

A Nerve Root-Centered Classification System for Lumbar Disc Herniation: Development and Reliability Assessment

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Abstract

Background

Existing classifications of lumbar disc herniation (LDH) mainly describe disc morphology, migration, or canal compromise, but provide limited information regarding the spatial relationship between the herniated disc and the affected nerve root. This study developed a nerve root-centered classification for patients undergoing percutaneous endoscopic lumbar discectomy (PELD) and evaluated its observer reliability and agreement with intraoperative findings.

Methods

This single-center retrospective classification-development and reliability study included 516 patients with LDH who underwent PELD between January and December 2022. The Peking University Third Hospital (PUTH) classification integrates the cranio-caudal origin pattern of the affected nerve root (Types 1–3) with the location of the herniated disc relative to the nerve root (Types A–D). Preliminary classifications based on preoperative magnetic resonance imaging (MRI) were compared with consensus reference classifications established through blinded review of intraoperative videos by senior spine surgeons. Intraobserver and interobserver reliability were evaluated by three surgeons from the study institution using all 516 cases and by five surgeons from external institutions using 100 proportionately stratified cases from the same cohort. Clinical outcomes were summarized descriptively after a minimum follow-up of 2 years.

Results

MRI-based classifications agreed with the consensus video-based reference classifications in 486 of 516 cases (94.2%). Thirty discordant cases were mainly attributable to severe nerve root compression, incomplete visualization of the nerve root origin on MRI, or anatomical variation. Internal intraobserver agreement was substantial to excellent ($\kappa = 0.776\text{--}0.842$), and internal interobserver agreement was excellent ($\kappa = 0.837$). Among external raters, intraobserver agreement was substantial ($\kappa = 0.659\text{--}0.756$), whereas interobserver agreement was also substantial but lower than that observed internally ($\kappa = 0.645$). At final follow-up, lower VAS and ODI scores and a higher JOA score were observed compared with preoperative values. Symptomatic recurrence occurred in 13 patients (2.52%), and postoperative complications occurred in 9 patients (1.74%).

Conclusion

The PUTH classification demonstrated substantial-to-excellent observer reliability and high MRI–operative agreement in a single-center cohort undergoing PELD. Independent prospective multicenter studies are required to determine its generalizability and influence on surgical decision-making and clinical outcomes.

Background

Lumbar disc herniation (LDH) is one of the most common degenerative disorders of the lumbar spine^{1, 2}. It is defined as displacement of disc material beyond the normal confines of the intervertebral disc. Symptomatic LDH

affects approximately 1%–3% of adults, and the lifetime risk of lumbar disc herniation has been reported to be approximately 30%³. Patients with LDH may present with low back pain, radiating leg pain, sciatica, paresthesia, muscle spasm, or weakness of the lower limb^{4, 5}. Most patients can initially be managed with conservative treatment, including medication, physical therapy, activity modification, and epidural steroid injection. Previous studies have reported that 60%–90% of symptomatic LDH cases may improve spontaneously or with nonoperative treatment. However, surgical intervention is generally considered for patients with persistent radicular symptoms, progressive neurological deficits, or unsatisfactory response to conservative management.

The surgical treatment of LDH has evolved from conventional open discectomy to microdiscectomy and, more recently, to percutaneous endoscopic lumbar discectomy (PELD). With advances in endoscopic techniques, endoscopic lumbar spine surgery has been increasingly adopted by spine surgeons worldwide. It can remove herniated disc material and decompressing neural structures, with reported advantages including reduced paraspinal muscle injury, preservation of posterior ligamentous structures, and less disruption of normal spinal anatomy compared with conventional open procedures^{6,7}. Nevertheless, PELD remains technically demanding. Many spine surgeons are trained primarily through the anatomical concepts and operative exposure of open surgery, whereas endoscopic surgery requires a different understanding of the surgical corridor, neural structure orientation, and disc–nerve root relationship within a restricted operative field^{8, 9}. The steep learning curve, limited endoscopic visualization, anatomical variation of the nerve root, and complex spatial relationship among the herniated disc, traversing nerve root, exiting nerve root, and dural sac may increase the risk of intraoperative disorientation^{4, 10–12}. Therefore, a practical technical framework that can assist surgeons in preoperative image interpretation and intraoperative anatomical recognition is needed.

LDH has traditionally been described according to pathological and anatomical morphology, including bulging, protrusion, extrusion, and sequestration^{13, 14}. Several MRI-based classification systems have also been developed to characterize the location, size, migration, and distribution of herniated disc material^{15–19}. However, most existing systems are primarily based on preoperative radiological morphology and may not fully reflect the actual intraoperative relationship among the herniated disc, nerve root, and dural sac. In endoscopic lumbar discectomy, this relationship may be more relevant than fragment size alone. Even a small fragment located at the shoulder of the nerve root may cause severe radicular pain. Therefore, a classification framework emphasizing the nerve root–disc relationship may be useful for preoperative interpretation, intraoperative orientation, and safe neural decompression.

Based on our clinical experience with PELD for LDH, we summarized several technical notes and developed the Peking University Third Hospital (PUTH) classification, which characterizes LDH according to the origin of the nerve root and the location of the herniated disc relative to the nerve root. The objectives of this study were fourfold: first, to describe the key technical notes of PELD; second, to introduce the concept and clinical application of the PUTH classification; third, to evaluate its reproducibility among surgeons with different levels of experience; and fourth, to summarize the preliminary clinical outcomes after a minimum follow-up of 2 years.

Methods

Study design

This study was designed as a retrospective technical note with preliminary clinical results. We retrospectively reviewed patients who underwent PELD within the framework of the PUTH classification. The PUTH classification was developed to help surgeons identify neural structures, localize the herniated disc in relation to the affected nerve root, and assess whether adequate decompression had been achieved. Surgical strategies were determined by the treating surgeons based on clinical symptoms, imaging findings, intraoperative anatomy, and surgical experience, rather than by the classification alone.

This study was not designed as a comparative effectiveness study. The clinical outcomes were not intended to prove the superiority of the PUTH classification or to establish its independent prognostic value. Instead, they were used as preliminary evidence to assess the feasibility and safety of applying this classification in clinical practice.

This study was approved by the ethics committee of our hospital and was conducted in accordance with the Declaration of Helsinki (S2024580). The requirement for informed consent was waived because of the retrospective nature of the study. The overall study framework is shown in Fig. 1.

Patient selection

The inclusion criteria were as follows: (1) patients were diagnosed with LDH according to the clinical manifestations and imaging; (2) patients whose symptoms were not alleviated or even worse after 8 weeks conservative treatment; (3) patients do not have lumbar instability; (4) patients undergoing primary PELD; (5) follow-up time > 2 years. The exclusion criteria were as follow: (1) LDH with intermittent neurogenic claudication as the primary symptom; (2) lumbar instability or spondylolisthesis; (3) LDH with other spinal disease; (4) incomplete clinical data.

From January 2022 to December 2022, a total of 963 patients underwent endoscopic lumbar surgery at our institution. Of these, 447 patients were excluded because of insufficient follow-up duration ($n = 103$), incomplete clinical data ($n = 19$), missing intraoperative video recordings ($n = 21$), diagnosis other than lumbar disc herniation ($n = 282$), and recurrent lumbar disc herniation ($n = 22$). Finally, 516 patients with lumbar disc herniation were included. For all included patients, preoperative imaging and intraoperative findings were reviewed and classified according to the PUTH classification. Clinical and radiological data from the preoperative period to the last follow-up were systematically reviewed.

PUTH classification

The PUTH classification consists of two components: the origin pattern of the affected nerve root and the location of the herniated disc relative to the affected nerve root (Fig. 2). The nerve root origin was categorized into three types. **Type 1** indicated that the affected nerve root originated above the level of the intervertebral disc. **Type 2** indicated that the nerve root originated at the disc level. **Type 3** indicated that the nerve root originated below the disc level. The location of disc herniation was categorized into four regions. **Type A** referred to disc herniation located at the shoulder of the nerve root. **Type B** referred to disc herniation located anterior to the shoulder of the nerve root. **Type C** referred to disc herniation located in the axilla of the nerve root. **Type D** indicated far-lateral disc herniation.

The final PUTH type was determined by combining the nerve root origin type and the disc herniation location type. Each patient had only one nerve root origin type, whereas the herniated disc could involve one or more anatomical

regions. Therefore, combined disc-location subtypes were allowed. For example, patients could be classified as Type 1BC, Type 2BC, or Type 3B according to the anatomical relationship between the nerve root and the herniated disc (Figs. 3–5).

All included cases had complete and interpretable intraoperative video recordings. Preoperative MRI was first used to assign the preliminary PUTH type. Intraoperative videos were then reviewed to confirm the actual nerve root position and disc–nerve root relationship. The video-confirmed classification was determined by two senior spine surgeons and was used as the final reference classification. Disagreements were resolved by consensus with a third senior surgeon. The overall agreement rate and number of discrepant cases between the MRI-based preliminary classification and the video-confirmed reference classification were calculated. The video reviewers were blinded to the preoperative MRI-based classification results during video assessment. The observers involved in the reliability assessment independently evaluated the cases and were not involved in establishing the consensus reference classification.

Reliability Testing

The reproducibility of the PUTH classification was evaluated in two steps.

First, internal reliability testing was performed at our institution. Three spine surgeons (WLJ, LZJ and JS) with different levels of clinical experience were invited to independently apply the PUTH classification. The raters included: a resident (<5 years of practice), an attending physician (5–10 years of practice), and an associate chief physician (> 10 years of practice). All patient data, including clinical presentation and preoperative imaging, were anonymized and randomly numbered. The three raters independently assigned the PUTH classification in a blinded manner.

Second, external-rater reliability assessment was performed. 100 cases were selected from the original cohort using proportionate stratified random sampling according to the three nerve-root origin types of the consensus reference classification. No intentional oversampling of rare subtypes was performed. Therefore, the distribution of the sampled cases was designed to approximate that of the complete clinical cohort. Each case included clinical presentation and preoperative imaging. Five experienced spine surgeons from outside our institution were invited to classify these cases using the PUTH classification. Their results were used to evaluate the external applicability and interobserver reliability of the classification system.

After a 2-week interval, the same patient data were reshuffled and renumbered. The raters repeated the classification independently (both internal and external raters). They were blinded to their previous ratings and to the ratings of the other surgeons. The results of the two rounds were used to evaluate intra-observer and inter-observer reliability.

Surgery procedure

Percutaneous endoscopic interlaminar discectomy (PEID)

All patients were placed in the prone position on a Wilson frame under general anesthesia. C-arm fluoroscopy was utilized to localize the operative segment, and the skin entry point was marked 1.5 cm lateral to the midline. Under real-time C-arm fluoroscopic guidance, the working cannula was inserted perpendicular to the ground. The trajectory was planned to target the interlaminar space between the medial border of the pedicle and the lateral

edge of the superior articular process. Following the creation of a bony window, the unilateral ligamentum flavum was resected. The epidural fat was then cleared to expose the nerve root and dural sac. The herniated disc was resected using nucleus pulposus forceps. As much loose nucleus pulposus as feasible was removed from the intervertebral space to achieve complete decompression of the nerve root and dural sac. Bleeding sites were carefully explored and given sufficient hemostasis. Finally, the working cannula was removed.

Percutaneous endoscopic transforaminal discectomy (PETD)

All patients were positioned prone on a Wilson frame under local anesthesia. With the guidance of C-arm fluoroscopy, the puncture site was confirmed and marked. Then a spinal needle was inserted into the target intervertebral disc level. In the lateral fluoroscopic view, the needle was positioned at ventral aspect of superior articular process, aligned with the posterior vertebral body line. In the anteroposterior view, the needle aligned with the lateral vertebral body line. A guidewire was inserted through the spinal needle, followed by placement of a working cannula along the guidewire. Finally, an endoscope was introduced through the working cannula, and the herniated disc tissue was resected using endoscopic forceps and a radiofrequency probe. The surgical incision was then closed.

Surgical strategy and technical considerations for PELD

First, both PEID and PETD are feasible options for most patients with LDH. The choice of approach largely depends on the surgeon's experience, technical preference and characteristics of the herniated disc. However, a small proportion of special types of LDH may be more suitable for one specific approach. For example, PETD is generally more appropriate for far-lateral disc herniation, whereas PEID may provide a more favorable decompression corridor for giant sequestered disc herniation and annular calcification. In cases of giant sequestered disc herniation, removal of the free disc fragment is often followed by bleeding from surrounding vessels because of local inflammatory adhesion and vascular proliferation. Hemostasis can be difficult during PETD, particularly in patients undergoing surgery under local anesthesia. Although partial removal of the nucleus pulposus can be achieved, prolonged hemostasis may increase patient anxiety and discomfort, resulting in elevated blood pressure and further bleeding. This may create a vicious cycle. In contrast, PEID allows posterior access to the spinal canal and provides a more direct operative field for managing both the disc fragment and bleeding points. For calcified disc herniation, PEID also allows more effective removal of the calcified disc tissue, whereas PETD may leave residual calcified fragments on the ventral side of the dural sac because of limitations in the working angle.

Second, during patient positioning for PEID, the target interlaminar space should be adjusted to be as perpendicular to the ground as possible. This positioning facilitates fluoroscopic localization, working-channel placement, and subsequent endoscopic manipulation.

Third, during PEID, the working channel should be inserted perpendicular to the ground and directed toward the target interlaminar space. This technical principle helps prevent disorientation during the procedure and allows the surgeon to reach the pathological area directly. It also facilitates the removal of deep, loose disc material from the intervertebral space.

Fourth, when decompressing the ligamentum flavum during PEID, en bloc resection is recommended whenever feasible. The ligamentum flavum should preferably be opened from its caudal edge. This maneuver allows

sufficient exposure of the lateral recess, enlarges the working space, and reduces traction or irritation of the nerve root and dural sac. Therefore, it may decrease the risk of intraoperative and postoperative nerve irritation.

Fifth, the PUTH classification may help surgeons identify neural structures during PELD. In PEID, the neural structures encountered through the interlaminar window differ according to the preoperative classification. When the affected nerve root originates above the disc level, the structures observed through the interlaminar window usually correspond to the axillary region of the nerve root and the border of the dural sac. When the affected nerve root originates at the disc level, the neural structure directly facing the interlaminar window is usually the nerve root itself. When the affected nerve root originates below the disc level, the structures observed through the interlaminar window usually correspond to the shoulder region of the nerve root or the border of the dural sac. Similarly, during PETD, after partial resection of the superior articular process and entry into the spinal canal, the preoperative PUTH classification may also help the surgeon identify the neural structures encountered intraoperatively.

Finally, the PUTH classification may help surgeons achieve adequate decompression. Preoperative classification based on imaging allows the surgeon to anticipate the spatial relationship among the herniated disc, nerve root, and dural sac. This information can guide intraoperative exploration of the responsible disc fragment and help determine whether decompression is complete. Therefore, the PUTH classification may reduce the risk of missing deep or hidden compressive lesions and may improve the completeness and safety of decompression.

Clinical Outcome Assessment

All patients were followed up for a minimum of 2 years. During the follow-up period, the VAS score, ODI score, imaging, complications and other relevant information were collected to assess preliminary clinical outcomes and safety.

Statistical analysis

Data were recorded and analyzed using SPSS 29.0 software. Continuous variables were expressed as mean $\pm$ standard deviation (mean $\pm$ SD). The final PUTH classification assigned by each observer was treated as a nominal categorical variable. Cohen's kappa coefficient was used to assess intra-observer repeatability by comparing the first and second assessments of each observer. Fleiss' kappa coefficient was used to assess inter-observer reliability among multiple observers. A Kappa value ≤ 0.40 indicated poor agreement, 0.41–0.60 indicated moderate agreement, 0.61–0.80 indicated substantial agreement, and 0.81–1.00 indicated excellent agreement.

Results

General data for patients

A total of 516 patients were retrospectively enrolled in this study. The mean follow-up duration was 35.52 ± 11.24 months. The cohort included 305 males and 211 females, with a mean age of 43.07 ± 16.16 years and a mean BMI of 28.35 ± 5.49 kg/m². Regarding the level of disc herniation, 1 case was at L1-2, 3 at L2-3, 22 at L3-4, 286 at L4-5, and 204 at L5-S1. Several special types of LDH were identified, including 68 far-lateral herniations, 26 migrated herniations and 31 calcified herniations (Table 1).

Table 1
Baseline characteristics of enrolled patients

Variable	Enroll Patients (n = 516)
Gender	
Female	211
Male	305
Age	43.07 ± 16.16
BMI	28.35 ± 5.49
Level	
L1-2	1
L2-3	3
L3-4	22
L4-5	286
L5-S1	204
Smoking	215
Drinking	127
Symptom duration	
≤ 3 months	32
3 months-1 year	232
n ≥ 1 year	252
Chronic disease	
Hypertension	98
Diabetes	121
Special type of LDH	
Far-lateral LDH	68
Migrated LDH	26
Calcified LDH	31

Reliability of the PUTH classification

Given potential discrepancies between preoperative imaging and intraoperative findings, all classifications were confirmed by intraoperative video recordings (**Supplemental Table 1**). In total, 53 patients were classified as type 1, including 3 at L4–5 and 50 at L5–S1. A total of 218 patients were classified as type 2, including 70 at L4–5, and 148 at L5–S1. A total of 245 patients were classified as type 3, including 1 at L1–2, 3 at L2–3, 22 at L3–4, 213 at L4–5 and 6 at L5–S1.

The MRI-based PUTH classification was consistent with the video-confirmed reference classification in 486 of 516 cases, yielding an overall agreement rate of 94.19%. Discrepancies were observed in 30 cases. The most common cause of discrepancy was severe nerve root compression, which made it difficult to identify the exact level of nerve root origin on preoperative MRI (18 cases). Other causes included anatomical variations (5 cases) and insufficient MRI coverage of the nerve root origin (7 cases).

Among three spine surgeons(WLJ, LZF. and JS) from our institution, intraobserver reliability between the first and second assessments showed substantial to excellent agreement (Table 2). The kappa values were 0.842 for observer 1, 0.776 for observer 2, and 0.800 for observer 3. The inter-observer reliability was 0.837, indicating excellent agreement.

Table 2
Reliability Testing

	Internal reliability testing (n = 516)			External reliability testing (n = 100)				
	Observer 1	Observer 2	Observer 3	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5
Intra-observer reliability	0.842	0.776	0.800	0.734	0.724	0.692	0.659	0.756
95% CI	0.796–0.889	0.721–0.830	0.748–0.851	0.644–0.824	0.633–0.815	0.598–0.786	0.562–0.756	0.669–0.843
Inter-observer reliability	0.837			0.645				
95% CI	0.788–0.886			0.600–0.690				

Among five spine surgeons (WYT, ZZH, XLG, LM, CY) from outside our institution, intraobserver reliability between the first and second assessments showed substantial agreement (Table 2). The kappa values were 0.734 for observer 1, 0.724 for observer 2, 0.692 for observer 3, 0.659 for observer 4, and 0.756 for observer 5. The inter-observer reliability was 0.645, further supporting the reproducibility of the PUTH classification.

Preliminary clinical outcomes.

The preliminary clinical outcomes are summarized in Table 3. Preoperatively, the VAS score for low back pain, VAS score for leg pain, JOA score, and ODI were 7.2 ± 1.5 , 8.1 ± 1.1 , 16.23 ± 3.6 , and 56.35 ± 16.27 , respectively. At the final follow-up, these scores improved to 1.1 ± 1.79 , 0.92 ± 1.77 , 26.37 ± 3.7 , and 4.11 ± 5.72 , respectively. Symptomatic recurrence occurred in 13 patients, with a mean time to recurrence of 9.04 ± 7.76 months. The overall complication rate was 1.74%.

Table 3
Follow-up index and complications

Score	Pre-operation	Final follow-up
VAS (lumbar)	7.2 ± 1.5	1.1 ± 1.79
VAS (Leg)	8.1 ± 1.1	0.92 ± 1.77
JOA	16.23 ± 3.6	26.37 ± 3.7
ODI	56.35 ± 16.27	4.11 ± 5.72
Recurrence (%)	/	13(2.5%)
Time of recurrence	/	9.04 ± 7.76
Complications (%)	/	9 (1.74%)
Dura tear	/	5
Hematoma	/	1
Nerve root injury	/	3

Discussion

LDH is a common clinical disorder and a leading cause of lumbar radiculopathy. In this technical note, we summarized our experience in endoscopic treatment of LDH and proposed the PUTH classification, a novel nerve root-centered system. Maintaining accurate orientation within the limited surgical field of endoscopic lumbar discectomy remains challenging. Intraoperative disorientation may lead to misidentification of neural structures, unnecessary nerve manipulation, incomplete decompression, or residual disc fragments. Shoulder, axillary, ventral, and far-lateral herniations have been described in previous studies. However, most existing classifications focus on the morphology, migration, or local position of the herniated disc. The main novelty of the PUTH classification is that it integrates the origin pattern of the affected nerve root with the position of the herniated disc relative to that nerve root. This framework may help surgeons read preoperative images more systematically and maintain safer orientation during endoscopic decompression.

Previous classifications of LDH have mainly focused on pathological features, anatomical location, or MRI findings (Table 4). For example, the MSU classification proposed by Mysliwiec et al. evaluates disc herniation according to the size and location of the herniated fragment on axial MRI¹⁷. It divides the disc space into different zones based on the medial borders of the facet joints and provides a simple method to describe the transverse location of the herniation. This system is useful for radiological description and communication between surgeons. In addition to MRI-based classifications, some authors have described LDH according to its relationship with the nerve root^{18–22}. For example, shoulder-type and axillary-type disc herniations describe whether the disc fragment is located lateral or medial to the traversing nerve root²³. Ventral-type herniation has also been described in endoscopic lumbar discectomy, in which the disc fragment is located ventral to the nerve root and may require a surrounding nerve root discectomy route²⁴. These descriptions are clinically meaningful because they are closely related to surgical orientation, nerve root mobilization, and approach selection.

Table 4
Comparison Between Existing LDH Classifications and the PUTH Classification

Classification/Description	Representative studies	Core concept	Difference from PUTH
Standard disc nomenclature /morphology-based classification	Fardon et al. ¹⁴ ; Zhu et al. ²¹	Describes disc morphology, including protrusion, extrusion, sequestration, migration, location, and containment status	Mainly focuses on the disc lesion itself, rather than the nerve-root origin pattern or disc-root relationship.
Size / location /canal morphology-based classification	MSU classification ¹⁷ ; Carragee et al. ¹⁵ ; Halldin et al. ²⁰	Evaluates disc size, canal compromise, transverse location, centrality, or three-dimensional distribution	Useful for radiological description, but the nerve root is not the central anatomical reference.
Nerve root compromise grading	Pfirrmann et al.	Grades nerve root compromise as contact, deviation, or compression on MRI.	Focuses on the severity of compression, but does not describe the nerve-root origin pattern or endoscopic spatial orientation
Migration-based classifications	Lee et al.; Ahn et al. ¹⁹ ; Gao et al. ²²	Classifies migrated LDH according to direction and degree of cranial or caudal migration.	Mainly answers where the fragment has migrated, but not how it relates to the involved nerve root.
Local disc-root relationship descriptions	Parmar et al. ²³ ; Shi et al. ²⁴	Describes shoulder, axillary, ventral, or far-lateral relationships between the disc fragment and nerve root.	Clinically useful but represents isolated anatomical patterns rather than an integrated classification system.
PUTH classification	Present study	Uses the involved nerve root as the central reference and integrates nerve-root origin pattern with disc-root spatial relationship.	Translates MRI anatomy into an endoscopic orientation system for nerve identification, disc localization, and decompression assessment.

However, most existing classifications still describe the disc fragment as the main object. The nerve root is often regarded as an adjacent structure rather than the central anatomical reference. In endoscopic lumbar discectomy, the operative field is relatively limited, and accurate identification of neural structures is essential for safe and sufficient decompression. In clinical practice, the first neural structure encountered during surgery may not always be the nerve root expected from preoperative imaging, especially in patients with anatomical variation, high or low nerve root origin, shoulder-type herniation, axillary herniation, or severe compression. Misinterpretation of the nerve root position may lead to inadequate decompression, excessive traction, or neural injury. By using the nerve root as the central reference, the PUTH classification allows surgeons to evaluate not only where the disc fragment is located but also how it relates to the involved nerve root.

Another important feature of the PUTH classification is its emphasis on the potential discrepancy between conventional anatomical assumptions and actual intraoperative findings. In this cohort, most L5 and S1 nerve roots followed the commonly recognized anatomical pattern, with the L5 nerve root originating below the disc space and the S1 nerve root originating at the level of the disc space. However, in some special cases, the L5 nerve root originated at a relatively high level, whereas the S1 nerve root originated at a relatively low level. These

anatomical variations may increase the difficulty of identifying neural structures during endoscopic surgery. When combined with massive disc sequestration, anterior-shoulder herniation, or severe compression, the risk of intraoperative disorientation and incomplete decompression may be further increased. Therefore, the PUTH classification provides a practical framework for describing the positional relationship between the nerve root and the herniated disc.

The reproducibility of a classification system is essential before it can be widely used in clinical practice. In the present study, all classifications were confirmed by intraoperative video recordings to reduce the potential bias caused by discrepancies between preoperative imaging and intraoperative findings. The PUTH classification showed substantial to excellent intraobserver agreement among surgeons from our institution and excellent interobserver agreement. External-rater reliability assessment by five spine surgeons from outside our institution also demonstrated substantial intra-observer agreement and acceptable inter-observer agreement. These findings suggest that the PUTH classification is reproducible and can be understood by surgeons beyond the original study group.

In addition to the classification itself, we summarized several technical notes to facilitate intraoperative identification of the disc space and neural structures. Although cranial or caudal angulation of the working channel is commonly discussed, the exact angle can be difficult to judge accurately during surgery. In our experience, keeping the disc space as perpendicular to the ground as possible, aligning the working channel perpendicular to the ground, and directing the working channel toward the target disc space provide a simple and reproducible method for maintaining orientation. This technique may help reduce the risk of intraoperative disorientation, especially in cases with variant nerve root origin or complex disc morphology.

The clinical outcomes in this cohort were favorable. At the final follow-up, VAS scores for low back pain and leg pain, JOA scores, and ODI all showed marked improvement compared with preoperative values. Symptomatic recurrence occurred in 13 patients, and the overall complication rate was low. These findings suggest that satisfactory clinical outcomes can be achieved in patients classified using the PUTH system and treated with endoscopic lumbar discectomy. However, these results should be interpreted cautiously. Because this was a retrospective study without a control group, the favorable outcomes cannot be attributed solely to the PUTH classification. The classification was used to help surgeons understand the anatomical relationship between the herniated disc and the nerve root, identify neural structures, and assess decompression. It was not prospectively tested as a treatment algorithm. Therefore, the clinical outcome data should be regarded as preliminary observational evidence rather than definitive proof that the classification itself improves surgical efficacy.

Based on the anatomical patterns summarized by the PUTH classification and our clinical experience, we proposed preliminary surgical considerations for different LDH types. For upper lumbar disc herniations, the nerve root is usually located below the disc space, and the transforaminal approach may provide direct access to the herniated fragment in many cases. For L4–5 and L5–S1 herniations, the choice of approach should be individualized according to the nerve root position, disc location, migration direction, iliac crest height, foraminal anatomy, surgeon experience, and patient-specific factors. Therefore, the proposed surgical considerations should not be interpreted as rigid treatment guidelines. Instead, they provide an anatomical reference that may assist surgical planning and intraoperative decision-making. Prospective studies are needed to determine whether treatment strategies based on this classification can improve surgical safety or clinical outcomes.

This study also has implications for surgical education. Endoscopic lumbar discectomy has a steep learning curve, and junior surgeons may have difficulty identifying neural structures through a limited working corridor. The PUTH classification may provide a simple and reproducible method for preoperative image reading and intraoperative orientation. By encouraging surgeons to identify the nerve root first and then analyze the position of the herniated disc relative to the nerve root, this classification may reduce disorientation and help avoid incomplete decompression or unnecessary nerve traction^{25, 26}.

This study has several limitations. First, it was retrospective and did not include a control group of patients treated without reference to the PUTH classification. Therefore, the study can demonstrate the reproducibility and feasibility of the classification, but it cannot prove that the classification improves surgical outcomes. Second, external-rater reliability assessment was performed by five spine surgeons, but the validation process was still limited in scale. Multicenter studies involving surgeons with different levels of experience are needed to further evaluate the generalizability of the classification. Third, all final classifications were confirmed by intraoperative video review, which may not fully reflect routine preoperative decision-making based on imaging alone. Finally, the surgical considerations proposed in this study were based on anatomical analysis and clinical experience. Their effectiveness should be tested in future prospective studies.

Conclusion

The PUTH classification provides a reproducible, nerve root-centered framework for describing lumbar disc herniation. By integrating the origin of the affected nerve root with the location of the herniated disc, it may assist preoperative imaging interpretation, intraoperative orientation, and assessment of adequate decompression during PELD. The preliminary clinical outcomes support its feasibility and safety, although further prospective multicenter studies are needed to confirm its clinical value.

Abbreviations

PELD, percutaneous endoscopic lumbar discectomy

PUTH, Peking University Third Hospital

LDH, lumbar disc herniation

PEID, Percutaneous endoscopic interlaminar discectomy

PETD, Percutaneous endoscopic transforaminal discectomy

Declarations

Ethics approval and consent to participate:

This study was approved by the Peking University Third Hospital Medical Science Research Ethics Committee (approval No. S2024580; May 15, 2024) and was conducted in accordance with the Declaration of Helsinki. The requirement for informed consent was waived by the Ethics Committee due to the retrospective nature of the study.

Consent for publication:

The clinical data and images presented in this study were fully anonymized. The requirement for consent for publication was waived by the institutional ethics committee due to the retrospective and anonymized nature of the study.

Competing interests:

The authors have declared that no conflict of interest exists

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Author Contribution:

- Longjie Wang: Conceptualization, methodology, data curation, internal reliability assessment, visualization, and writing—original draft.
- Zhuofu Li: Data curation, investigation, internal reliability assessment, and writing—review and editing.
- Zhenhai Zhou: Investigation and external-rater reliability assessment.
- Lige Xiao: Investigation and external-rater reliability assessment.
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- Miao Li: Investigation and external-rater reliability assessment.
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- Woquan Zhong: Investigation, validation, consensus review of intraoperative videos, and writing—review and editing.
- Chuiguo Sun: Investigation, validation, consensus review of intraoperative videos, and writing—review and editing.
- Shuai Jiang: Investigation, internal reliability assessment, data curation, and writing—review and editing.
- Weishi Li: Conceptualization, methodology, project administration, supervision, and writing—review and editing.
- All authors read and approved the final manuscript.

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Not applicable

Data Availability

The datasets analyzed during the current study are not publicly available because they contain patient-related information but are available from the corresponding author on reasonable request.

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Figures

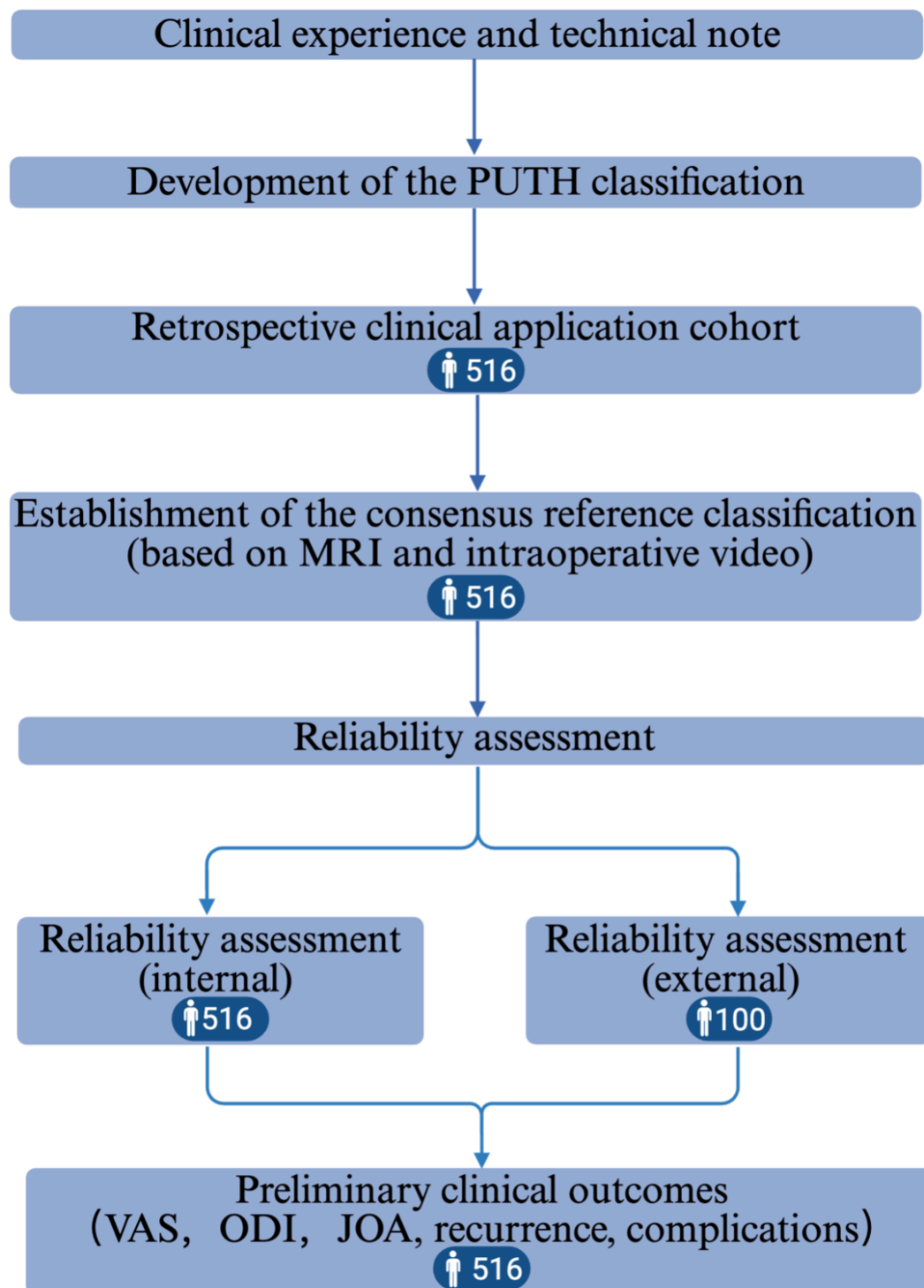
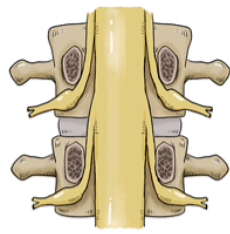


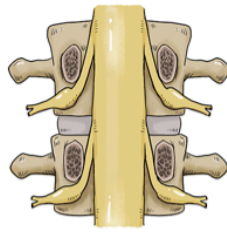
Figure 1

Flow chart of the article

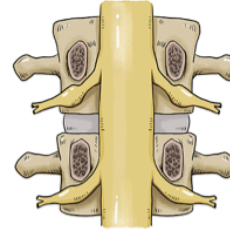
Nerve Root



Type 1

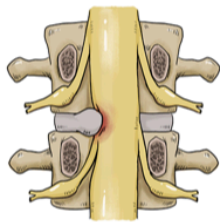


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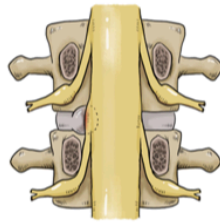


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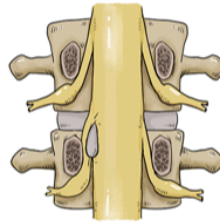
Herniated disc



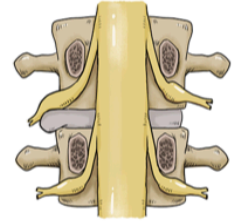
Type A



Type B



Type C



Type D

Figure 2

PUTH classification

Nerve root

Type 1 The nerve root originates above the level of intervertebral disc

Type 2 The nerve root originates at the level of the intervertebral disc

Type 3 The nerve root originates below the level of the intervertebral disc

Disc herniation

A The herniated disc is located at the shoulder of the nerve root.

B The disc herniation is located anterior to the shoulder of the nerve root

C The herniated disc is located in the axilla of the nerve root

D The herniated disc is located in the far lateral region

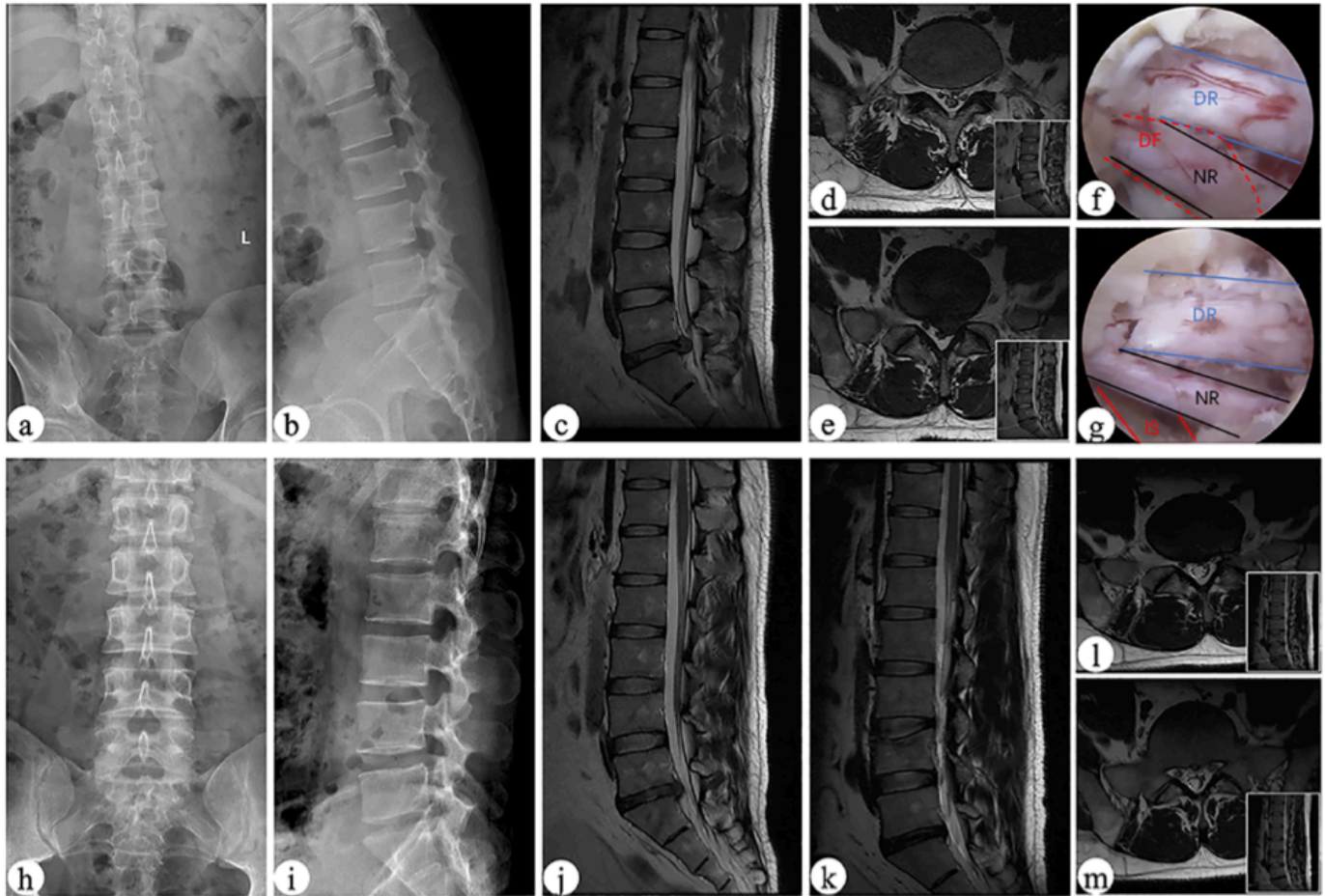


Figure 3

L5S1 Type 1BC

(a,b) Preoperative radiographs demonstrate positional scoliosis secondary to radicular pain. (c) Preoperative sagittal magnetic resonance imaging (MRI) demonstrates disc herniation at the L5/S1 level. (d,e) Preoperative axial MRI images reveal that the S1 nerve root originates cranial to the L5/S1 disc space, and the herniated disc fragment compresses the anterior shoulder and axillary region of the nerve root, corresponding to Type 1BC in the PUTH classification. (f) Intraoperative endoscopic findings confirm the anatomical relationship between the nerve root and disc fragment. The left side indicates cranial direction and the right side indicates caudal direction. The blue area represents the dural sac, the black area represents the nerve root, and the red dashed outline indicates the herniated disc fragment. (g) After complete decompression, the S1 nerve root is released and returns to its anatomical position. The red solid outline indicates the intervertebral disc space, demonstrating that the nerve root originates from the cranial border of the disc space. (h,i) Immediate postoperative radiographs demonstrate disappearance of positional scoliosis. (j) Immediate postoperative sagittal MRI demonstrates adequate decompression. (k–m) Follow-up images obtained 25 months after surgery demonstrate sustained decompression without evidence of recurrent disc herniation.

NR, nerve root; DR, dura; DF, disc fragment; IS, intervertebral space.

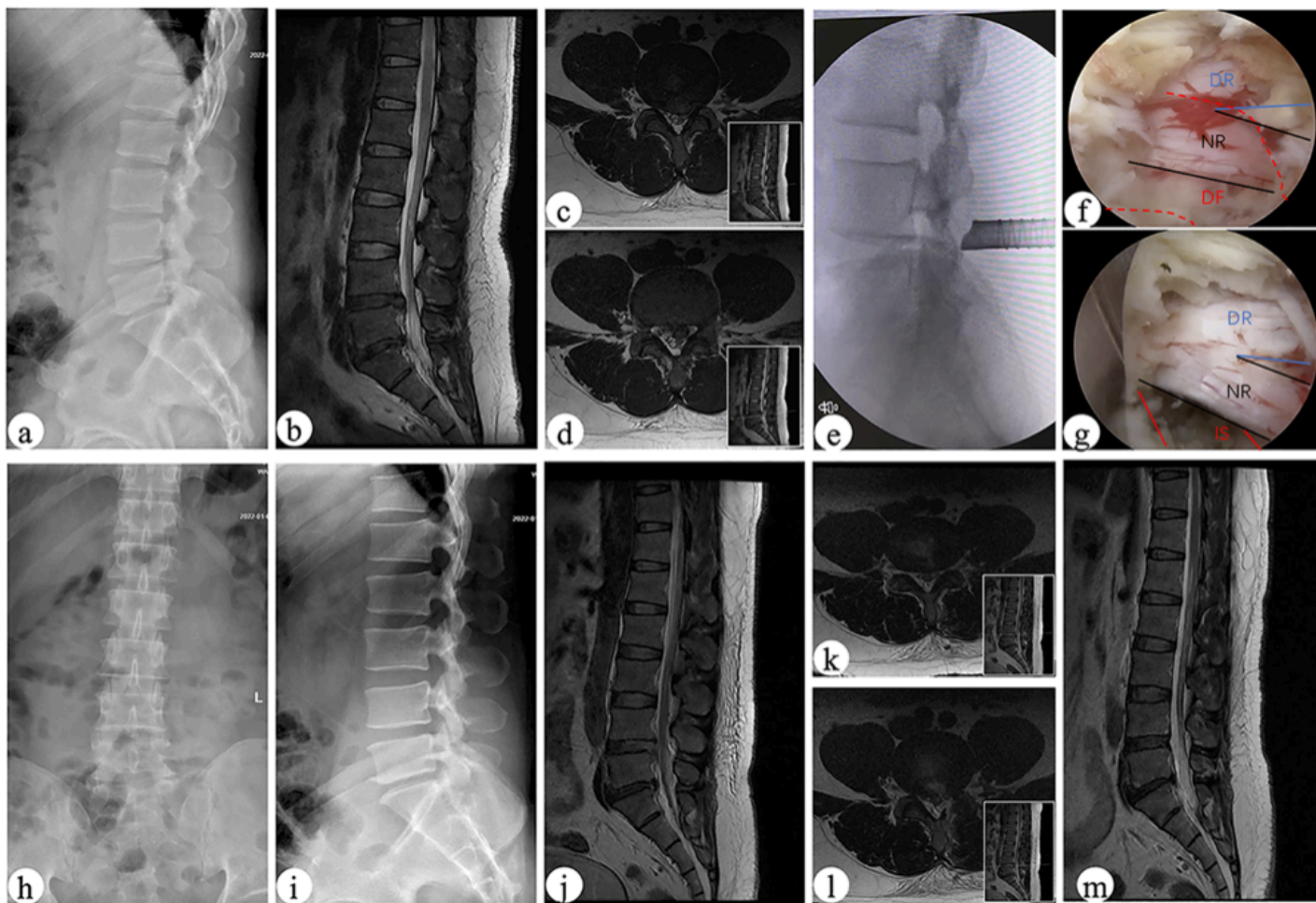


Figure 4

L45 Type 2ABC

(a) Preoperative radiograph. (b) Preoperative sagittal magnetic resonance imaging (MRI) demonstrates disc herniation at the L4/5 level. (c,d) Preoperative axial MRI images reveal that the L5 nerve root originates at the level of the L4/5 disc space. The disc fragment is located superior to the shoulder, anterior to the shoulder, and within the axillary region of the L5 nerve root, corresponding to Type 2ABC in the PUTH classification. (e) Intraoperative C-arm fluoroscopic image. (f) Intraoperative endoscopic findings. The left side indicates cranial direction and the right side indicates caudal direction. The blue area represents the dural sac, the black area represents the nerve root, and the red dashed outline indicates the herniated disc fragment. (g) Complete intraoperative decompression confirms that the L5 nerve root originates at the level of the L4/5 disc space. (h,i) Immediate postoperative radiographs. (j-l) Immediate postoperative MRI demonstrates adequate decompression of the L5 nerve root. (m) Follow-up images obtained 35 months after surgery demonstrate sustained decompression without evidence of recurrent disc herniation.

NR, nerve root; DR, dura; DF, disc fragment; IS, intervertebral space.

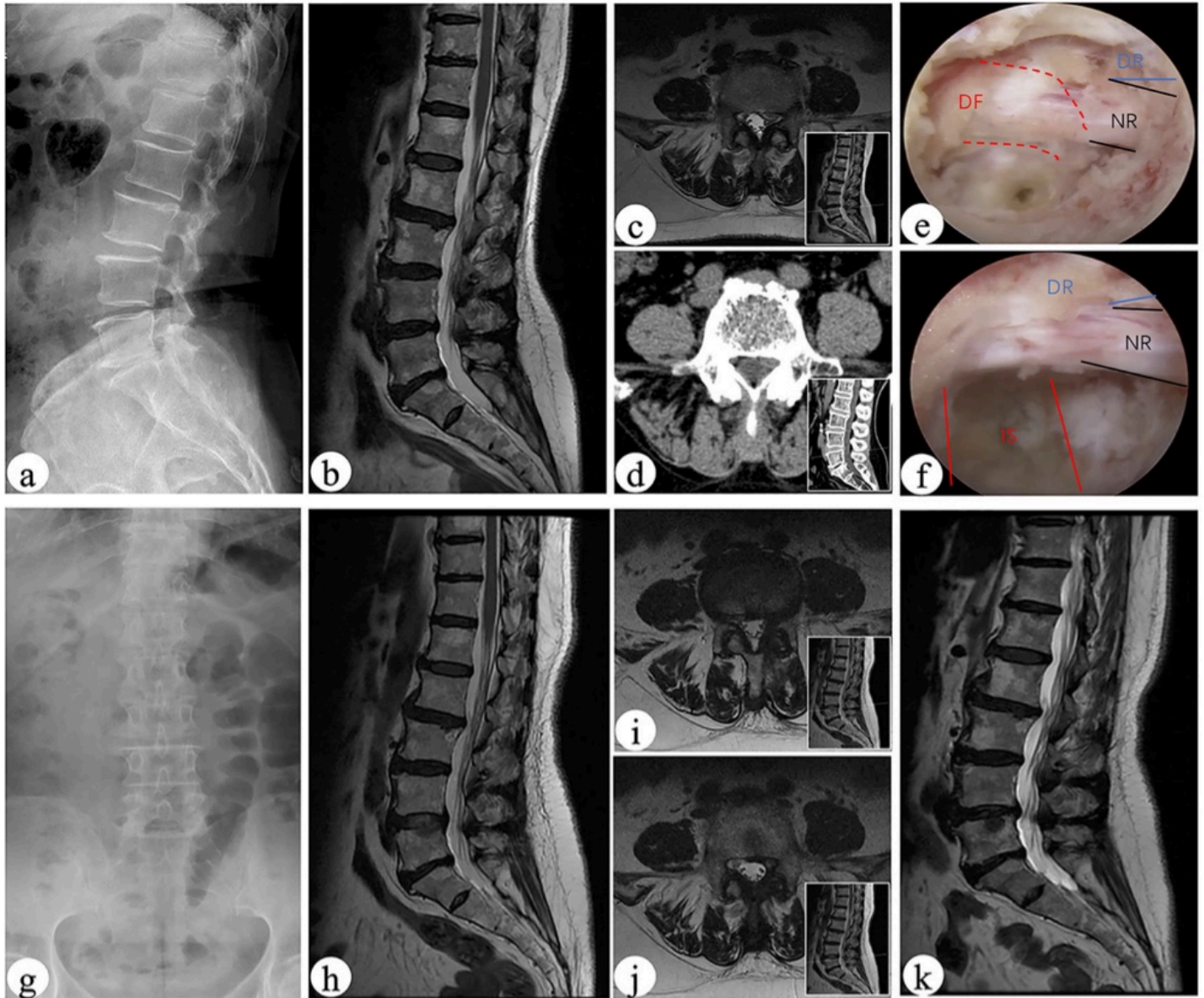


Figure 5

L45 Type 3AB

(a) Preoperative lateral radiograph. (b–d) Preoperative magnetic resonance imaging (MRI) and computed tomography (CT) demonstrate L4/5 disc herniation. The L5 nerve root originates caudal to the L4/5 disc space, and the left-sided disc fragment is located at the shoulder and anterior shoulder regions of the L5 nerve root, corresponding to Type 3AB in the PUTH classification. (e) Intraoperative endoscopic view. The left side indicates cranial direction and the right side indicates caudal direction. The blue area represents the dural sac, the black area represents the nerve root, and the red dashed outline indicates the herniated disc fragment. (f) Following complete decompression, the L5 nerve root, which originates caudal to the disc space, is fully released and restored to its anatomical position. (g) Immediate postoperative radiograph. (h–j) MRI obtained 3 months after surgery demonstrates adequate decompression. (k) Follow-up MRI obtained 46 months after surgery demonstrates sustained decompression at L4/5 without evidence of recurrent disc herniation.

NR, nerve root; DR, dura; DF, disc fragment; IS, intervertebral space.

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