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A Comparative Study of the Efficacy of Unilateral Dual-Channel Endoscopic Targeted Resection of the S1 Superior Articular Process Tip versus MIS-TLIF in the Treatment of High-Level L5-S1 Extremely Lateral Disc Prolapse

YANCHUN XIE
General Hospital of Northern Theater Command
YI LIAN
General Hospital of Northern Theater Command
ANWU XUAN
General Hospital of Northern Theater Command
HONGWEN GU
General Hospital of Northern Theater Command
JUNCHAO LI
General Hospital of Northern Theater Command
HAILONG YU
yuhailong1116@126.com

General Hospital of Northern Theater Command

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Abstract

Objective

For L5-S1 extraforaminal lumbar disc herniation combined with a high iliac crest, conventional transforaminal endoscopic approaches are hindered by iliac crest obstruction, while minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) is associated with greater trauma and loss of segmental mobility. The rapid emergence of unilateral biportal endoscopy (UBE) provides a revolutionary solution to this challenge.This study aimed to compare the clinical efficacy and safety of UBE with targeted resection of the tip of the S1 superior articular process (SAP) (simple decompression) versus MIS-TLIF for the treatment of this condition.

Methods

A retrospective analysis was conducted on 450 patients (UBE group: 300; MIS-TLIF group: 150) treated between July 2022 and December 2024. Perioperative parameters, Visual Analog Scale (VAS) for pain, Oswestry Disability Index (ODI), modified MacNab excellent/good rate, and radiographic parameters were compared.

Results

The UBE group had a slightly longer operative time (68.5 vs. 58.2 min, $P < 0.001$), but significantly better outcomes in intraoperative blood loss (35.6 vs. 185.3 mL), postoperative hospital stay (3.2 vs. 5.8 d), and fluoroscopy times (4.2 vs. 8.5 times) (all $P < 0.001$). At 12 months postoperatively, there were no significant differences between the two groups in VAS, ODI, or the modified MacNab excellent/good rate at final follow-up (94.0% vs. 92.7%, $P > 0.05$). The UBE group showed faster pain relief in the early postoperative period (from 3 days to 3 months, $P < 0.05$), and a lower complication rate (4.7% vs. 8.0%, $P = 0.158$).

Conclusion

UBE with targeted resection of the SAP tip for high iliac crest L5-S1 extraforaminal herniation achieves comparable long-term efficacy to MIS-TLIF, while offering advantages of less trauma, faster recovery, and preservation of segmental mobility. It represents an ideal minimally invasive surgical option.

1. Introduction

Extraforaminal lumbar disc herniation (EFLDH) and far-out syndrome (FOS) occupy a unique anatomical and pathological position among degenerative spinal disorders. Unlike central herniations, which compress the dural sac, extraforaminal herniations directly compress the exiting nerve root (ENR) and dorsal root ganglion (DRG) at the same level. Patients typically present with severe, radiating pain in the lower limbs; conservative treatment has a high failure rate, and the vast majority require surgical intervention[1–3]. Within the entire lumbar spine, lesions in the extreme lateral region of the L5-S1 segment are considered the ‘pinnacle of difficulty’ in minimally invasive spinal surgery[4]. In 1984, Wiltse et al. first proposed the concept of the extreme lateral syndrome, noting that the L5 exit nerve root is often constrained within the narrow space between the inferior margin of the L5 transverse process and the sacral wing, and is subjected to multiple compressions from a herniated disc, a thickened interspinous ligament, and the tip of the S1 superior articular process (SAP)[2]. More seriously, a significant proportion of patients exhibit the anatomical variant known as a ‘high iliac crest’. When, on lateral imaging, the highest point of the iliac crest extends beyond the midpoint of the L5 pedicle, this variant completely obstructs the natural pathway into the extreme lateral region from the lateral approach in terms of spatial geometry[5]. Research by Choi et al. indicates that when the iliac crest extends beyond the midpoint of the L5 pedicle, the puncture angle for transforaminal endoscopic lumbar discectomy (TELD) is forced to exceed 45°, resulting not only in a significant decrease in the success rate of puncture but also a substantial increase in the risk of nerve root injury[6]. Faced with this anatomical impasse, conventional single-channel percutaneous endoscopes encounter significant physical obstruction. To bypass the iliac crest, surgeons are forced to adopt an extremely steep puncture angle, causing the tip of the working sheath to directly compress the sensitive L5 exit nerve root, thereby greatly increasing the risk of iatrogenic nerve injury[7, 8]. At the same time, blind circular saw foraminoplasty, performed within the confined deep space of the L5–S1 level, is not only time-consuming but also carries risks of massive haemorrhage from the plexus, dural tear and exposure to high doses of fluoroscopic radiation[9]. On the other hand, Although traditional open surgery or the Wiltse approach under a microscope can expose the extreme lateral region, the limitations of the microscope’s linear light path necessitate extensive dissection of the multifidus muscle and substantial resection of the facet joints and part of the isthmus. This results in irreversible iatrogenic posterior column instability, compelling surgeons to ultimately resort to transforaminal lumbar interbody fusion (TLIF) for fusion and stabilisation. This not only deprives the patient of

lifelong mobility at that level and accelerates degeneration in adjacent segments, but also significantly increases the burden on healthcare economics[10].

Against this backdrop, the rapid emergence of unilateral biportal endoscopy (UBE) has provided a revolutionary solution to this challenge. By physically separating the high-resolution endoscopic viewing channel from the instrument manipulation channel, UBE technology has completely overcome the limitations of coaxial manipulation—namely restricted visual fields and instrument rigidity—thereby enabling the anatomical reconstruction required for the concept of extreme lateral decompression. Unlike the lateral puncture technique used in PELD, UBE employs a posterior-to-anterior working trajectory, thereby skilfully circumventing the lateral physical obstruction posed by the high iliac crest; simultaneously, the continuous fluid irrigation system creates a clear 'water cavity' within the narrow extraforaminal space, enabling a virtually bloodless surgical field of view[5, 11]. More importantly, the core procedure of UBE—the targeted resection of the tip of the S1 superior articular process—precisely relieves the 'pincer-like' compression of the nerve root. Biomechanical studies have confirmed that limited resection of the SAP tip (approximately 5–8 mm) results in only a slight increase in mobility in the anteroposterior and sagittal planes, whilst mobility in the flexion-extension, lateral bending and axial rotation planes shows no significant difference from the natural state, thus perfectly balancing adequate decompression with structural preservation[12]. However, current clinical studies on the use of UBE to target the tip of the SAP for the treatment of L5-S1 extreme lateral disc protrusion combined with a high iliac crest are predominantly small-sample case reports, and there is a lack of systematic validation based on large-scale data. This study retrospectively analysed the clinical data of 300 patients with L5-S1 extreme lateral disc protrusion complicated by high iliac crest who underwent UBE surgery at our hospital between July 2022 and December 2024. The aim was to evaluate the clinical efficacy, radiological decompression outcomes and safety of this technique, and to explore its clinical value as a new minimally invasive surgical option for 'de-fusion and functional preservation'.

2. Materials and Methods

2.1 Study Design and Patient Selection

This study is a retrospective cohort study that consecutively enrolled patients who underwent surgical intervention for extremely lateral L5-S1 disc herniation complicated by high iliac crest impingement at our hospital's Department of Spinal Surgery between July 2022 and December 2024. Patients were divided into two groups based on the surgical procedure: the UBE group (who underwent UBE-guided resection of the SAP apex with simple decompression) and the MIS-TLIF group (who underwent minimally invasive transforaminal lumbar interbody fusion).

Inclusion criteria for the UBE group: (1) Radiating pain in one lower limb, confirmed by imaging (CT/MRI) as a highly lateral L5-S1 disc herniation (including the intervertebral foramen region and extraforaminal types); (2) Lateral X-rays consistent with the definition of a high iliac crest (the highest point of the iliac crest exceeds the midpoint of the L5 pedicle); (3) Failure to respond to rigorous conservative treatment (medication, physiotherapy, etc.) for at least 6 weeks; (4) Undergoing UBE-guided resection of the SAP apex performed by the same surgeon.

Inclusion criteria for the MIS-TLIF group: (1) The criteria for diagnostic failure and failure of conservative treatment were the same as those for the UBE group; (2) Patients underwent MIS-TLIF surgery (single-level fusion and internal fixation) performed by the same surgeon.

Common exclusion criteria for both groups: (1) Multilevel disc herniation or stenosis; (2) Lumbar instability (change in intervertebral angle > 10° on dynamic X-rays or horizontal displacement > 3 mm), isthmic fracture or spondylolisthesis (Meyerding grade ≥ I); (3) History of previous surgery at the same level; (4) Concurrent spinal infection, tumour, fracture or severe osteoporosis (T-score ≤ -2.5); (5) Severe medical conditions rendering the patient unable to tolerate surgery, or incomplete follow-up data.

2.2 Surgical Techniques

2.2.1 Surgical Procedure in the UBE Group

All procedures were performed by the same senior spinal surgeon using a standardised UBE paraspinal approach. Positioning and anaesthesia: Following general anaesthesia, the patient was positioned prone with the abdomen elevated, and the L5–S1 segment was localised using a C-arm. Tract Creation: Two longitudinal incisions, each approximately 1 cm in length, are made approximately 1.5 cm and 3.5 cm lateral to the spinous process on the affected side, serving as the endoscopic observation channel and the instrument manipulation channel, respectively. Following stepwise dilation, a semi-cannula is inserted to establish the working space, and continuous saline irrigation is initiated (pressure 30–40 mmHg, flow rate approximately 300 mL/min).Targeted resection of the SAP tip: Expose the tip of the superior articular process of S1 and the inferior margin of the L5 transverse process. Use a 3 mm diamond ball burr to precisely grind away the tip of the SAP (the extent of resection is determined by preoperative CT measurements, typically 5–8 mm) until the dorsal aspect of the L5 nerve root at the exit is exposed. Subsequently, probe and remove protruding nucleus pulposus tissue, and release the thickened interspinous ligament to ensure the nerve root is completely relaxed and free from compression. Criteria for decompression: The nerve root moves freely, the dural pulsation is good, and no residual compressive structures are found on palpation of the axillary and ventral aspects. Closure of the incision: Withdraw the instruments, place a drainage tube (24–48 h), and suture the incision.

2.2.2 Surgical technique for the MIS-TLIF group

Standard MIS-TLIF technique was employed: Positioning and anaesthesia: As in the UBE group. Approach and exposure: Following C-arm guidance, a longitudinal incision (approximately 3–4 cm in length) was made approximately 3–4 cm lateral to the spinous process on the affected side. Tissue was dissected layer by layer, and access was gained via the Wiltse approach (the interval between the multifidus and longissimus muscles). An expandable channel system was placed to expose the facet joints and laminae. Decompression and fusion: Under microscopic guidance, perform partial resection of the facet joint and foraminotomy to decompress the intervertebral foramen, exposing and protecting the exiting nerve root. Resect the intervertebral disc, prepare the endplates, and implant an intervertebral fusion cage filled with autologous bone. Place a percutaneous pedicle screw system to achieve unilateral or bilateral fixation. Closure of the incision: Place a drainage tube and close the incision layer by layer.

2.3 Observation indicators

2.3.1 Perioperative indicators

Record the duration of the operation (from skin incision to closure), the number of fluoroscopy procedures, intraoperative blood loss (estimated by subtracting the volume of irrigation fluid from the volume of fluid collected by the suction device), postoperative drainage output, length of hospital stay, and complications (such as dural tear, nerve root injury, haematoma, infection, retroperitoneal fluid collection, and complications related to internal fixation).

2.3.2 Assessment of clinical efficacy

Visual Analogue Scale (VAS): Used to assess lower back pain and leg pain separately (0 = no pain, 10 = severe pain), recorded preoperatively and at 3 days, 1 month, 3 months, 6 months, 12 months and the final follow-up.

Oswestry Disability Index (ODI): Assesses lumbar function (0%–100%; higher scores indicate greater disability), recorded preoperatively and at 3, 6, 12 months postoperatively, and at the final follow-up.

Modified MacNab criteria: Patient satisfaction with treatment outcomes was assessed at the final follow-up, categorised as excellent (complete resolution of symptoms, return to normal work and daily life), good (occasional mild symptoms, no functional impairment), fair (symptoms improved but partial functional impairment remains), or poor (no improvement or worsening of symptoms).

2.3.3 Imaging assessment

CT measurements (both groups): Thin-section lumbar CT scans (1 mm slice thickness) were performed preoperatively and at 3 months postoperatively. The length of the resected SAP tip (mm) was measured in the coronal and sagittal planes (UBE group only), and the sagittal diameter and area of the intervertebral foramen were measured at the pedicle level (using ImageJ software).

MRI assessment (both groups): Lumbar MRI (T2-weighted images) was performed preoperatively and at 3 months postoperatively to observe the recovery of cerebrospinal fluid signal around the nerve roots and confirm adequate decompression.

Fusion assessment (MIS-TLIF group): Lumbar CT was performed at 6 and 12 months postoperatively, and intervertebral fusion was assessed according to the Bridwell criteria or Suk classification.

Lumbar Spinal Stability Assessment (both groups): Dynamic X-rays of the lumbar spine were taken preoperatively and at the final follow-up to measure changes in intervertebral angles (flexion and extension) and horizontal displacement, and to determine the presence of segmental instability (criteria: angle change > 10°or displacement > 3 mm).

2.4 Statistical Analysis

Statistical analysis was performed using SPSS 26.0 software. Continuous variables are expressed as mean ± standard deviation (x ± s), whilst categorical variables are presented as frequencies and percentages (%). Comparisons between groups: Comparisons of continuous variables between the two groups were performed using the independent samples t-test (for normally distributed data) or the Mann-Whitney U test (for non-normally distributed data); comparisons of categorical data were performed using the chi-square test or Fisher's exact test. Intra-group comparisons: Comparisons of VAS and ODI scores between preoperative and postoperative time points were performed using repeated measures analysis of variance (ANOVA), with Bonferroni correction applied for multiple comparisons. A p-value of < 0.05 was considered statistically significant.

3. Results

3.1 Baseline patient data

A total of 450 patients were enrolled, comprising 300 in the UBE group and 150 in the MIS-TLIF group. There were no statistically significant differences (P > 0.05) between the two groups in terms of baseline characteristics such as age, sex, BMI, side of the lesion, type of herniation and duration of symptoms; the groups were therefore comparable. Detailed baseline data are shown in Table 1.

Table 1
Comparison of baseline characteristics between the two groups of patients

Variable	UBE group(n = 300)	MIS-TLIF group(n = 150)	t/χ^2value	P value
Age	52.6 ± 11.3	53.2 ± 10.8	0.542	0.588
Sex(male/female)	172/128	81/69	0.478	0.489
BMI(kg/m²)	24.8 ± 3.2	25.1 ± 3.4	0.923	0.357
Lateral side of lesion(left/right)	163/137	78/72	0.186	0.666
Highlight type (intervertebral foramen type/ultra-lateral type)	188/112	96/54	0.102	0.749
Duration of symptoms (months)	8.5 ± 4.6	8.8 ± 4.9	0.635	0.526
Follow-up duration (months)	18.5 ± 5.2	18.2 ± 5.5	0.564	0.573

3.2 Comparison of perioperative indicators

Surgery was successfully completed in both patient groups, with no cases requiring conversion to open surgery. The operative time was longer in the UBE group than in the MIS-TLIF group (P < 0.05); however, intraoperative blood loss, postoperative drainage volume and postoperative hospital stay were all significantly better in the UBE group than in the MIS-TLIF group (P < 0.05). The number of fluoroscopic views was significantly lower in the UBE group than in the MIS-TLIF group (P < 0.001). See Table 2 for a detailed comparison.

Table 2
Comparison of perioperative parameters between the two groups

Index	UBE group(n = 300)	MIS-TLIF group(n = 150)	t value	P value
Operating time(min)	68.5 ± 15.3	58.2 ± 12.6	7.065	< 0.001
The number of fluoroscopic views(time)	4.2 ± 1.1	8.5 ± 2.3	25.147	< 0.001
intraoperative blood loss(mL)	35.6 ± 12.4	185.3 ± 42.5	52.681	< 0.001
postoperative drainage volume(mL)	28.4 ± 10.2	156.7 ± 38.9	49.236	< 0.001
postoperative hospital stay(day)	3.2 ± 1.1	5.8 ± 1.5	20.351	< 0.001

3.3 Comparison of clinical efficacy

VAS scores: In both groups, VAS scores for low back pain and leg pain at all postoperative time points were significantly lower than preoperative scores (P < 0.001). Intergroup comparisons showed that the VAS scores for low back pain in the UBE group were significantly lower than those in the MIS-TLIF group at 3 days, 1 month and 3 months post-operatively (P < 0.05), whilst the VAS scores for leg pain were significantly lower in the UBE group than in the MIS-TLIF group at 3 days and 1 month post-operatively (P < 0.05); there were no statistically significant differences between the two groups at 6 months and beyond (P > 0.05). See Table 3 and Fig. 1 for detailed data.

Table 3
Comparison of clinical efficacy indicators between the two groups

Index	Group	Preoperative	3 days postoperatively	1 month postoperatively	3 months postoperatively	6 months postoperatively	12 months postoperatively	Last follow-up
backache VAS	UBE group	5.2 ± 1.4	2.8 ± 0.9*#	2.4 ± 0.8*#	2.1 ± 0.7*#	1.9 ± 0.7*	1.8 ± 0.8*	1.8 ± 0.9*
	MIS-TLIF group	5.3 ± 1.3	3.2 ± 0.8*	2.8 ± 0.7*	2.4 ± 0.6*	2.0 ± 0.6*	1.8 ± 0.7*	1.7 ± 0.8*
leg pain VAS	UBE group	7.8 ± 1.2	2.5 ± 0.8*#	2.1 ± 0.7*#	1.8 ± 0.6*	1.7 ± 0.6*	1.6 ± 0.7*	1.6 ± 0.8*
	MIS-TLIF group	7.7 ± 1.3	2.9 ± 0.7*	2.4 ± 0.6*	2.0 ± 0.5*	1.8 ± 0.5*	1.6 ± 0.6*	1.5 ± 0.7*
ODI(%)	UBE group	65.3 ± 12.1	-	-	28.7 ± 9.3*#	21.5 ± 8.1*	18.9 ± 7.8*	18.2 ± 8.5*
	MIS-TLIF group	64.8 ± 11.8	-	-	32.4 ± 8.7*	23.2 ± 7.6*	19.5 ± 7.2*	18.6 ± 7.9*

*Compared with the preoperative values in the same group, $P < 0.05$; #Compared with the MIS-TLIF group at the same time point, $P < 0.05$

ODI score: The ODI score improved significantly in both groups compared with preoperative levels ($P < 0.001$). The ODI score in the UBE group was significantly lower than that in the MIS-TLIF group at 3 months postoperatively ($P < 0.05$); there was no statistically significant difference between the two groups at 6 months postoperatively and thereafter ($P > 0.05$). See Table 3.

Modified MacNab criteria: At the final follow-up, the rate of 'good' or 'excellent' outcomes was 94.0% (282/300) in the UBE group and 92.7% (139/150) in the MIS-TLIF group; the difference between the two groups was not statistically significant ($\chi^2 = 0.283$, $P = 0.595$)(Table 3).

3.4 Imaging results

UBE group: CT scans at 3 months post-operatively showed that the mean resection length at the tip of the SAP was 6.8 ± 1.2 mm (range 4.5–9.2 mm). The sagittal diameter of the intervertebral foramen increased from 7.2 ± 1.1 mm pre-operatively to 10.5 ± 1.3 mm post-operatively ($P < 0.001$); the foramen area increased from 85.3 ± 15.6 mm² preoperatively to 128.7 ± 18.4 mm² postoperatively, representing an average increase of 51.2% ($P < 0.001$). MRI at 3 months post-operation showed clear cerebrospinal fluid signal around the nerve roots in all patients, with no residual compression.

MIS-TLIF group: CT scans at 3 months post-operatively showed that the sagittal diameter of the intervertebral foramen increased from 7.1 ± 1.2 mm pre-operatively to 10.8 ± 1.4 mm post-operatively ($P < 0.001$); the foramen area increased from 84.6 ± 16.2 mm² preoperatively to 130.2 ± 19.1 mm² postoperatively, representing an average increase of 53.8% ($P < 0.001$). CT scans at 12 months post-operatively showed a vertebral fusion rate of 94.7% (142/150), comprising 118 cases (78.7%) of Bridwell Grade I, 24 cases (16.0%) of Grade II, and 8 cases (5.3%) of Grade III.

Stability assessment: Radiographs of the dynamic level at the final follow-up showed that in the UBE group, the intervertebral angle change was 4.2 ± 1.8°, and the horizontal displacement was 1.3 ± 0.6 mm; in the MIS-TLIF group, the change in intervertebral angle was 2.1 ± 1.2°, and the horizontal displacement was 0.8 ± 0.4 mm. Neither group exceeded the criteria for segmental instability; however, due to the presence of internal fixation, the MIS-TLIF group exhibited significantly less mobility than the UBE group ($P < 0.05$)(Table 4).

Table 4
Comparison of radiological parameters between the two groups

Index	time point	UBE group(n = 300)	MIS-TLIF group(n = 150)	P-value for intergroup comparison
sagittal diameter of intervertebral foramen(mm)	Preoperative	7.2 ± 1.1	7.1 ± 1.2	0.423
	3 months postoperatively	10.5 ± 1.3*	10.8 ± 1.4*	0.058
Intervertebral foramen area(mm^2)	Preoperative	85.3 ± 15.6	84.6 ± 16.2	0.674
	3 months postoperatively	128.7 ± 18.4*	130.2 ± 19.1*	0.436
Changes in intervertebral angle(°)	Last follow-up	4.2 ± 1.8	2.1 ± 1.2	< 0.001
horizontal shift(mm)	Last follow-up	1.3 ± 0.6	0.8 ± 0.4	< 0.001
*Compared with preoperative values within the same group, P < 0.05				

3.5 Comparison of Complications

The incidence of complications was lower in the UBE group than in the MIS-TLIF group, but the difference was not statistically significant (4.7% vs. 8.0%, P = 0.158). In the UBE group, transient sensory abnormalities were the most common, whereas in the MIS-TLIF group, incision-related and internal fixation-related complications were the most common.(Table 5)

Table 5
Comparison of complications between the two groups [n (%)]

Types of complications	UBE group(n = 300)	MIS-TLIF group(n = 150)	χ^2value	P value
Dural tear	2(0.7)	3(2.0)	1.506	0.220
Nerve root injury (transient)	11(3.7)	4(2.7)	0.315	0.575
Nerve root injury (permanent)	0(0)	1(0.7)	-	0.333*
Postoperative hematoma	1(0.3)	1(0.7)	-	0.537*
infection of incisional wound	0(0)	2(1.3)	-	0.109*
Internal fixation loosening/fracture	-	1(0.7)	-	-
Deposition of intervertebral fusion device	-	0(0)	-	-
total	14(4.7)	12(8.0)	1.995	0.158
*Fisher exact propability				

3.6 Typical cases

Figure 1: A 48-year-old female patient with extreme lateral disc herniation at the L5-S1 segment achieved adequate spinal canal decompression following superior uterine bony endosteal (UBE) resection of the S1 superior articular process. Preoperative lumbar anteroposterior and lateral X-ray films revealed the presence of a high iliac crest (A1-2). Preoperative CT (B1-3) and MRI (C1-3) examinations indicated extreme lateral disc herniation at the L5-S1 level. Intraoperative UBE fluoroscopic localization imaging (D1-2) was performed. Postoperative CT (E1-3) and MRI (F1-3) examinations confirmed that the S1 superior articular process tip was resected intraoperatively, the disc was removed, and adequate spinal canal decompression was achieved.

4. Discussion

4.1 Key findings and clinical implications

Based on clinical data from 450 patients with L5-S1 extreme lateral disc herniation complicated by a high iliac crest, this study is the first to systematically compare the clinical efficacy and safety of UBE-guided decompression of the SAP apex versus MIS-TLIF fusion and internal fixation. The results showed that: (1) There were no significant differences between the two groups in terms of long-term (6 months post-operatively and beyond) improvements in the VAS scores for low back pain and leg pain, or in the ODI disability index. At the final follow-up, the rates of ‘good’ or ‘excellent’ outcomes on the modified MacNab scale were 94.0% and 92.7% respectively (P > 0.05), which is consistent with the

findings of Lee et al[13]. (2) The UBE group showed significantly better perioperative outcomes (intraoperative blood loss, postoperative drainage volume, length of hospital stay, and number of fluoroscopy sessions) than the MIS-TLIF group ($P < 0.001$), which is consistent with the findings of Bahir et al[14]. (3) The UBE group experienced faster pain relief and functional recovery in the early postoperative period (3 days to 3 months) ($P < 0.05$). (4) Imaging studies confirmed that both groups achieved adequate foraminotomy, with comparable degrees of foramen enlargement (51.2% vs. 53.8%, $P > 0.05$). (5) The incidence of complications was lower in the UBE group than in the MIS-TLIF group (4.7% vs. 8.0%), but the difference was not statistically significant ($P = 0.158$). The results of this study indicate that for L5-S1 extreme lateral disc herniation complicated by a high iliac crest, targeted resection of the SAP apex via UBE with simple decompression can achieve long-term clinical outcomes comparable to those of MIS-TLIF without the need for fusion and internal fixation. At the same time, it offers significant advantages in terms of minimally invasiveness, early rehabilitation and radiation exposure, providing a new minimally invasive treatment option for lesions in this complex anatomical region that prioritises 'avoiding fusion and preserving function'[15].

4.2 Equivalent long-term efficacy: is fusion necessary?

One of the key findings of this study is that there was no significant difference in the degree of improvement in VAS and ODI scores between the UBE group and the MIS-TLIF group at 6 months post-surgery and beyond, with comparable rates of excellent outcomes. This result challenges conventional treatment principles: is fusion necessary for extremely lateral protrusions without clear instability? The theoretical basis and controversies surrounding fusion surgery: The traditional view holds that resection of part of the facet joint to expose the extreme lateral region may lead to iatrogenic instability, and therefore fusion and internal fixation are required to provide 'insurance'. However, this logic presents two potential issues: firstly, not all facet joint resections result in clinically significant instability; and secondly, fusion surgery itself introduces new problems—such as adjacent segment disease (ASD), complications associated with internal fixation, and loss of range of motion. A study by Shin et al. showed that the incidence of ASD five years after MIS-TLIF surgery was 35.23%, and that this rate increased gradually over time[16]. Chen et al. reported that the incidence of contralateral nerve root pathology following TLIF was 5.3%; inappropriate unilateral TLIF can reduce posterior disc height and foramen parameters, thereby leading to contralateral nerve root pathology[17]. The'de-fusion'strategy of UBE: In this study, the UBE group achieved adequate decompression through targeted resection of the SAP tip (mean 6.8 mm), whilst preserving the main structure of the articular process and its load-bearing function. A study by Merter et al. demonstrated that the UBE technique can achieve adequate decompression whilst preserving the main structure of the zygapophyseal joint, with a postoperative preservation rate of the IAP area of approximately 70–74%[18]. Biomechanical studies have confirmed that resection within this range results in only a slight increase in mobility in the anteroposterior and posterior-anterior planes, whilst having no significant effect on flexion-extension, lateral bending or rotational stability; this is consistent with the findings of Lee et al[19]. Dynamic radiographs at the final follow-up showed that neither the change in intervertebral angle (4.2° ± 1.8°) nor the horizontal displacement (1.3 ± 0.6 mm) in the UBE group exceeded the instability threshold, confirming the biomechanical safety of this procedure. Therefore, for patients without preoperative instability, UBE decompression alone is sufficient to achieve good long-term outcomes, and fusion is not essential. Luo et al found that the outcomes of the UBE decompression-only group were comparable to those of the UBE-PLIF fusion group (93% vs 90% achieving good or excellent results), with significantly better perioperative parameters, further confirming that fusion is not necessary for patients without preoperative instability[20].

4.3 Perioperative Benefits: A Quantitative Manifestation of the Minimally Invasive Approach

The UBE group's comprehensive advantage in perioperative indicators quantifies its minimally invasive nature across multiple dimensions. In terms of blood loss: intraoperative blood loss in the UBE group (35.6 mL) was less than one-fifth of that in the MIS-TLIF group (185.3 mL), whilst postoperative drainage volume (28.4 mL) was only one-sixth of that in the MIS-TLIF group (156.7 mL). In terms of hospital stay and utilisation of medical resources: the postoperative hospital stay in the UBE group (3.2 days) was 44.8% shorter than that in the MIS-TLIF group (5.8 days), implying lower utilisation of medical resources and a faster return to work. Although this study did not conduct a direct health economic analysis, when combined with savings on internal fixation materials, the economic advantages of UBE are evident. Regarding radiation exposure: the number of fluoroscopic examinations in the UBE group (4.2) was only half that of the MIS-TLIF group (8.5). This difference stems from the technical characteristics of the two procedures: UBE utilises a posterior longitudinal approach with clear anatomical landmarks, eliminating the need for repeated adjustments to the puncture angle; whereas the percutaneous screw placement process in MIS-TLIF requires multiple fluoroscopic examinations to confirm positioning. This advantage holds significant clinical importance for the radiation protection of both medical staff and patients.

4.4 Advantages in Early Recovery: Mechanistic Analysis and Clinical Implications

It is worth noting that the UBE group demonstrated significantly better VAS scores at 3 days, 1 month and 3 months post-operatively, as well as a significantly lower ODI score at 3 months post-operatively, compared with the MIS-TLIF group, suggesting that UBE patients recover more rapidly in the early post-operative period. This phenomenon can be explained by the following mechanisms: Differences in Muscle Injury: Although MIS-TLIF is a minimally invasive approach, it still requires the placement of an expandable channel through the Wiltse's space, which causes a certain degree of compression and traction injury to the multifidus muscles[21]. Discomfort associated with internal fixation: In the early postoperative

period following MIS-TLIF, some patients may experience a foreign body sensation or muscle irritation associated with the internal fixation devices; UBE completely avoids this issue. This finding has significant clinical implications: for active individuals who need to return to work as soon as possible or who seek a higher quality of life, the advantage of early recovery offered by UBE may be a key factor in the choice of surgical procedure[13].

4.5 Comparative Interpretation of Imaging Findings

In both groups, the postoperative sagittal diameter and area of the intervertebral foramen were significantly enlarged, and the degree of enlargement was comparable (P > 0.05), indicating that both surgical techniques achieve effective intervertebral foramen decompression. However, the mechanisms by which decompression was achieved differed markedly. UBE group: This study involves the targeted resection of the tip of the SAP to directly release the dorsal 'pincer-like compression', whilst preserving the main body of the articular process. This constitutes an 'anatomical reconstruction'-style decompression—removing the compressive structure whilst preserving the main body of the articular process in terms of both structure and function. A study by Hadgaonkar et al. on navigation-assisted UBE for the treatment of intervertebral foramen protrusions also confirmed that the postoperative articular process area was reduced by an average of only 5.1%, with no incidence of new-onset segmental instability or spondylolisthesis, thereby validating the feasibility of the UBE technique in preserving articular process integrity from a biomechanical perspective[22]. Several studies on UBE have highlighted the technical advantage of preserving the articular processes[18]. MIS-TLIF group: Restores intervertebral height and indirectly enlarges the intervertebral foramen by resecting part of the articular process and inserting a fusion cage. This is a 'structural replacement' approach to decompression—sacrificing mobility in exchange for stability and indirect decompression. Both strategies have their respective advantages and disadvantages. The advantage of UBE lies in preserving physiological mobility and proprioception, whilst preventing degeneration of adjacent segments; the advantage of MIS-TLIF lies in the complete elimination of segmental micro-movement through fusion, making it theoretically more suitable for patients with severe instability. As all subjects in this study were free of preoperative instability, the UBE strategy is more appropriate.

4.6 Analysis of differences in the spectrum of complications

The patterns of complications differed between the two groups: In the UBE group, symptoms of nerve root irritation predominated (11 cases, 3.7%), manifesting as transient sensory abnormalities in the anteromedial aspect of the thigh. This may be related to traction on the dorsal root ganglion (DRG) or radiofrequency thermal injury during the procedure to expose the L5 exit root. All patients recovered within 1–3 months, suggesting nerve disuse rather than axonal rupture. Two cases (0.7%) of dural tears were observed, which healed well following intraoperative repair. MIS-TLIF group: The types of complications were more diverse, including incisional infection (2 cases), dural tears (3 cases), permanent nerve root injury (1 case) and loosening of internal fixation (1 case). It is worth noting that complications related to internal fixation (loosening, fracture, fusion cage subsidence, etc.) are risks specific to fusion surgery. Although only one such case occurred in this group—a relatively low proportion—such events often necessitate secondary surgical intervention. The difference in the overall complication rate between the two groups was not statistically significant (4.7% vs. 8.0%, P = 0.158). A multicentre cohort study by Chen et al. similarly demonstrated that there was no statistically significant difference in complication rates between UBE-LIF and MIS-TLIF, although the numerical trends differed slightly from those observed in the present study[23]. A cohort study by Huang et al. also reported similar complication rates between the two groups[24]. However, in terms of the spectrum of complications, those associated with UBE are primarily characterised by transient nerve irritation, which resolves spontaneously; whereas complications associated with MIS-TLIF involve internal fixation and the surgical incision, and may have more serious consequences. This difference should be taken into account when selecting a surgical procedure.

4.7 Technical Advantages and Learning Curve of UBE

The technical advantages of UBE for treating extreme lateral protrusions at the L5-S1 level can be summarised as a 'three-dimensional breakthrough'. Anatomical dimension: The posterior longitudinal approach completely avoids lateral obstruction by the high iliac crest, transforming what was previously an 'inaccessible' lesion into one that can be routinely managed. The latest reviews indicate that a high iliac crest, an enlarged sagittal articular process, and a hypertrophied superior articular process significantly restrict the lateral trajectory required for a foraminous approach to the L5-S1 segment. In contrast, the interlaminar or dual-channel posterior approach utilises the naturally wide lamina window in this segment, providing a direct and spacious working channel for the herniated nucleus pulposus[25]. Operational aspects: The dual-channel design allows for independent movement of the instrument and the camera, offering a degree of manoeuvrability far exceeding that of coaxial endoscopes. Continuous irrigation with water creates a clear field of view, enabling precise management of axillary herniations and free-floating nucleus pulposus; complete removal was achieved in all 112 cases of extreme lateral herniation in this cohort. Philosophical Dimension: The strategy of 'removing bone first, then treating soft tissue' at the tip of the SAP reduces the risk of nerve traction injury whilst preserving facet joint function, embodying the surgical philosophy of 'adequate decompression with minimal destruction'. A study by Hadgaonkar et al. utilising navigation-assisted contralateral translaminar approaches for the treatment of foraminally herniated discs demonstrated that, whilst precisely excising the herniated nucleus pulposus, the articular surface area was reduced by an average of only 5.1%. No new cases of segmental instability or spondylolisthesis were observed postoperatively, confirming the feasibility of this procedure in preserving articular function[22]. It should be noted that UBE involves a certain learning curve. All procedures in this cohort were performed by the same experienced surgeon, and the operative time remained relatively consistent (68.5 ± 15.3 min). Novice surgeons require systematic training to master intraoperative

anatomy, maintain fluid balance and manage bleeding. Some studies have suggested that the learning curve for UBE is relatively short, as the instruments used are similar to those in conventional open surgery; however, familiarity with intraoperative anatomy still requires experience gained through a certain number of cases[26]. It is recommended that you start with relatively straightforward cases and gradually build up your experience.

4.8 Comparative Analysis with the Literature

The findings of this study are consistent with those reported in recent literature. Park et al. reported a success rate of 93.3% for UBE in the treatment of L5-S1 extreme lateral stenosis, which is similar to the 94.0% observed in this study[27]. Kim et al. compared UBE with MIS-TLIF for the treatment of lumbar degenerative disease and found that the UBE group had a shorter hospital stay, less bleeding and a faster early recovery, which is consistent with the findings of this study[28]. A cohort study by Huang et al. comparing UBE-TLIF with MIS-TLIF for the treatment of lumbar degenerative disease showed that the degree of improvement in VAS and ODI scores was comparable between the two groups postoperatively; however, intraoperative blood loss was significantly lower in the UBE-TLIF group (248.2 ± 32.8 mL vs. 319.8 ± 30.5 mL, $P < 0.001$), which is consistent with the findings of this study[24]. A multicentre cohort study by Chen et al. similarly found that the length of hospital stay was significantly shorter in the UBE-LIF group than in the MIS-TLIF group (5.2 ± 1.1 days vs. 6.3 ± 1.2 days, $P < 0.001$), and that VAS scores for low back pain at one week post-operatively were lower (1.4 ± 1.1 vs. 2.1 ± 1.0, $P = 0.001$), further confirming the perioperative advantages of the UBE technique[23]. In the field of treatment for extreme lateral disc herniation, Zheng et al. employed a sacral wing–transverse process approach using percutaneous endoscopic lumbar discectomy (PELD) to treat the condition. Postoperatively, the Visual Analogue Scale (VAS) score for leg pain decreased from 7.8 to 2.2, and the Osteoarthritis Index (ODI) score fell from 52.8 to 16.9, demonstrating excellent clinical outcomes[7]. In this study, the VAS score for leg pain in the UBE group fell from 7.8 to 1.6, representing a more significant improvement; this may be attributed to the clearer visualisation and more thorough decompression offered by UBE.

4.9 Reconsideration of Clinical Significance and Surgical Indications

Based on the findings of this study, we propose the following treatment strategies for L5–S1 extreme lateral disc herniation with high iliac crest involvement: UBE with simple decompression is the preferred option in the following scenarios: (1) single-level extreme lateral herniation without preoperative instability. (2) herniated material consisting primarily of soft disc tissue, without severe calcification or ossification. (3) Active patients seeking rapid recovery and preservation of mobility. (4) Patients sensitive to radiation exposure (e.g. women of childbearing age). Considerations for MIS-TLIF: (1) Cases with confirmed segmental instability (angular change > 10° or displacement > 3 mm). (2) Cases with massive herniation accompanied by severe endplate damage or discogenic low back pain. (3) Recurrent herniation requiring revision surgery. (4) Patients unable to comply with strict postoperative activity restrictions. This strategy recommends upgrading UBE from an ‘alternative option’ to a ‘preferred option’, thereby redefining the treatment paradigm for this type of condition.

4.10 Limitations of the Study

This study has the following limitations: Firstly, it is a retrospective study. Although the baseline data between the two groups were balanced and comparable, the selection bias inherent in retrospective studies cannot be entirely ruled out. Patient allocation was determined jointly by the surgeon and the patient, which may introduce potential confounding factors. Prospective randomised controlled trials are required in the future to validate the findings of this study. Second, the follow-up period was limited. The average follow-up duration of 18.5 months, whilst exceeding that of most comparable studies, remains insufficient for assessing long-term complications following fusion surgery (such as adjacent segment degeneration and failure of internal fixation). Our research team will continue to monitor this cohort and plans to conduct an interim analysis at the 5-year postoperative mark. Thirdly, this was a single-centre study. All surgeries were performed by the same senior surgeon, which may limit the generalisability of the results. A multicentre study would help to validate the universality of these findings.

4.11 Future Research Directions

Based on the findings of this study and recent advances in the literature, the following future research directions are proposed: Firstly, conduct a multicentre, prospective, randomised controlled trial. Compare the efficacy, safety and health economic benefits of UBE versus MIS-TLIF in patients with L5-S1 extreme lateral disc herniation complicated by high iliac crest involvement; the sample size should be calculated based on the efficacy results of this study. Second, establish an individualised predictive model for the extent of SAP resection. By combining preoperative CT three-dimensional reconstruction, finite element analysis and machine learning algorithms, predict the impact of different resection extents on neural decompression and segmental stability, thereby enabling ‘tailor-made’ precision surgery. Third, explore the application of UBE in more complex pathologies. For instance, in cases involving mild instability (Meyerding Grade I), isthmic fissures, recurrent herniation, and calcified herniation, evaluate its efficacy and safety following the expansion of indications. Fourthly, develop novel endoscopic instruments and navigation technologies. Design specialised curved burrs and steerable radiofrequency tips tailored to the anatomical characteristics of the extreme lateral region; explore the integration of UBE with O-arm navigation and augmented reality technologies to further enhance precision and safety. Fifthly, conduct long-term follow-up and real-world studies. Establish a registry system to collect large-scale, multi-centre real-world data, and evaluate the long-term efficacy and complications of UBE in real clinical settings.

5. Conclusion

For L5-S1 extreme lateral disc herniation complicated by a high iliac crest, UBE-guided targeted resection of the SAP apex for decompression alone offers comprehensive advantages over MIS-TLIF fusion and internal fixation, including comparable long-term clinical outcomes, significantly superior perioperative parameters, faster early postoperative recovery, and a safer complication profile. This technique ingeniously circumvents the obstruction of the iliac crest via a posterior longitudinal approach. By targeting the resection of the SAP apex, it achieves adequate decompression whilst preserving the function of the articular processes, thereby providing a new minimally invasive surgical option for lesions in this complex anatomical region that prioritises 'non-fusion and functional preservation'. Based on the findings of this study, we recommend UBE as one of the preferred surgical procedures for this type of lesion and propose conducting prospective studies to further validate its long-term efficacy.

Abbreviations

Unilateral biportal endoscopic discectomy for the treatment of high L5–S1 lateral disc herniation.

Declarations

● **Ethics approval and consent to participate**: This study was performed in line with the principles of the Declaration of Helsinki and the approval was granted by the Ethics Committee of General Hospital of Northern Theater Command (**Lun Shen Y (2026) No. 37**). This study is a retrospective study; therefore, it was not necessary for the patients or their families to sign an informed consent form for the study.

● **Consent for publication**: Prior to surgery, both patients and their families received comprehensive explanations regarding the surgical approach, perioperative risks, and potential complications. All parties indicated full understanding and informed consent was obtained through signed surgical consent forms.

● **Availability of data and materials**

The data underpinning the conclusions of this study may be obtained from the General Hospital of Northern Theater Command. Owing to the hospital's specialised nature, patient data is subject to access restrictions—its use requires authorisation and is not publicly available. However, upon reasonable request and with permission from the General Hospital of Northern Theater Command, the relevant data may be obtained from the authors.

Author Contribution

*YANCHUN XIE and YI LIAN contributed equally to this study. They are responsible for data processing and analysis, work summarisation, and the final drafting of articles.HAILONG YU is responsible for final review and proofreading.ANWU XUAN were responsible for reviewing the data and references.JUNCHAO LI and HONGWEN GU were responsible for image production.

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Figures

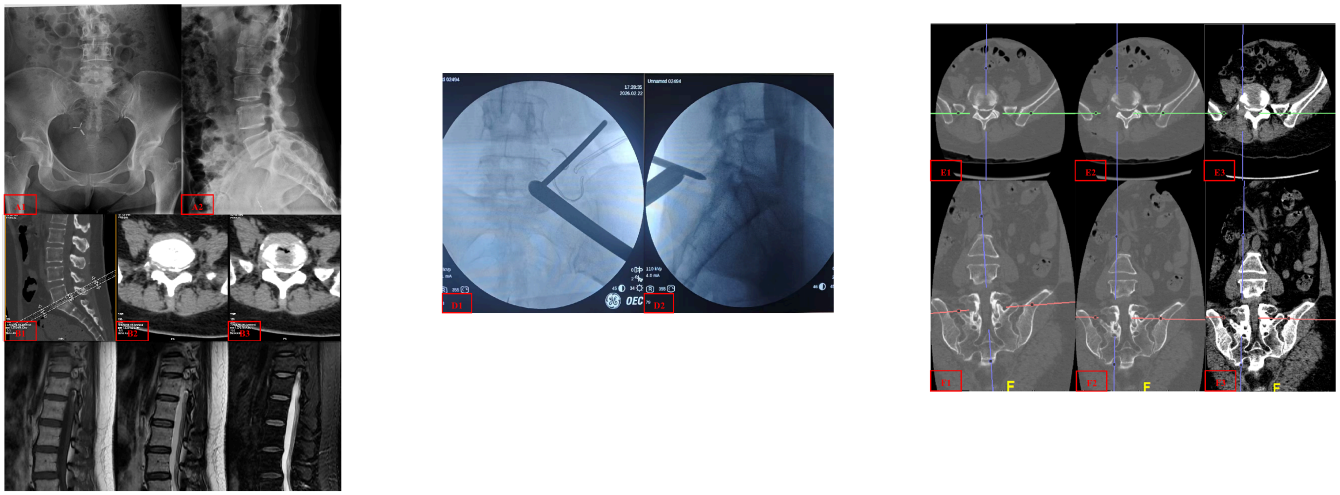


Figure 1

A 48-year-old female patient with extreme lateral disc herniation at the L5-S1 segment achieved adequate spinal canal decompression following superior uterine bony endosteal (UBE) resection of the S1 superior articular process. Preoperative lumbar anteroposterior and lateral X-ray films revealed the presence of a high iliac crest (A1-2). Preoperative CT (B1-3) and MRI (C1-3) examinations indicated extreme lateral disc herniation at the L5-S1 level. Intraoperative UBE fluoroscopic localization imaging (D1-2) was performed. Postoperative CT (E1-3) and MRI (F1-3) examinations confirmed that the S1 superior articular process tip was resected intraoperatively, the disc was removed, and adequate spinal canal decompression was achieved.