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RESEARCH

Comparative study of the learning curves for percutaneous endoscopic interlaminar lumbar discectomy and unilateral biportal endoscopy techniques

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Abstract

Background Minimally invasive spinal surgery techniques, such as Percutaneous Endoscopic Interlaminar Lumbar Discectomy (PEID) and Unilateral Biportal Endoscopy (UBE), have been developed to reduce surgical morbidity and enhance patient recovery. Although both techniques demonstrate promising clinical outcomes, the learning curves required for surgeons to achieve proficiency with these methods remain unclear.

Objective To compare the learning curves of PEID and UBE in the treatment of lumbar disc herniation.

Methods We conducted a retrospective analysis of 173 patients who underwent either PEID ($n=94$) or UBE ($n=79$), performed by two independent surgeons between January 2020 and January 2022. Eligible patients were aged 18–75 years, diagnosed with lumbar disc herniation, and had no previous spinal surgeries at the affected level. Metrics analyzed included operative time, intraoperative blood loss, postoperative recovery, complication rates, and clinical outcomes, assessed using the Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) scores.

Results The PEID group demonstrated significantly shorter operative times (99.96 ± 34.74 min vs. 116.52 ± 47.20 min, $P<0.05$) and less blood loss (20.85 ± 11.06 ml vs. 80.19 ± 22.81 ml, $P<0.01$) compared to the UBE group. Both techniques showed significant improvements in VAS and ODI scores postoperatively, with no significant differences between the groups at any follow-up points. Learning curve analysis revealed that operative times for PEID stabilized at approximately 70 min after about 40 cases, while UBE stabilized at around 65 min after approximately 35 cases. Complication rates were low, and patient satisfaction was high in both groups. According to the Modified MacNab criteria, 83% of patients in the PEID group and 79.7% in the UBE group achieved excellent outcomes, while only 5.3% and 3.8% of patients experienced fair or poor outcomes in the PEID and UBE groups, respectively.

Conclusion Both PEID and UBE are effective minimally invasive techniques for the treatment of lumbar disc herniation, offering comparable clinical outcomes and low complication rates. However, PEID is associated with

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shorter operative times and reduced intraoperative blood loss. Understanding the learning curves of these techniques is crucial for surgeons to improve proficiency and optimize patient outcomes.

Keywords Percutaneous endoscopic interlaminar lumbar discectomy (PEID), Unilateral biportal endoscopy (UBE), Learning curve, Lumbar disc herniation, Minimally invasive spine surgery

Introduction

The development of spinal endoscopic surgery has revolutionized spine surgery over the past few decades [1]. Traditionally, open spinal surgeries were the standard approach for treating various spinal pathologies. While effective, these procedures often involved significant muscle dissection, longer recovery times, and a higher risk of complications [2]. In response to these challenges, minimally invasive spinal surgery techniques were developed, significantly reducing surgical morbidity and improving patient recovery [3]. Among these advancements, spinal endoscopic surgery has emerged as a particularly promising technique. This approach allows for minimal tissue disruption, reduced blood loss, shorter hospital stays, and a quicker return to daily activities [4]. The integration of endoscopic technology into spine surgery has therefore transformed patient outcomes and set new standards in the field.

Within the realm of spinal endoscopic surgery, two prominent techniques have gained considerable attention: Percutaneous Endoscopic Interlaminar Lumber Discectomy (PEID) and Unilateral Biportal Endoscopy (UBE). PEID involves using a single small incision through which an endoscope and surgical instruments are inserted to perform the procedure. This technique is highly valued for its minimal invasiveness, precise targeting of the pathology, and reduced recovery time [5]. On the other hand, UBE utilizes two separate portals—one for the endoscope and the other for surgical instruments. This bimanual approach allows for enhanced maneuverability and visualization, potentially improving surgical precision [6]. Both techniques have demonstrated favorable clinical outcomes in treating various spinal disorders such as herniated discs, spinal stenosis, and degenerative spine conditions. However, they also present unique challenges, particularly in terms of the learning curve required for surgeons to achieve proficiency [7].

The learning curve associated with PEID and UBE presents some challenges, due to the complexity of the technical aspects of these minimally invasive procedures. PEID requires high level of precision as surgeons must navigate through a single, narrow working channel to access the target pathology. This involves precise hand-eye coordination, meticulous instrument handling, and an in-depth understanding of spinal anatomy to avoid damage to critical neural and vascular structures. The limited visual field provided by the endoscope further adds to the difficulty, requiring the surgeon to develop excellent spatial awareness and adaptability. Similarly, UBE has its own challenges, especially in coordinating two separate working portals. This technique demands simultaneous manipulation of the endoscope and surgical instruments, necessitating advanced bimanual skills and the ability to maintain clear visualization of the operative field. Achieving optimal triangulation between the two portals, particularly in anatomically challenging or small spaces, can be technically hard and time-consuming during the initial phases of training. Both PEID and UBE techniques require proficiency in using imaging guidance, such as fluoroscopy or navigation systems, to accurately localize the pathology and guide instrument placement [7, 8].

The steep learning curve can significantly impact surgical outcomes, particularly in the early stages of skill acquisition. Inexperienced surgeons may encounter longer operative times, incomplete removal of pathological tissues, or higher damages to surrounding structures and tissues, potentially resulting in suboptimal clinical outcomes. These challenges can lead to increased rates of complications, such as nerve injuries, dural tears, or inadequate decompression, which may prolong recovery and negatively affect patient prognosis [9].

The primary objective of this study is to compare the learning curves associated with PEID and UBE techniques. Understanding these learning curves is crucial for evaluating the ease of adoption and effectiveness of each technique in clinical practice. By analyzing metrics such as operative time, complication rates, and postoperative recovery outcomes, this study aims to provide comprehensive insights into the training and skill acquisition processes for these techniques. Ultimately, the findings will inform clinical decision-making, guiding spine surgeons in selecting the most appropriate technique based on their expertise and the specific needs of their patients.

Materials and methods

Patients

A retrospective analysis was conducted at Tangdu Hospital of Air Force Medical University, reviewing medical records of patients who underwent PEID and UBE performed by a single surgeon between January 2020 and January 2022. The objective of this study was to gain in-depth insights into the learning curves associated with these two surgical approaches. A total of 173 patients met the inclusion and exclusion criteria and were included in the study.

Inclusion Criteria:

1. Patients aged 18–75 years diagnosed with lumbar disc herniation;
2. Patients who underwent either PEID or UBE between January 2020 and January 2022 by a single surgeon who had no previous experience with PEID or UBE but had completed standardized training and passed the examination for both techniques;
3. Availability of clinical follow-up data for more than 2 years.

Exclusion Criteria:

1. Patients with previous spinal surgeries at the affected level;
2. Patients with severe comorbidities that could impact surgical outcomes;
3. Patients whose medical records were incomplete or missing critical data;
4. Combination of lumbar spine instability;
5. History of lumbar surgery.

Surgical technique

All surgical procedures were performed by two independent surgeons who had no previous experience with PEID or UBE but had completed standardized training and passed the examination for both techniques under general anesthesia.

UBE

The patients were positioned prone on the operating table. Two skin incisions were made 1–1.5 cm lateral to the midline at the level of the interlaminar space. An endoscope was inserted through the incision over the upper edge of the lower lamina, while surgical instruments were introduced through the incision over the lower edge of the upper lamina. A radiofrequency ablation electrode was used to clear the soft tissue from the lamina surface, exposing the ligamentum flavum. A burr was then utilized to remove part of the upper lamina of the lower vertebra and the lower lamina of the upper vertebra. Subsequently, a Kerrison punch was used to excise the interlaminar ligament, and the protruding annulus. Finally, after confirming complete removal of the nucleus pulposus and adequate decompression of the nerve root, the surgical incisions were closed (Fig. 1).

PEID

The patients were positioned supine. Under X-ray guidance, the target intervertebral space was identified, and an incision approximately 8 mm in length was made about 1 cm lateral to the spinal midline. A guide needle was inserted through the incision down to the surface of the ligamentum flavum, followed by the placement of a working cannula over the guide needle. An endoscope was then introduced through the working cannula. Using endoscopic medullary forceps and a radiofrequency probe, the herniated disc material was exposed and removed after resecting the ligamentum flavum. Finally, the surgical incision was closed (Fig. 2).

Data collection

General information collected included age, gender, body mass index (BMI), smoking status, alcohol consumption, duration of symptoms, herniated segment, herniation type (based on the Michigan State University [MSU] classification), postoperative hospitalization duration, surgical duration, intraoperative bleeding, complication rates, recurrence rates, and the number of X-ray examinations.

The MSU classification provides a straightforward and reliable method for objectively assessing herniated

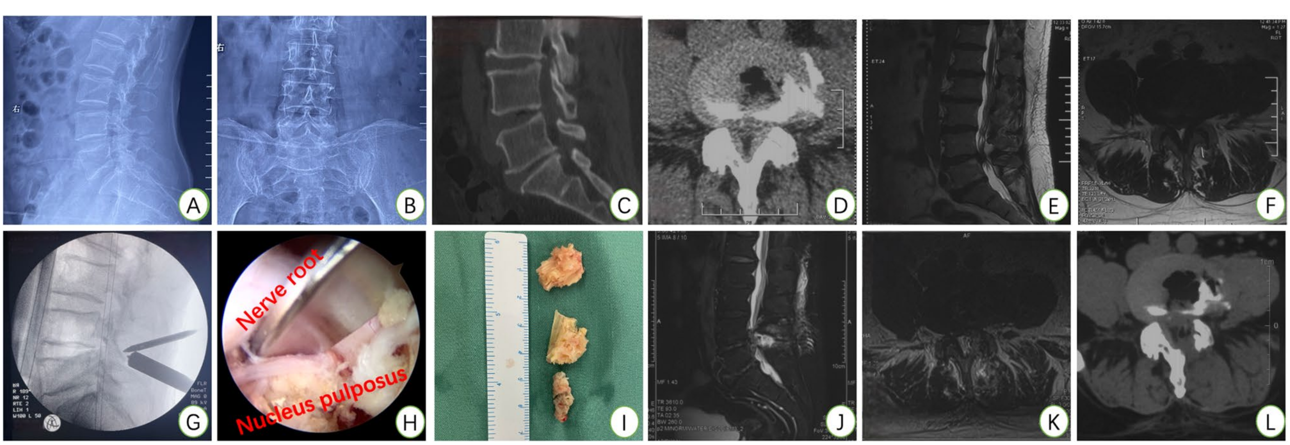

Fig. 1 A 75-year-old female treated with UBE. (**A-B**) Lumbar spine X-ray, anteroposterior and lateral views. (**C-D**) Lumbar CT scans showing L4/5 lumbar disc herniation. (**E-F**) Lumbar MRI scans confirming L4/5 lumbar disc herniation. (**G**) Insertion of the working cannula. (**H**) Depression of the L5 nerve root. (**I**) Herniated nucleus pulposus. (**J-L**) Postoperative decompression status

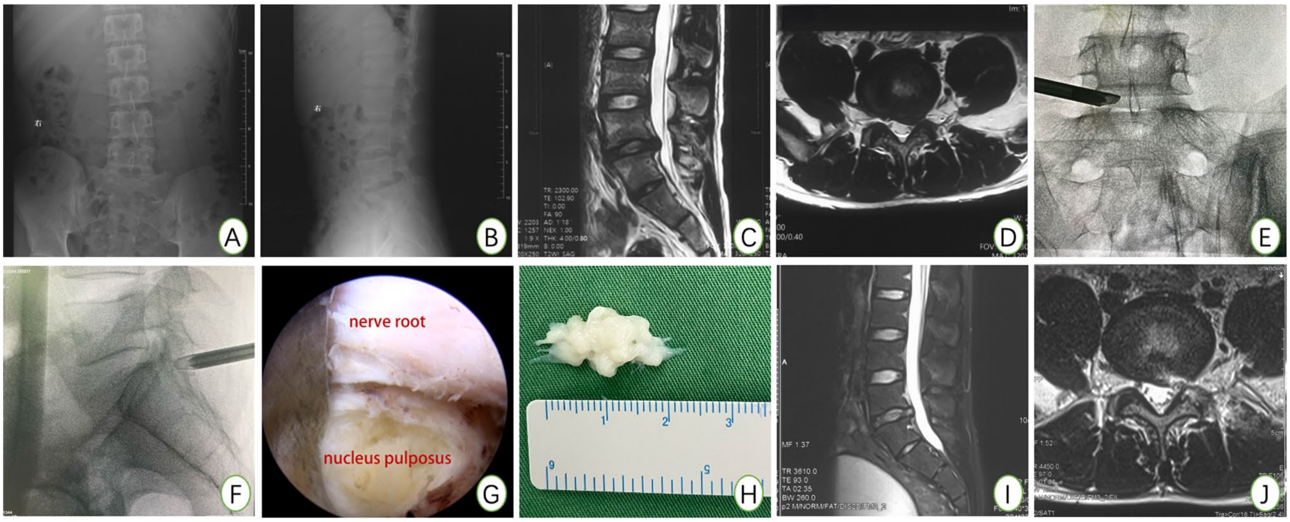

Fig. 2 A 51-year-old female treated with PEID. (**A-B**) Lumbar spine X-ray, anteroposterior and lateral views. (**C-D**) Lumbar MRI scans showing L5/S1 lumbar disc herniation. (**E-F**) Insertion of the working cannula. (**G**) Depression of the S1 nerve root. (**H**) Herniated nucleus pulposus. (**I-J**) Postoperative decompression status

lumbar discs. It evaluates both the size and location of the herniation, taking into account the anatomical constraints of the surrounding structures. A single intra-facet line is used as a reference point to determine the extent of disc herniation at the level of maximum extrusion, where the greatest impact on neurological structures is most likely to occur [10]. To describe the size of the herniation, the classification categorizes the lesion into size-1, size-2, or size-3. A size-1 herniation occurs when the disc extends up to or less than 50% of the distance from the non-herniated posterior edge of the disc to the intra-facet line. A size-2 herniation is identified when the extension exceeds 50% of this distance. If the herniation extends completely beyond the intra-facet line, it is classified as a size-3 herniation.

Clinical outcomes were evaluated using the Visual Analogue Scale (VAS) and the Oswestry Disability Index (ODI) at preoperative baseline and at 1 month, 6 months, and 1 year postoperatively. Patient satisfaction with clinical outcomes was assessed using the Modified MacNab criteria. The patient satisfaction index, based on a modified version of the MacNab criteria, was evaluated two weeks after surgery. Patients were asked to select one of the following four options:

1. Excellent: The endoscopic surgery met my expectations. I have minimal pain and can perform desired activities with few limitations.
2. Good: The endoscopic surgery met my expectations. I experience occasional pain or sensory issues but can perform daily activities with minor limitations and do not require pain medication.
3. Fair: The endoscopic surgery met my expectations. My pain has somewhat improved, but I still require pain medication.
4. Poor: The endoscopic surgery did not meet my expectations. My condition has worsened, or I required additional surgery.

Statistical analysis

Statistical analysis was conducted using SPSS software (version 26.0; IBM, Armonk, NY, USA).

Between-group differences for continuous variables were assessed using independent paired t-tests, while the Chi-square test or Fisher's exact test was used for categorical variables. A significance level of $P \leq 0.05$ was considered statistically significant. The 95% confidence intervals (CIs) were reported to provide additional context for the P-values.

We also compared patients' baseline characteristics between the groups using T-test statistical analysis to identify potential significant differences, which could be considered as confounding variables.

The CUSUM (cumulative sum control chart) technique was used for the quantitative assessment of the learning curve. CUSUM is the running total of the differences between individual data points and the mean of all data points, allowing for recursive calculation. The cases were ordered chronologically, from the earliest to the latest surgery date. The operation time and intraoperative blood loss for each case were denoted as xi, and the mean value of all cases was represented by μ. The CUSUM for these values was calculated using the following equation:

Equation 1: $CUSUM = \sum_{i=1}^{n} x_i - \mu$

Table 1 Baseline and demographic characteristics of patients

Characteristic		PEID group (*N* = 94)	UBE group (*N* = 79)	t/χ2	*P*-value
Gender	Male	52	43	0.01	1.00
	Female	42	36		
Age, mean ± SD, (y)		44.03 ± 14.19 (95% CI: 41.39–46.67)	47.35 ± 14.07 (95% CI: 44.44–50.26)	-1.54	0.13
BMI, mean ± SD, (kg/m^2)		22.99 ± 2.06 (95% CI: 22.58–23.40)	22.51 ± 2.38 (95% CI: 21.99–23.03)	1.45	0.15
Duration of symptoms, mean ± SD, (months)		13.98 ± 10.98 (95% CI: 11.85–16.11)	14.81 ± 11.00 (95% CI: 12.44–17.18)	-0.50	0.62
Alcohol consumption	Yes	33	34	0.43	0.52
	No	61	55		
Smoking status	Yes	37	33	0.10	0.76
	No	57	46		
Sides	Left	41	35	0.38	0.84
	Right	42	37		
Herniated segments	L4-L5	44	38	0.56	0.80
	L5-S1	44	38		
	Other segments	6	3		
Herniated type (MSU classification), number (%)	I	10	12	0.88	0.67
	II	42	32		
	III	42	35		
Preoperative VAS for Back, mean ± SD		5.24 ± 1.44 (95% CI: 4.95–5.53)	5.34 ± 1.39 (95% CI: 5.04–5.64)	-0.45	0.65
Preoperative VAS for Legs, mean ± SD		6.54 ± 1.22 (95% CI: 6.28–6.80)	6.48 ± 1.23 (95% CI: 6.20–6.76)	-1.83	0.86
Preoperative ODI, mean ± SD		60.93 ± 11.58 (95% CI: 58.49–63.37)	59.75 ± 11.93 (95% CI: 57.07–62.43)	-0.66	0.51

Note: SD - Standard Deviation; BMI - Body Mass Index; VAS-Visual Analog Scale; ODI - Oswestry disability index; t- Student's t-test; χ2 - Chi-square test

Table 2 Comparison of perioperative data between the two groups

Parameter	PEID group (*N* = 94)	95% CI (PEID)	UBE group (*N* = 79)	95% CI (UBE)	t	*P*-value
Operative time, mean ± SD, (min)	99.96 ± 34.74	92.82–107.10	116.52 ± 47.20	106.20–126.84	-2.58	0.01*
Blood loss, mean ± SD, (ml)	20.85 ± 11.06	18.58–23.17	80.19 ± 22.81	75.13–84.99	-21.13	< 0.01*
Post-operative bedtime, mean ± SD, (h)	18.05 ± 7.51	16.55–19.55	27.35 ± 12.05	24.89–29.81	-5.96	< 0.01*
Number of x-ray examinations, mean ± SD, (times)	2.99 ± 1.04	2.78–3.20	3.28 ± 1.67	2.93–3.63	-13.17	< 0.01*
Post-operative hospitalization, mean ± SD, (d)	3.47 ± 1.23	3.22–3.72	7.34 ± 2.36	6.84–7.84	-1.34	0.18

Note: *significant difference between the two groups

The $CUSUM_1$ for the first case was calculated as the difference between the measured value of the first case and the mean (μ). The $CUSUM_2$ for the second case was obtained by adding the previous case's CUSUM to the difference between the second case's measured value and μ. This recursive process continued until the last case was included. When the fitted polynomial curve reached the CUSUM and plateaued, it indicated that additional experience had been gained, leading to the achievement of expert competence.

Results

Baseline and demographic characteristics

A total of 173 patients were included in this study, with 94 patients undergoing PEID and 79 patients undergoing UBE. There were no significant differences between the two groups in terms of gender, age, BMI, duration of symptoms, alcohol consumption, smoking status, sides affected, herniated segments, herniated type, or preoperative VAS and ODI scores (Table 1).

Perioperative data

The perioperative data revealed several significant differences between the PEID and UBE groups (Table 2). The operative time was significantly shorter for the PEID group (99.96 ± 34.74 min) compared to the UBE group (116.52 ± 47.20 min, $P = 0.01$). The PEID group also experienced significantly less blood loss (20.85 ± 11.06 ml) than the UBE group (80.19 ± 22.81 ml, $P < 0.01$). Additionally, the postoperative bed rest time was shorter in the PEID group (18.05 ± 7.51 h) compared to the UBE group (27.35 ± 12.05 h, $P < 0.01$). The number of X-ray examinations was significantly lower for the PEID group (2.99 ± 1.04 times) compared to the UBE group (3.28 ± 1.67 times, $P < 0.01$). However, there was no significant difference in postoperative hospitalization duration between the two groups.

Clinical outcomes

Clinical outcomes were evaluated using VAS and ODI scores at preoperative, 1 month, 6 months, and 2 years postoperatively (Table 3). Both groups showed significant

Table 3 Comparative analysis of clinical parameters between the two groups

Parameter		PEID group (N = 94)	UBE group (N = 79)	95% CI (PEID)	95% CI (UBE)	t/χ2	P-value
VAS for back, mean ± SD	Pre-OP	5.24 ± 1.44	5.34 ± 1.39	4.95–5.53	5.04–5.64	-0.45	0.65
	Post-OP (1 month)	0.78 ± 0.83	0.75 ± 0.88	0.61–0.95	0.56–0.94	0.23	0.82
	Post-OP (6 months)	0.28 ± 0.50	0.19 ± 0.40	0.18–0.38	0.10–0.28	1.28	0.20
	Post-OP (2 years)	0.15 ± 0.36	0.13 ± 0.34	0.08–0.22	0.06–0.20	0.42	0.67
VAS for legs, mean ± SD	Pre-OP	6.54 ± 1.22	6.48 ± 1.23	6.29–6.79	6.22–6.74	-1.83	0.86
	Post-OP (1 month)	1.10 ± 0.83	1.14 ± 0.93	0.93–1.27	0.94–1.34	-0.33	0.75
	Post-OP (6 months)	0.26 ± 0.49	0.30 ± 0.54	0.16–0.36	0.20–0.40	-0.62	0.54
	Post-OP (2 years)	0.22 ± 0.59	0.21 ± 0.44	0.10–0.34	0.12–0.30	0.12	0.91
ODI, mean ± SD	Pre-OP	60.93 ± 11.58	59.75 ± 11.93	58.49–63.37	57.07–62.43	-0.66	0.51
	Post-OP (1 month)	14.19 ± 8.12	14.85 ± 7.93	12.62–15.76	13.15–16.55	-0.54	0.59
	Post-OP (6 months)	10.81 ± 7.03	9.95 ± 5.50	9.45–12.17	8.73–11.17	0.90	0.37
	Post-OP (2 years)	6.96 ± 4.68	6.23 ± 3.13	6.00–7.92	5.55–6.91	1.20	0.23
Modified MacNab criteria	Excellence	78	63	—	—	1.17	0.82
	Good	11	13	—	—		
	Fair	2	1	—	—		
	Poor	3	2	—	—		
Clinical efficacy classification	Excellence and good	89	76	—	—	0.23	0.73
	Fair and poor	5	3	—	—		
Complications	Tear of the Dural sac	2	1	—	—	1.18	0.98
	Hematoma	1	2				
	Sensory abnormalities of the lower limbs	2	2	—	—		
	Recurrence	3	2	—	—		

Note: SD - Standard Deviation; OP - Operative; VAS-Visual Analog Scale; ODI - Oswestry disability index

improvements in VAS and ODI scores over time. However, there were no significant differences between the groups in VAS scores for back or leg pain, or ODI scores at any of the follow-up points.

At 2 years postoperation, the VAS scores for back pain were 0.15 ± 0.36 for the PEID group and 0.13 ± 0.34 for the UBE group ($P = 0.67$). The VAS scores for leg pain were 0.22 ± 0.59 for the PEID group and 0.21 ± 0.44 for the UBE group ($P = 0.91$). The ODI scores were 6.96 ± 4.68 for the PEID group and 6.23 ± 3.13 for the UBE group ($P = 0.23$).

Learning curve for PEID and UBE based on operation time and bleeding

Both groups exhibited a decreasing trend in operation time as the number of surgeries increased (Fig. 3). Significant variability was noted in the PEID group during the first 20 cases, indicating a crucial learning period. Stabilization points were defined as the inflection points in the CUSUM curve, determined through polynomial fitting, which represent a plateau in operative efficiency. After approximately 44 surgeries, the operation time stabilized around 70 min. In the UBE group, the first 35 cases showed considerable variability, marking a key learning phase. After about 35 surgeries, the operation time stabilized around 65 min. It should be noted that the accuracy of operation time measurement was one minute.

Intraoperative blood loss was measured with an accuracy of one milliliter. Blood loss showed a decreasing trend with the increasing number of procedures in both groups (Fig. 4). In the PEID group, blood loss was initially higher but progressively decreased as more surgeries were performed, stabilizing at approximately 20 ml after around 16 operations. In the UBE group, blood loss remained high, averaging around 100 ml for the first 34 cases. After this initial phase, blood loss significantly decreased with continued surgical experience, eventually stabilizing at approximately 60 ml after around 64 surgeries.

Patient satisfaction and complications

Patient satisfaction, as assessed by the modified MacNab criteria, was high in both groups, with no significant difference between them. In the PEID group, 78 patients reported excellent outcomes, 11 reported good outcomes, 2 reported fair outcomes, and 3 reported poor outcomes. In the UBE group, 63 patients reported excellent outcomes, 13 reported good outcomes, 1 reported fair outcome, and 2 reported poor outcomes ($P = 0.82$).

The complication rates were lower in both groups, and no serious complications occurred. In the PEID group, there were 2 cases of dural sac tears less than 2 mm, 1 case of lumbar major muscle hematoma measuring approximately 3 cm × 4 cm × 3 cm, 2 cases of sensory

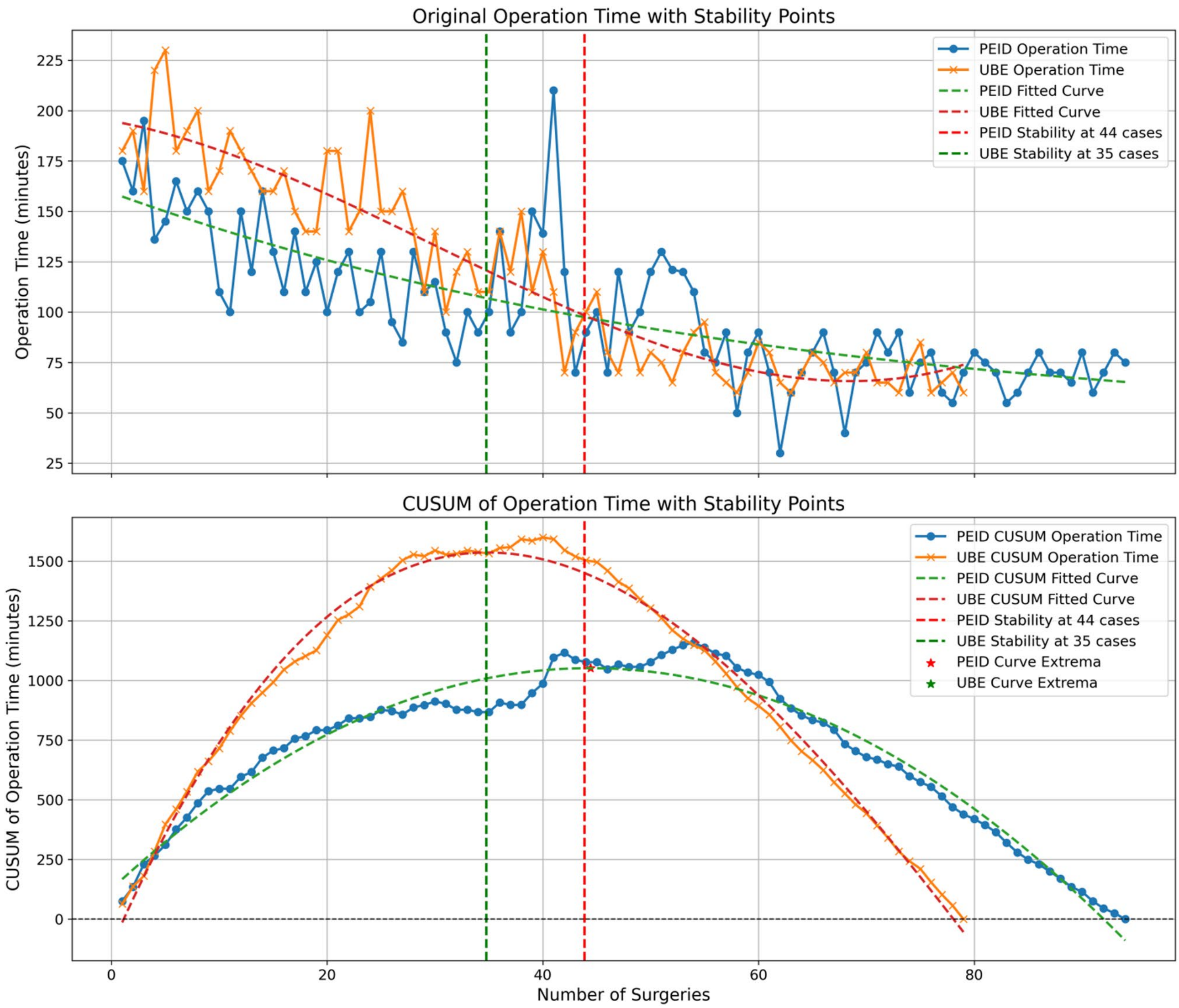

Fig. 3 Original operation time measurements (top image) and CUSUM of operational time measurements (bottom image) for all cases (surgeries) in the PEID and UBE groups, along with the fitted curves and calculated stability points

abnormalities in the lower limbs, and 3 cases of recurrence within 2 years post-operation. In the UBE group, there was 1 case of a dural sac tear measuring about 3 mm, 2 cases of small back hematomas, 2 cases of lower limb sensory abnormalities, and 2 cases of recurrence ($P = 0.98$). All patients achieved satisfactory outcomes through conservative treatments, such as physical therapy (exercises to strengthen the core and back muscles, improve flexibility, and enhance spinal stability), medications (non-steroidal anti-inflammatory drugs), epidural steroid injections, and bracing, depending on each patient's situation.

Discussion

The results of this study indicate that both PEID and UBE are effective surgical techniques for treating lumbar disc herniation, providing significant improvements in patient outcomes as measured by VAS and ODI scores, with no serious complications observed during the follow-up period. The comparable clinical outcomes in terms of VAS and ODI scores between the PEID and UBE groups suggest that both techniques effectively alleviate symptoms of lumbar disc herniation postoperatively. This finding aligns with previous research demonstrating that minimally invasive spine surgeries generally achieve similar clinical improvements in pain and function compared to traditional open surgeries [11]. The lack of significant differences in clinical outcomes further supports the notion that both PEID and UBE are viable options for

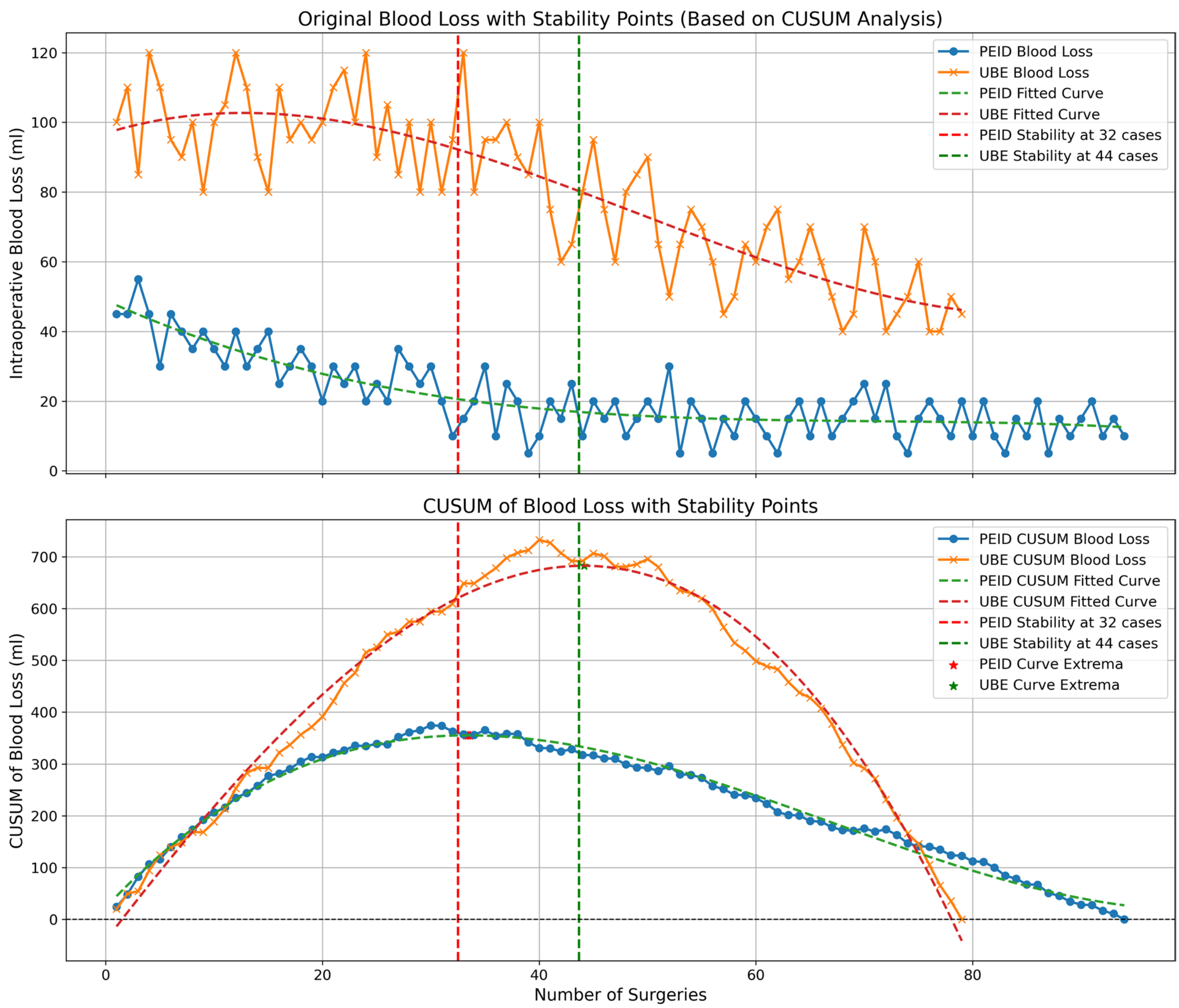

Fig. 4 Original intraoperative blood loss values (top image) and the CUSUM of intraoperative blood loss values (bottom image) for all cases (surgeries) in the PEID and UBE groups, along with the fitted curves and calculated stability points

patients seeking minimally invasive treatment for lumbar disc herniation. However, the surgeon's decision on which procedure to employ may be predominantly influenced by the respective learning curves associated with each technique.

Although both PEID and UBE can be used to treat intervertebral disc herniation [6, 7], it should be noted that these techniques are primarily utilized for different types of lumbar pathologies. PEID is mainly used for treating intervertebral disc herniation, while UBE is more commonly employed for spinal stenosis. While both techniques are minimally invasive spinal surgeries, the differences in the underlying pathologies may contribute to variations in the learning curves associated with each procedure. PEID generally involves simpler, more localized dissection to remove herniated disc material, whereas UBE, being a more extensive decompression procedure, requires more complex surgical techniques aimed at relieving spinal canal stenosis. The existing literature on the comparative analysis of learning curves between PEID and UBE for lumbar disc herniation is limited. Despite their promising clinical outcomes, the learning curves required for surgeons to achieve proficiency with these techniques remain unclear. Therefore, the primary objective of this study is to fill this knowledge gap by identifying and analyzing the learning curves associated with both PEID and UBE.

The learning curve in spine surgery is complex and challenging to measure accurately, thus metrics such as post-operative bedtime, post-operative hospitalization, number of X-ray examinations, VAS and ODI scores, Modified MacNab criteria, and clinical efficacy classification are utilized. Additionally, it has been confirmed that operating time and intraoperative bleeding control are significant indicators of technical skill and proficiency in surgery, making them key elements in the assessment of the learning curve [12].

Firstly, the operative time was significantly shorter for the PEID group compared to the UBE group (99.96 ± 34.74 min vs. 116.52 ± 47.20 min, $P = 0.01$). Secondly, patients in the PEID group experienced significantly less blood loss compared to those in the UBE group (20.85 ± 11.06 ml vs. 80.19 ± 22.81 ml, $P < 0.01$). This difference may be attributed to the less invasive nature of the PEID procedure, which likely reduces tissue disruption and facilitates quicker access to the surgical site [13, 14]. Additionally, the extrusion of the surgical cannula, advancing cannula to the target site for precise surgical access and visualization, in PEID can effectively decrease intraoperative bleeding [15, 16]. Furthermore, the direct visualization of the surgical field in PEID likely aids in achieving precise and efficient microscopic hemostasis, thereby contributing to shorter procedure times [17]. In contrast, UBE, although minimally invasive, involves a dual-port approach that may require more tissue manipulation, leading to longer operative times and increased blood loss [18]. In accordance with the present results, previous studies have demonstrated similar outcomes regarding operative time and blood loss for minimally invasive spinal surgeries. For instance, Hao et al. [18] and Ma et al. [19] reported that PEID resulted in shorter operative times and less intraoperative blood loss compared to other endoscopic techniques, which aligns with our findings. However, the findings of the current study do not fully align with those of Wei et al. [20], who found no significant difference in operative time between PEID and UBE. This discrepancy could be due to differences in surgical techniques, surgeon experience, or patient populations. Wei et al.'s study may have included a broader range of surgeons with varying levels of expertise, whereas our study focused on procedures performed by a single experienced surgeon, which could have influenced the consistency and efficiency of the operative times.

Besides, the shorter post-operative bed rest time in the PEID group (18.05 ± 7.51 h vs. 27.35 ± 12.05 h, $P < 0.01$) indicates a faster initial recovery, which is consistent with the findings of previous studies that also reported shorter bed rest times and faster return to daily activities for patients undergoing PEID [15, 18, 21]. This can be attributed to the minimal invasiveness of the procedure, which reduces postoperative pain and facilitates quicker mobilization [22]. Both PEID and UBE are minimally invasive techniques; however, PEID typically results in a shorter bed rest time after surgery compared to UBE. This difference can be attributed to the surgical technique used in PEID. The single-portal approach in PEID minimizes tissue disruption, leading to less postoperative pain, reduced muscle trauma, and quicker mobilization. In contrast, UBE involves two working portals and slightly more soft tissue handling. Although recovery is still faster compared to open surgeries, UBE may result in slightly more postoperative discomfort, potentially requiring a marginally longer bed rest period. Overall, the exact duration of bed rest following either procedure depends on several factors, including the patient's overall health, the extent of the pathology, the surgeon's approach, and the postoperative care protocol.

It is noteworthy that the duration of post-operative hospitalization did not differ significantly between the two groups (3.47 ± 1.23 days for PEID vs. 7.34 ± 2.36 days for UBE, $P = 0.18$). There are several possible explanations for this result. One hypothesis is that the dual-port approach in UBE may lead to increased paraspinal muscle trauma and discomfort, necessitating longer bed rest to alleviate postoperative pain and facilitate recovery [23]. This hypothesis is consistent with studies suggesting that the extent of muscle trauma during surgery can influence postoperative recovery times and patient-reported outcomes [24–26].

In this study, we conducted an in-depth analysis of the learning curves for PEID and UBE, two minimally invasive techniques used for treating lumbar disc herniation. The results indicate significant trends in both operative time and intraoperative blood loss, reflecting the learning curves for these procedures. For the PEID group, operative time stabilized around 70 min after approximately 40 surgeries, and intraoperative blood loss stabilized around 20 milliliters after about 16 surgeries. This suggests that as surgeons gain experience, they perform the surgery more efficiently with significantly reduced blood loss, highlighting a strong correlation between surgical proficiency and reduced operative time and blood loss in PEID procedures. In comparison, the UBE group exhibited a different trend in the learning curve. The operative time stabilized around 65 min after approximately 35 surgeries, while intraoperative blood loss stabilized around 60 milliliters after about 64 surgeries. Although UBE showed higher operative time and blood loss in the early stages of the learning curve, these metrics improved significantly with increased surgical experience. This phenomenon can be attributed to the complexity of UBE techniques and the dual-portal approach, which requires more intricate handling and coordination. These findings are consistent with previous research [27, 28]. However, it is important to note that the findings of Xu et al. differ from our observations [23]. Xu et al. concluded that the learning curve for UBE is relatively shorter than that for PEID. This discrepancy could be attributed to several factors, including variations in study design, surgeon experience levels, and specific techniques used within each procedure. Xu et al.'s study may have involved surgeons with prior extensive training in endoscopic techniques, which could accelerate the learning curve for UBE. Alternatively, the discrepancy might be due to differences in patient populations or procedural nuances. A deeper analysis of these findings suggests that while PEID allows for faster initial proficiency, UBE's more complex nature necessitates a longer period for surgeons to master the technique. This longer learning period may ultimately lead to a higher level of precision and skill in complex cases. Additionally, the dual-lumen approach (using two portals for simultaneous visualization and precise surgical manipulation) in UBE, though initially challenging, may offer better visualization and access in certain anatomical scenarios, which could contribute to its eventual proficiency [29, 30].

Inter-surgeon variability significantly influences the outcomes of discectomy PEID and UBE surgeries. Both procedures demand a high level of technical proficiency, and differences in surgeons' experience and skill levels can lead to variations in patient outcomes. In PEID, the learning curve is notably steep. A retrospective study comparing outcomes of PEID at different stages of proficiency found that increased experience correlated with improved clinical results and reduced perioperative complications [31]. It was suggested that as surgeons become more adept with the technique, patient outcomes improve, highlighting the impact of individual surgeon expertise [31]. Similarly, UBE requires substantial technical skill, and the surgeon's experience plays a crucial role in determining surgical success. A study examining the learning curve and complications associated with UBE indicated that proficiency develops over time, with a decrease in complication rates as surgeons gain more experience [23]. This underscores the importance of adequate training and experience in achieving optimal results with UBE. Moreover, a comparative analysis of UBE and PEID demonstrated that both procedures have similar efficacy in alleviating pain and improving functional ability in patients with lumbar disc herniation. The study also noted that UBE surgery results in higher costs than PEID surgery, which may influence a surgeon's choice of technique based on their proficiency and the specific needs of the patient [20]. These findings collectively emphasize that inter-surgeon variability, influenced by factors such as experience and familiarity with the specific surgical technique, plays a pivotal role in the outcomes of PEID and UBE procedures. Standardized training programs and sufficient practice are essential to minimize variability and enhance patient outcomes across different surgeons.

Limitations and future directions

This study has several limitations. First, we did not assess patient variability or long-term outcomes, which could be explored in future studies. Potential biases due to the retrospective design and the limited two-year follow-up period are additional limitations. The surgeons' standardized training may not fully reflect real-world variability. Key outcomes, such as long-term functional status and quality of life, were not comprehensively evaluated.

Moreover, this study was conducted at a single institution, highlighting the need for multi-institutional investigations. Additionally, only two independent surgeons performed the PEID and UBE techniques, which may limit the generalizability of our findings. Finally, we did not assess patients through radiological findings, such as evaluating residual disc material or the reherniation rate. Radiological outcomes, combined with our evaluated parameters, could provide a better understanding of the learning curves associated with these endoscopic techniques.

Further multicenter, prospective studies incorporating radiologic and ergonomic assessments are warranted. Extended follow-up is necessary to evaluate long-term outcomes. Future studies should also include comprehensive assessments of functional status, quality of life, and cost-effectiveness to better inform clinical decision-making and policy.

Conclusion

Our study compares the learning curves of PEID and UBE for lumbar disc herniation. PEID may have a slightly more predictable early learning curve, particularly in minimizing blood loss. UBE, while offering enhanced visualization, requires a steeper learning curve. Both techniques are effective, with PEID being more accessible for less experienced surgeons and UBE being better suited for complex cases. Surgeons should consider their level of expertise and patient-specific factors when selecting the technique to optimize outcomes. Further research is needed to refine our understanding of these methods.

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Author contributions
Conceptualization of the study: W.G. and S.G.; Preparation of paper-based questionnaire: X.Z., W.Z., and G.X.; Patient recruitment and data collection: B.L., W.G. and S.G; Analysis and interpretation of results: X.Z. and W.Z.; Manuscript draft and generation of table/figures: B.L. and W.Z.; Critical revisions to the manuscript: B.L. All authors read and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The study was conducted in accordance with the Declaration of Helsinki and were approved by the ethics committee of Tangdu Hospital of Air Force Medical University (Grant number: TDLL-202408-02). Informed written consent has been taken from all participants after explaining the aim of the study. Confidentiality of the collected data of the participants was considered.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

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