Research Square

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Percutaneous microscopic lumbar discectomy via the trans-superior ligamentum flavum boundary approach for highly upward-migrated lumbar disc herniation: radiological and technical considerations

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Abstract

Background

Precise localization is critical for the minimally invasive removal of highly upward-migrated lumbar disc herniation (HUM-LDH), a procedure that conventionally relies on repeated intraoperative fluoroscopy. This study aimed to evaluate the radiological and clinical outcomes of percutaneous microscopic lumbar discectomy via the trans-superior ligamentum flavum boundary (trans-sup-LF) approach for HUM-LDH.

Methods

Patients with HUM-LDH (levels L2–L3 to L5–S1) who underwent percutaneous microscopic lumbar discectomy via the trans-sup-LF approach under general anesthesia were enrolled. All patients had a minimum follow-up of two years. Preoperative MRI measurements included the distances from the distal end of the herniated fragment to the SBLF (d1) and to the originating disc (d2), and from the spinous process root (point S) to the SBLF (h1) and to the disc (h2). Key perioperative parameters recorded included the number of intraoperative fluoroscopic exposures, estimated blood loss, operative time, and length of hospital stay.Clinical outcomes were assessed using the Visual Analog Scale (VAS) for back and leg pain, the Oswestry Disability Index (ODI), the Japanese Orthopaedic Association (JOA) score, and the modified Macnab criteria at the final follow-up.

Results

A total of 27 patients were enrolled. The mean preoperative distances were as follows: d1, 5.6 ± 1.9 mm; d2, 15.5 ± 2.1 mm; h1, 7.6 ± 0.7 mm; and h2, 2.8 ± 0.9 mm. All herniated fragments were completely removed via the trans-sup-LF approach, and no residual fragments or procedure-related complications were observed. The mean operative time was 60.2 ± 9.8 minutes, mean estimated blood loss was 34.2 ± 10.9 mL, and the mean number of intraoperative fluoroscopic exposures was 4.1 ± 1.7. At a mean follow-up of 817.9 ± 131.5 days, significant improvements were observed in the VAS score for back pain (from 6.1 ± 0.9 to 0.4 ± 0.5) and leg pain (from 6.6 ± 1.2 to 0.4 ± 0.5), as well as in the JOA score (from 15.2 ± 1.8 to 27.7 ± 1.9), and the ODI (from 69.4 ± 4.5% to 12.9 ± 1.8%; all *p* < 0.01). One patient experienced symptomatic recurrence and subsequently underwent fusion surgery.

Conclusions

The percutaneous microscopic trans-sup-LF approach appears to be a safe and effective alternative for the treatment of HUM-LDH. The SBLF may serve as a consistent and reliable intraoperative landmark, enabling precise localization and resection of HUM-LDH.

Introduction

Highly upward-migrated lumbar disc herniation (HUM-LDH) is a distinct and challenging subtype, accounting for approximately 5–10% of all lumbar disc herniations[1, 2]. The surgical management of HUM-LDH, which is primarily performed through microsurgical or endoscopic techniques, relies heavily on precise intraoperative localization of the migrated fragment[3].

Current localization strategies for the transforaminal approach typically rely on preoperative zoning systems that categorize the migration distance of the herniated nucleus pulposus (HNP)[4–6]. However, a significant limitation of these systems is the lack of reliable real-time anatomical landmarks during endoscopic visualization. This limitation frequently necessitates repeated intraoperative fluoroscopy, potentially increasing both radiation exposure and operative time. Moreover, when the HNP has migrated to the pedicle, it may obstruct the lateral surgical corridor, rendering a purely transforaminal approach technically challenging[7].

Alternative posterior approaches, such as interlaminar endoscopic discectomy or microsurgery, are commonly employed for the management of HUM-LDH[8, 9]. These techniques typically require partial removal of the lamina and the pars interarticularis (isthmus) to expose the cranially migrated HNP. However, the lack of a standardized method for accurately determining the optimal extent of bone removal during endoscopic visualization remains a persistent challenge. This may lead to either inadequate exposure or an unnecessarily extensive laminectomy.

Based on the anatomical relationship between the posterior bony landmarks of the lumbar spine and the ligamentum flavum, our group previously proposed a modified four-zone classification of the posterior lumbar spinal canal[10]. Among these zones, the trans-sup-LF approach is suited for lesions located near the SBLF. In our clinical practice, preoperative T2-weighted sagittal MRI revealed a consistent anatomical relationship: the distal end of the HUM-LDH was frequently located immediately superior to the SBLF. This observation led us to hypothesize that the trans-sup-LF approach is particularly suitable for the localization and removal of HUM-LDH. To validate this approach, we conducted a single-center study that measured preoperative MRI-based spatial relationships among the migrated HNP, the SBLF, the intervertebral disc, and a bony landmark defined as the caudal end of the spinous process root (point S). The aim of this study was to evaluate the clinical outcomes and complications of the trans-sup-LF approach for percutaneous removal of HUM-LDH using microscope-assisted tubular retraction.

Materials and methods

Clinical data collection

We retrospectively reviewed consecutive patients with HUM-LDH who underwent percutaneous microscopic discectomy via the trans-sup-LF approach between October 2021 and March 2024. The study was carried out in compliance with the Declaration of Helsinki and was approved by the Ethics Committee of the 904th Hospital of the Joint Logistics Support Force (Approval No: 20231015). Written

informed consent was provided by all participants and/or their legal guardians. The inclusion criteria were: (1) low back pain with radicular leg pain; (2) lumbar MRI and three-dimensional CT scans confirming upward migration of the nucleus pulposus, classified as "Superior high" or "Superior very high" according to established zoning systems [9]; and (3) failure of standard conservative treatment for at least 6 weeks, or the presence of significant or progressive neurological deficit, or intolerable pain. The exclusion criteria were: (1) radiographic findings inconsistent with clinical symptoms or signs; (2) multilevel lumbar disc herniation; (3) lumbar instability or spinal stenosis; (4) previous surgery at the index level; and (5) concomitant spinal infection, trauma, or metabolic bone disease.

Radiological measurements

Preoperative radiological measurements were performed independently by two senior spinal surgeons using the Carestream PACS imaging system (Centricity, GE Healthcare). On T2-weighted sagittal MRI sequences, a reference line was drawn parallel to the inferior endplate of the cranial vertebra adjacent to the pathological segment. The following parameters were then measured: (1) on the slice traversing the herniated nucleus pulposus, the distance from the distal end of the HNP to the SBLF (d1) and to the midpoint of the posterior margin of the intervertebral disc of origin (d2); (2) on the slice traversing the spinous process, the distance from point S to the SBLF (h1) and to the midpoint of the posterior margin of the intervertebral disc of origin (h2). All measurements were performed twice, and the mean values were used for subsequent analysis. A schematic representation of the measurement protocol is presented in Fig. 1.

All procedures were performed by two senior surgeons (L.F.S. and W.Z.), each with more than 10 years of experience. All patients provided written informed consent. A schematic illustration of the key surgical steps is presented in Fig. 2. Under general anesthesia, the patient was positioned in the prone position. The surgical table was adjusted to position the target disc space perpendicular to the floor. Intraoperative neurophysiological monitoring was employed. After confirming the pathological level with lateral fluoroscopy, a longitudinal skin incision, 1.6–1.8 cm in length, was marked 1.5 cm paramedian from the midline on the symptomatic side. Following standard aseptic preparation, an initial 6–8 mm skin incision was made. The junction of the spinous process root and the inferior lamina (point S) was palpated and identified (Fig. 3B). The incision was then extended cranially to a total length of 16–18 mm, with point S serving as the caudal endpoint. A sequential dilator system was used to establish a working channel with a 16-mm inner diameter. The channel was fixed with a retractor arm, and its position was confirmed with lateral fluoroscopy (Fig. 3C). After removing the overlying paravertebral musculature, point S was confirmed at the caudal end of the surgical field (Figs. 2B, 3D). A laminectomy was initiated at point S (Fig. 2A-□) using a 4-mm drill and was extended cranially to expose the attachment of the SBLF (Fig. 2A-□). The laminectomy was extended laterally to the transition zone between the SBLF and the spinal canal (Fig. 2A-□). Further cranial bone removal, approximately equal to the preoperatively measured distance d1, was performed to expose the dural sac (Fig. 2A-□). The SBLF was identified within the surgical corridor (Figs. 2C, 3E). The ligamentum flavum was resected, the dural sac was gently

retracted medially, and the herniated nucleus pulposus was identified and removed from the cranial aspect of the surgical field (Figs. 2C, 3F). The caudal region was explored for residual disc fragments. The surgical cavity was irrigated, and the wound was closed in layers.

Outcome measures

Outcome measures

The following general parameters were recorded: operative time, estimated intraoperative blood loss, number of intraoperative fluoroscopic exposures, length of hospital stay, follow-up duration, complications, and reoperations. Clinical outcomes were assessed using the Visual Analogue Scale (VAS) score for back pain and leg pain, the Japanese Orthopaedic Association (JOA) score, and the Oswestry Disability Index (ODI). These outcomes were evaluated preoperatively, at postoperative day 1, at 1 month, and at the final follow-up. Patient satisfaction was assessed at the final follow-up using the modified Macnab criteria. Lumbar stability was evaluated with dynamic radiographs, and postoperative MRI was performed to assess the adequacy of decompression and to detect recurrence.

Statistical analysis

Statistical analysis was performed using SPSS software (version 22.0). Categorical data are presented as counts and percentages. Normally distributed continuous data are expressed as mean ± standard deviation. Comparisons of clinical scores across different time points were analyzed using repeated-measures analysis of variance (ANOVA), with post-hoc pairwise comparisons conducted using the LSD test. $p < 0.05$ was considered statistically significant.

Results

Baseline clinical characteristics and demographic data

The study cohort comprised 27 patients. The cohort comprised 11 male and 16 female patients, with a mean age of 52.6 ± 9.1 years (range, 35–67 years). The mean preoperative duration of symptoms was 4.8 ± 2.1 weeks (range, 2–12 weeks). Radicular pain was localized to the left lower limb in 15 patients and to the right lower limb in 12 patients. According to the established zoning system [9], the herniation was classified as “Superior very high” in 19 patients and “Superior high” in 8 patients (Table 1).

Table 1
The main demographic data of the study patients.

Variable	Total HUM-LDH (n = 27) no. (%) or mean ± SD
Age (year)	52.6 ± 9.1
Sex	
Male	11 (40.7%)
Female	16 (59.3%)
Duration of symptoms (week)	4.8 ± 2.1
Side of disc herniation	
Left	15 (55.6%)
Right	12 (44.4%)
Degree of migrated disc herniation	
Superior very high	19 (70.4%)
Superior high	8 (29.6%)
Operative time (min)	60.2 ± 9.8
Blood loss (mL)	34.2 ± 10.9
C-arm fluoroscope method	
Anteroposterior	0 (0%)
Lateral	27 (100%)
Number of fluoroscopies	4.1 ± 1.7
Length of stay (day)	7.1 ± 1.3
Follow-up (day)	817.9 ± 103.2

Preoperative MRI parameters

The involved levels were L2–L3 in 6 patients, L3–L4 in 7 patients, L4–L5 in 9 patients, and L5–S1 in 5 patients. The mean distance from the distal end of the HNP to the SBLF (d1) was 5.6 ± 1.9 mm, and the mean distance from the distal end of the HNP to the midpoint of the intervertebral disc (d2) was 15.5 ± 2.1 mm. The mean distance from point S to the SBLF (h1) was 7.6 ± 0.7 mm, and the mean distance from point S to the midpoint of the intervertebral disc (h2) was 2.8 ± 0.9 mm. The preoperative MRI measurements are summarized in Table 2.

Table 2
Preoperative MRI parameters of the study patients (mm).

Segment	n	d1	d2	h1	h2
L2–3	6	5.1 ± 2.3	15.8 ± 2.6	8.0 ± 0.7	2.2 ± 0.7
L3–4	7	5.8 ± 1.1	17.2 ± 1.4	7.6 ± 0.5	2.5 ± 0.6
L4–5	9	6.1 ± 2.1	15.4 ± 1.2	7.9 ± 0.4	2.9 ± 0.7
L5–S1	5	4.9 ± 1.9	13.2 ± 1.5	6.9 ± 0.7	4.1 ± 0.4
Total	27	5.6 ± 1.9	15.5 ± 2.1	7.6 ± 0.7	2.8 ± 0.9

Surgical outcomes

The SBLF was successfully identified and exposed in all 27 patients. Subsequent limited laminectomy allowed for the successful localization and removal of the migrated HNP in all patients, without any intraoperative complications, including nerve root injury, dural tear, or infection. The mean operative time was 60.2 ± 9.8 minutes (range, 40–75 minutes), and the mean estimated intraoperative blood loss was 34.2 ± 10.9 mL (range, 20–60 mL). The mean number of intraoperative fluoroscopic exposures was 4.1 ± 1.7 (range, 2–6). The mean hospital stay was 7.1 ± 1.3 days (range, 6–11 days). Detailed surgical data are presented in Table 1.

Clinical efficacy and follow-up

The mean follow-up duration was 817.9 ± 131.5 days (range, 741–1456 days). At the final follow-up, all clinical outcome measures demonstrated significant improvement (all $p < 0.01$). The VAS score for back pain decreased from 6.1 ± 0.9 to 0.4 ± 0.5, and the VAS score for leg pain decreased from 6.6 ± 1.2 to 0.4 ± 0.5. The JOA score improved from 15.2 ± 1.8 to 27.7 ± 1.9, and the ODI decreased from 69.4% ± 4.5% to 12.9% ± 1.8%. One patient developed symptomatic recurrence at 9 months postoperatively and subsequently underwent fusion surgery. Follow-up imaging of the remaining 26 patients revealed no evidence of recurrent disc herniation, spondylolisthesis, laminar fracture, or spinal deformity. Detailed follow-up data are provided in Tables 3 and 4.

Table 3
Preoperative MRI parameters of the study patients .

Outcome	Preoperative	Post-1 day	Post-1 month	Final follow-up	F-value	*p*-value
VAS back pain	6.1 ± 0.9	1.8 ± 0.9*	0.8 ± 0.6*	0.4 ± 0.5*	304.3	< 0.001
VAS leg pain	6.6 ± 1.2	2.5 ± 0.7*	0.9 ± 0.6*	0.4 ± 0.5*	318.3	< 0.001
ODI score	69.4 ± 4.5	28.4 ± 4.1*	17.7 ± 2.3*	12.9 ± 1.8*	1575	< 0.001
JOA score	15.2 ± 1.8	20.4 ± 2.5*	25.5 ± 2.5*	27.7 ± 1.9*	175.9	< 0.001

VAS: visual analogue scale; ODI: Oswestry Disability Index; JOA: Japanese Orthopaedic Association Score.* Significantly different compared with the preoperative, p-value < 0.001.

Table 4
Functional outcomes and complications at final follow-up.

Variable	Total HUM-LDH (n = 27) no. (%)
Modified MacNab criteria	
Excellent	16 (59.3%)
Good	9 (33.3%)
Fair	2 (7.4%)
Poor	0 (0%)
Complications	
Spinal subdural empyema	0 (0%)
Neurological deterioration	0 (0%)
Reoperations	1 (3.7%)
Laminar fracture	0 (0%)
Spondylolisthesis	0 (0%)
Spinal deformity	0 (0%)

HUM-LDH: Highly upward-migrated lumbar disc herniation.

Discussion

The management of HUM-LDH has evolved with the adoption of minimally invasive techniques, including microscopic, endoscopic, and unilateral biportal endoscopic (UBE) approaches, performed through either interlaminar [5, 6, 18] or lateral [11–17] corridors. A central challenge common to all these

techniques is the precise intraoperative localization of the migrated fragment. Conventional methods rely heavily on determining the spatial relationship between the herniation and bony landmarks, such as the pedicle or vertebral body, using repeated fluoroscopy. However, fluoroscopy does not provide a real-time correlation with the surgical field. This limitation is particularly pronounced during posterior coaxial endoscopic procedures, in which only a restricted bone window is created. Without clear anatomical landmarks, the surgeon may encounter tissues with similar endoscopic appearances, such as epidural fat. This can lead to disorientation, repeated fluoroscopic confirmation, and, consequently, increased radiation exposure.

In this study, we employed the trans-sup-LF approach, which is based on our modified four-zone classification of the posterior lumbar spinal canal, to localize and remove highly upward-migrated disc fragments by exposing the SBLF within the tubular surgical field. The SBLF is a consistent and readily identifiable structure within the posterior spinal canal and has been recognized as an important landmark in minimally invasive spinal surgery[20, 21]. Our preoperative MRI analyses confirmed that, in most cases, the distal end of the migrated fragment was located cranial to the SBLF. By preoperatively measuring the distance from the herniated fragment to the SBLF, we established a reliable intraoperative guide for determining the required extent of cranial laminectomy after the SBLF was exposed. Using lateral fluoroscopy alone, the trans-sup-LF approach enabled successful localization and complete resection of all migrated fragments in our series, eliminating the need for anteroposterior views and thereby reducing radiation exposure.

Intraoperative identification of the SBLF was consistently facilitated by another key landmark—the caudal end of the spinous process root, which we designated point S. This osseous landmark is widely used in minimally invasive procedures because of its reliable anatomical position[20]. Our measurements showed that the mean distance from point S to the SBLF (h1) was 7.6 ± 0.7 mm, approximately half the internal diameter of the 16-mm working channel. When point S was positioned at the caudal edge of the surgical field during channel placement, a laminectomy extending cranially by a distance equivalent to approximately half the channel's diameter reliably exposed the SBLF near the midline.

Our surgical technique emphasizes a sequential, tactile-driven approach to initial localization. An initial 6–8 mm skin incision allows a straight clamp to be inserted, which is used to palpate the spinous process and is then advanced caudally until firm resistance is encountered at the junction between the spinous process root and the lamina. A distinct "drop-off" sensation, felt as the instrument passes caudal to this junction, confirms the location of point S. The skin incision is then extended cranially to a final length of 16–18 mm, and point S serves as the caudal endpoint prior to insertion of the working channel. This technique ensures reliable positioning of point S at the caudal edge of the surgical field, providing a fixed and reproducible starting point for the subsequent laminectomy and SBLF exposure.

Although some authors have reported satisfactory clinical outcomes following removal of the herniated fragment alone [22–24], we contend that, in posterior minimally invasive surgery for highly upward-

migrated disc herniations, it is essential to explore the annular defect site in addition to localizing and removing the migrated fragment. This allows removal of any loose disc material within the defect, thereby potentially reducing the risk of postoperative recurrence. Our analysis confirmed that point S is consistently located 2.8 ± 0.9 mm caudal to the intervertebral disc. By establishing the surgical corridor with point S at the caudal end of the surgical field, we achieve two key objectives: guiding exposure of the SBLF and providing the necessary access to explore and address the intervertebral disc space. This facilitates removal of both the migrated fragment and any potentially unstable disc material from the annular defect site.

This study has several limitations. First, the retrospective design and relatively small sample size from a single center may limit the generalizability of our findings. Second, the SBLF does not represent a uniform geometric structure. Moreover, the preoperative MRI measurements d1 (distance from the herniated fragment to the SBLF, measured on the slice traversing the HNP) and h1 (distance from point S to the SBLF, measured on the slice traversing the spinous process) were obtained from different sagittal planes. For less experienced surgeons, inadequate assessment of these landmarks may lead to failure to expose the SBLF. Third, similar to the classic interlaminar approach, the trans-sup-LF approach initiates bone removal at point S[25, 26]. However, use of the SBLF as a landmark necessitates additional cranial laminectomy to expose the portion of the dural sac not covered by the ligamentum flavum, which may increase the risk of excessive inferior lamina removal. Future research could explore techniques that preserve a portion of the inferior lamina and employ a simpler laminotomy to achieve exposure, thereby further reducing surgical trauma. Finally, given that coaxial endoscopy and UBE techniques[19, 27] lack a fixed tubular channel to provide an inherent depth reference, further investigation is warranted to determine whether a drill bit or other surgical instruments can serve as intraoperative references for guiding the extent of cranial laminotomy, thus obviating the need for channel-based spatial cues.

Conclusions

The superior boundary of the ligamentum flavum serves as a consistent and reliable intraoperative landmark for the trans-sup-LF approach in the percutaneous minimally invasive removal of highly upward-migrated lumbar disc herniations. The use of this landmark provides real-time guidance for determining the required extent of laminotomy, thereby enabling precise localization and exposure of the migrated fragment. While our technique demonstrates promising efficacy and a favorable safety profile, this study is limited by its single-center design, relatively small sample size, and mid-term follow-up duration. Future multicenter studies with larger sample sizes and longer follow-up are warranted to validate the long-term clinical outcomes and generalizability of this approach.

Abbreviations

HUM-LDH	Highly upward-migrated lumbar disc herniation
SBLF	Superior boundary of the ligamentum flavum

HNP Herniated nucleus pulposus

VAS Visual Analogue Scale

MRI Magnetic resonance images

JOA Japanese Orthopaedic Association Score

ODI Oswestry Disability Index

Declarations

Conflicts of interest:

None.

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Author Contribution

L.F.S.: Conceptualization, methodology, visualization, investigation, and writing—original draft. F.H.D.: Formal analysis, data curation, methodology. X.M.L.:writing - review & editing. D.K.N.: Methodology, supervision, writing—review and editing. Y.H.W.: Data curation, methodology. W.Z.: Conceptualization, methodology, writing—review and editing. All authors gave their consent for publication.

Data Availability

The original contributions presented in this study, including preoperative MRI measurements, intraoperative parameters, and clinical outcome scores, are included in the article tables. Further inquiries and de-identified participant data can be directed to the corresponding author and will be shared upon reasonable request, in accordance with institutional ethics committee policies.

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Figures

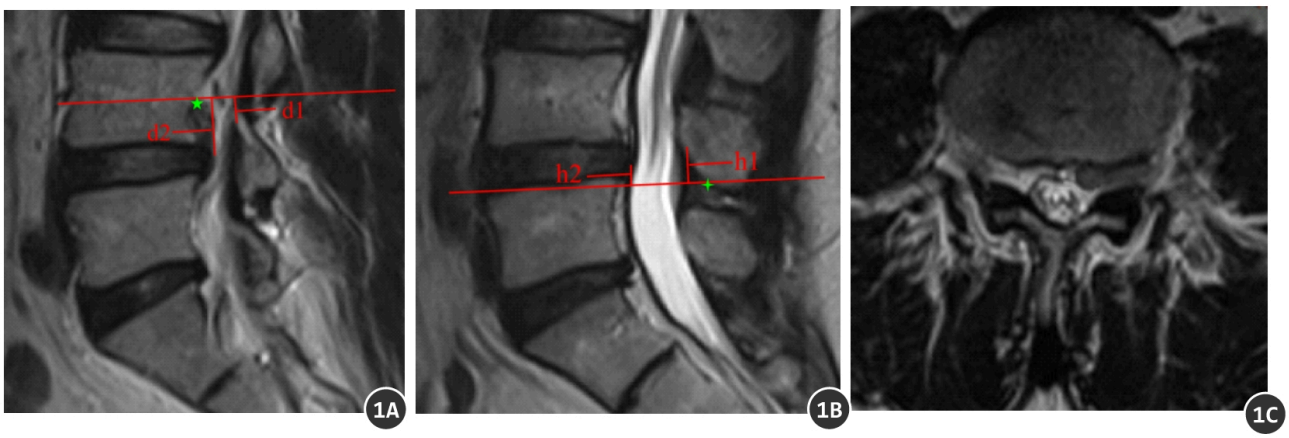


Figure 1

Schematic of MRI-based measurement protocol for a highly upward-migrated L4-5 disc herniation. (A) Sagittal view through the HNP measures: d1, distal HNP (green pentagram) to SBLF; d2, distal HNP to posterior disc margin midpoint. (B) Paramedian sagittal view through the spinous process measures: h1, point S (green signal) to SBLF; h2, point S to disc midpoint. (C) Corresponding T2-weighted axial image localizes the left-sided herniation.

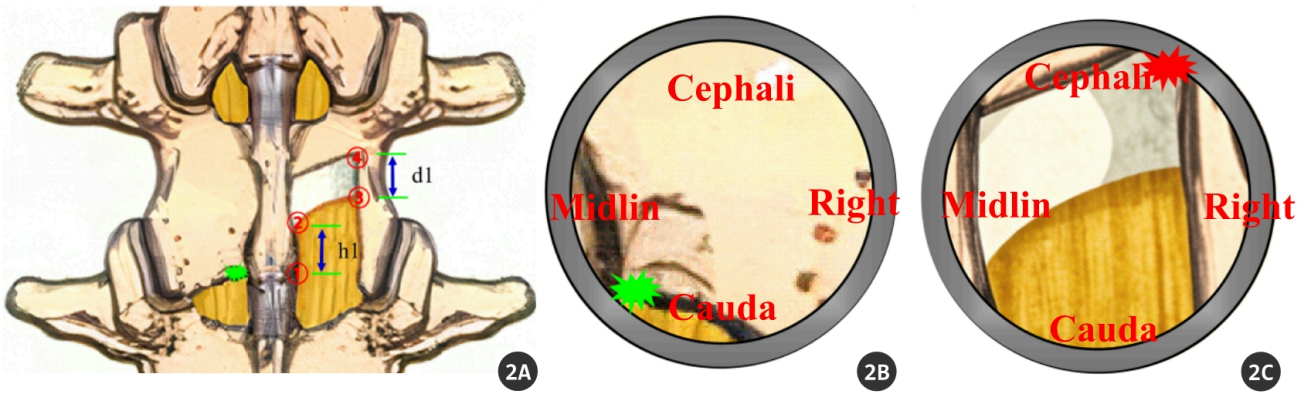


Figure 2

Surgical localization of a HUM-LDH using the SBLF. (A) Key surgical landmarks and bone removal steps. The green point marks point S, which serves as the starting point for laminectomy (). Subsequent steps involve exposing the midline () and lateral () attachments of the SBLF, followed by cranial bone removal to expose the dural sac (). The distance between and corresponds to the preoperative measurement h1, while the distance between and corresponds to d1. (B) Intraoperative view after tubular retractor

placement, with point S (green point) anchored at the caudal end of the surgical field. (C) Final surgical view after bone removal. The superior border of the ligamentum flavum is showed in the field, with the migrated herniated nucleus pulposus (red point) located cranially.

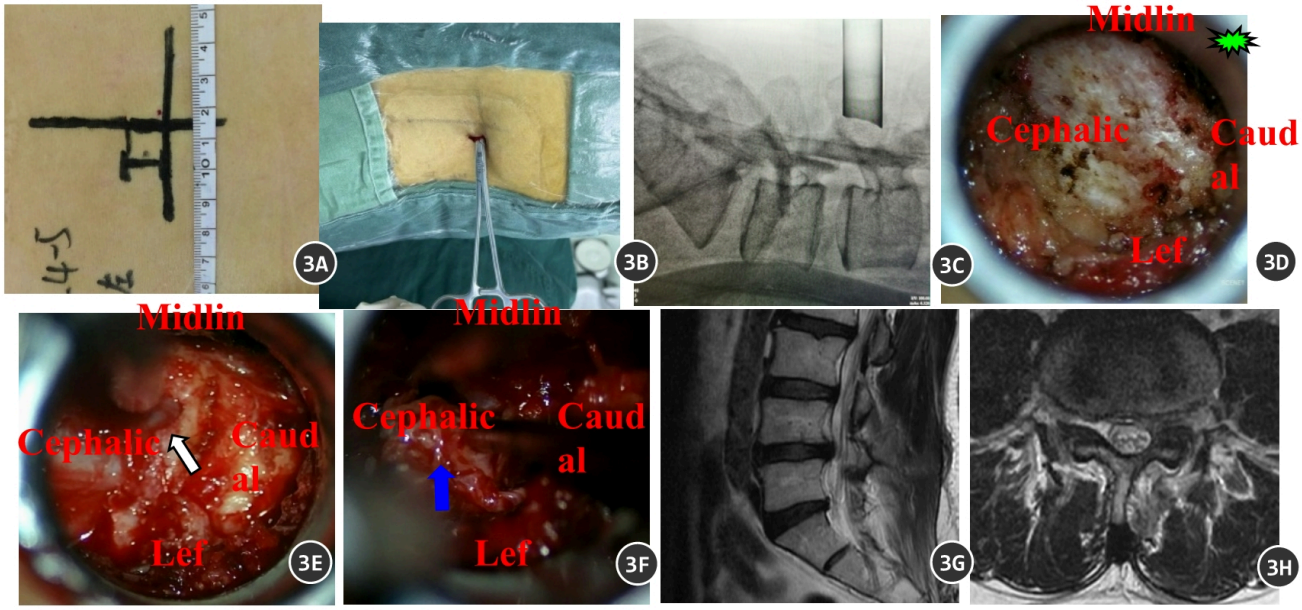


Figure 3

Surgical steps for resecting a HUM-LDH at the left L4-5 level. (A) Skin incision planning. (B) Initial incision and palpation of point S at the caudal endpoint. (C) Intraoperative fluoroscopy confirming the final tubular retractor position. (D) Surgical field after soft tissue removal, with point S (green point) visible at the caudal end. (E) Exposure of the superior border of the LF (white arrow) and dural sac following laminectomy. (F) The migrated herniated nucleus pulposus (blue arrow) is exposed after ligamentum flavum resection and dural retraction. (G, H) Postoperative MRI at 3 months (sagittal and axial view) confirming complete removal of the herniated fragment.