mass on MRIs taken 1 h post-surgery. The signal distribution on T2 was 64% high, 28% intermediate, and 8% low. Specifically, T2 high and intermediate signals typically indicated epidural edema or hematoma, while T2 low signals were associated with residual annulus fibrosus. As postoperative recovery progressed, the body absorbed epidural edema and hematoma, whereas the residual annulus fibrosus underwent structural alterations, distancing it from the nerve root. Wang et al[8] deduced that post-PELD early MRIs typically displayed quicker subsidence of the T2 high residual mass signal than open lumbar discectomy, predominantly within three months post-surgery. This T2 signal was linked to short-term clinical outcomes ($p = 0.004$) but not to medium- and long-term results. Furthermore, a multifactorial regression analysis found that a smaller DCSA in the early postoperative phase was linked to radicular pain after lumbar decompression (sig < 0.05, OR: 1.26). This radicular pain tended to be alleviated as the dural sac expanded in most patients.[9] In our findings, short-term ODI variations were correlated with the intensity of the T2 signal of the residual mass observed at 1 h post-surgery (B = −10.22, sig < 0.05). Meanwhile, long-term ODI alterations were associated with changes in the size of the residual mass (B = 5.63, sig < 0.05) and the spinal canal cross-sectional area (B = −0.13, sig < 0.05). In essence, early post-surgery MRIs with high T2 signals in the residual mass primarily forecasted short-term clinical improvement, whereas the decrease in residual mass and dural area expansion signified long-term clinical improvement.

Earlier research on the "residual mass" in the literature has posited, based on multiple postoperative MRI evaluations, that this mass primarily consisted of intraoperative remnants of the annulus fibrosus.[7,8,19] Simultaneously, because lumbar MR enhancement is weak for intraoperative visualization of the retained annulus fibrosus, intuitive results cannot be achieved. Consequently, a distinctive aspect of our study is the intraoperative injection of 3–5 mL of gadopentetate dimeglumine contrast solution (0.02 g/mL) directly into the retained annulus fibrosus. This allows immediate postoperative

MRI T1-weight scans to distinctly visualize the periphery of the annulus fibrosus rupture distinctly. Gadolinium, a water-soluble, non-iodine contrast agent, is dispersed in extracellular fluid. It generates a potent magnetic field that alters proton relaxation rates in water molecules. Due to the long T1 relaxation time of body tissue, low concentrations of gadopentetate dimeglumine contrast medium have a large effect on the T1 relaxation time, which can enhance tissue signal, and are often used as MRI-positive enhancers.[11,20] The rate of adverse reactions to intravenously administered gadolinium-based medications was 0.06%.[11] Vital signs were monitored throughout the operation to mitigate risks, such as allergic reactions. Renal function tests (BUN, Scr, etc.) were performed within 24–48 h postoperatively, and no renal impairment was observed in the laboratory results. In the postoperative MRI T1-weight scan, a pronounced high signal could be seen around the exterior of the residual mass. This signal, which coincides with the size and location of the preoperative disc herniation and is aligned with the endoscopically observed contrast medium injection site, solidified its identification as the retained annulus fibrosus (Figures 3 and 4).

Following PELD, the early postoperative stage usually involves nerve root compression by the residual mass without manifesting distinct clinical symptoms.[21] Nonetheless, some patients report persistent symptoms postoperatively, including sensations of numbness, tingling, or localized burning in the lower limbs. Several factors may be responsible for these manifestations; the first of them is, preoperative nerve root fiber bundle injury. Wang et al[22] identified that the length of preoperative symptoms and the extent of nerve root compression were independent risk factors for numbness and weakness in the lower extremities post-PELD ($p < 0.05$, OR: 1.015). Second, inadequate local anesthesia, compression from the endoscopic working cannula, and irritation from surgical instruments could induce inflammatory swelling in the nerve root, which can lead to temporary sensory and motor deficits.[16] Third is the premature resumption of work and activities. Liang et al[23] reported a lower VAS score for post-surgical lumbar pain in patients with limited mobility than in those without such restrictions within a month after the operation. Restricting mobility after PELD may significantly reduce LDH recurrence and alleviate lumbar pain. Finally, inflammatory edema of nerve roots during the recovery stage. Zhang et al[24] found that rebound pain started within one month after PELD (10.4%, 15/114), typically with leg pain with or without lower back pain lasting less than one month, which was relieved after a short period of adequate rest or conservative treatment. In addition, the degree of neural decompression achieved during surgery is not always accurately reflected in early postoperative MRIs. In our study, the size of the residual mass and the spinal canal cross-sectional area demonstrated no significant differences between the groups at 1 h, 6 months, or 12 months post-surgery ($p < 0.05$). The only notable difference was in the clinical symptoms reported one-week post-operation ($p > 0.05$). In contrast to clinical outcomes based on the presence or absence of post-PELD residual disc herniation, Baek et al[10] suggested that for asymptomatic patients with observable residual disc tissue, a "watchful waiting" approach could be more prudent than immediate follow-up surgery. For patients with lingering symptoms post-surgery, we advocate for symptomatic remedies, such as bed rest and rehabilitative physiotherapy. For those experiencing negligible postoperative improvements or exacerbation of pre-surgical symptoms, especially if imaging indicates "nerve root compression" and "herniation with T2 low signal", we advise 6–12 weeks of symptomatic treatment. Surgical exploration should be considered if no substantial improvement is observed.

This study has several limitations. A notable limitation was the small sample size, which may have affected the study's broader applicability. Furthermore, all surgeries were performed by a single surgeon using an identical procedure, which further limits generalizability. Although patients exhibited a range of symptoms one-week post-surgery, such as numbness in the lower extremities, soreness, and swelling, this study did not differentiate or delve into these varied symptoms. We relied solely on VAS to gauge the patient's tolerance to these residual symptoms. Furthermore, MRI parameters during follow-up, such as cut level, thickness, and angle, may differ from the initial MRI scan. This discrepancy could introduce minor inaccuracies in SR and SCSA.

Conclusion

By injecting contrast into the annulus fibrosus during percutaneous spinal endoscopy, our team determined that the residual mass on the early post-PELD MRI images was the annulus fibrosus left during surgery. At 1-year postoperative follow-up, 90.1% (101/112) of the patients displayed remodeling of the fibrous annulus, although 68.7% (77/112) still demonstrated herniation of the fibrous annulus. Short-term variations in clinical symptoms after PELD were associated with the T2 signal intensity of the residual mass. Meanwhile, long-term changes were associated with alterations in the size of the residual mass and cross-sectional area of the spinal canal.

Data Sharing Statement

All data generated or analyzed during this study are included in this published article.

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board of Xuzhou Central Hospital. The participants provided their written informed consent to participate in this study.

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Author Contributions

Jinhui Bu is the first author and Zhenfei Wang is the first co-first author, their contributions are the same. All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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