International Journal of Medicine
pISSN 1468-3814 | eISSN 2667-7008
https://theinternationalmedicine.com/

Original Research Article DOI: 10.61336/im/26-2-102

Learning Curve and Perioperative Complication Profile of Unilateral Biportal Endoscopic TLIF Versus MIS-TLIF: A Comparative CUSUM-Based Analysis

Samir Jagannath Kale[1], Rajawardhan Reddy[2], Param Shah[3]

[1]*Assistant Professor, Department of Neurosurgery, Dr D.Y. Patil Medical School and Hospital, Ayyappa Temple Rd, Dr D Y Patil Vidyanagar, Sector 5, Nerul, Navi Mumbai, Maharashtra 400706, India.*

[2]*JR-III, Department of Neurosurgery, Dr D.Y. Patil Medical School and Hospital, Ayyappa Temple Rd, Dr D Y Patil Vidyanagar, Sector 5, Nerul, Navi Mumbai, Maharashtra 400706, India.*

[3]*JR-III, Department of Neurosurgery, Dr D.Y. Patil Medical School and Hospital, Ayyappa Temple Rd, Dr D Y Patil Vidyanagar, Sector 5, Nerul, Navi Mumbai, Maharashtra 400706, India.*

Correspondence:
Dr. Samir Jagannath Kale

Received: January 05, 2026
Revised: January 29, 2026
Accepted: February 27, 2026
Published: March 07, 2026

Abstract

Background: Transforaminal Lumbar Interbody Fusion (TLIF) is a widely used surgical technique for the management of degenerative lumbar spine disorders. Minimally invasive approaches such as Minimally Invasive TLIF (MIS-TLIF) have been developed to reduce tissue trauma and postoperative morbidity. Recently, Unilateral Biportal Endoscopic TLIF (UBE-TLIF) has emerged as an innovative endoscopic technique that allows improved visualization and instrument maneuverability. However, the learning curve and perioperative safety profile of UBE-TLIF compared with MIS-TLIF remain areas of active investigation. Aim: To evaluate the learning curve and perioperative complication profile of Unilateral Biportal Endoscopic TLIF compared with MIS-TLIF using CUSUM-based analysis. ***Methods:*** This comparative observational study included 120 patients undergoing lumbar interbody fusion surgery for degenerative lumbar spine disorders at a tertiary care hospital. Patients were divided into two groups: UBE-TLIF (n = 59) and MIS-TLIF (n = 61). Baseline demographic and clinical characteristics were recorded. Perioperative outcomes including operative time, blood loss, hospital stay, time to ambulation, and complication rates were analyzed. Cumulative Sum (CUSUM) analysis was used to evaluate the learning curve and determine the number of cases required to achieve surgical proficiency. ***Results:*** Baseline clinicodemographic characteristics were comparable between the two groups. CUSUM analysis demonstrated that surgical proficiency for UBE-TLIF was achieved after 24 cases, while MIS-TLIF required approximately 31 cases. Operative time in the UBE-TLIF group significantly decreased from 192 ± 28 minutes in the early phase to 154 ± 22 minutes in the late phase ($p < 0.001$). Intraoperative blood loss and hospital stay also decreased significantly with increasing surgical experience. Comparison of perioperative outcomes showed that operative time and complication rates were comparable between the two techniques. However, UBE-TLIF demonstrated shorter hospital stay ($p = 0.008$) and earlier ambulation ($p = 0.013$) compared with MIS-TLIF. ***Conclusion:*** UBE-TLIF demonstrates a manageable learning curve and comparable perioperative safety profile to MIS-TLIF. After the initial learning phase, UBE-TLIF provides similar operative efficiency while offering advantages in terms of shorter hospitalization and faster postoperative recovery. The technique represents a promising minimally invasive alternative for the surgical management of degenerative lumbar spine disorders.

Keywords: Unilateral Biportal Endoscopic Surgery (UBE). Transforaminal Lumbar Interbody Fusion (TLIF). CUSUM Learning Curve Analysis.

INTRODUCTION

Lumbar degenerative spine disorders, including lumbar spinal stenosis, degenerative spondylolisthesis, and intervertebral disc degeneration, represent a major cause of chronic low back pain and disability worldwide. These conditions significantly impair quality of life and often require surgical intervention when conservative management fails. Transforaminal lumbar interbody fusion (TLIF) has become one of the most commonly performed surgical procedures for lumbar instability and degenerative disorders, as it allows decompression of neural elements, restoration of disc height, and stabilization of the spinal segment. Traditional open TLIF techniques, although effective, are associated with extensive muscle dissection, increased blood loss, postoperative pain, and prolonged hospital stay. Consequently, minimally invasive surgical approaches have been developed to minimize soft tissue damage and enhance postoperative recovery. [1]

Minimally Invasive TLIF (MIS-TLIF) was introduced to reduce the morbidity associated with open surgery. The technique utilizes tubular retractors and microscopic visualization to achieve adequate decompression and interbody fusion with limited muscle injury. Numerous studies have demonstrated that MIS-TLIF leads to reduced intraoperative blood loss, shorter hospitalization, and faster recovery compared with open procedures while maintaining comparable fusion rates and clinical outcomes. However, MIS-TLIF is technically demanding, requires specialized instrumentation, and involves a steep learning curve for surgeons transitioning from conventional open techniques. [2]

Recently, Unilateral Biportal Endoscopic (UBE) spine surgery has emerged as an innovative endoscopic technique that allows spinal decompression and fusion through two independent portals one for visualization and the other for surgical instruments. Unlike uniportal endoscopic procedures, UBE provides a wider operative field and greater instrument maneuverability, which may facilitate complex spinal procedures such as TLIF. UBE-TLIF has shown promising results in terms of reduced muscle trauma, improved visualization, and enhanced precision during decompression and endplate preparation. Furthermore, continuous saline irrigation improves visualization and reduces bleeding, which may contribute to improved surgical outcomes.[3]

Despite these advantages, UBE-TLIF is a relatively new technique, and its learning curve remains a significant concern. Surgeons must acquire proficiency in endoscopic visualization, biportal instrument handling, and spatial orientation within the spinal canal. The evaluation of surgical learning curves is crucial for understanding the time required to achieve procedural competency and for optimizing training strategies. Cumulative Sum (CUSUM) analysis has been widely used in surgical research to objectively assess learning curves by tracking performance indicators such as operative time, complication rates, and conversion rates over sequential procedures. This method allows identification of the point at which a surgeon achieves technical proficiency.[4]

Comparative evaluation of UBE-TLIF and MIS-TLIF is particularly important in terms of perioperative complications, operative efficiency, and learning curve dynamics. While MIS-TLIF is already well established, UBE-TLIF may offer improved visualization and tissue preservation but could initially involve longer operative times and higher complication rates during the early learning phase. Understanding these factors is essential for guiding surgical adoption and improving patient safety. Therefore, the present study aimed to compare the learning curve and perioperative complication profile of UBE-TLIF and MIS-TLIF using a CUSUM-based analytical approach.[5]

AIM

To evaluate the learning curve and perioperative complication profile of Unilateral Biportal Endoscopic TLIF compared with MIS-TLIF using CUSUM-based analysis.

OBJECTIVES

1. To analyze the learning curve associated with UBE-TLIF using CUSUM analysis based on operative time and complication rates.
2. To compare perioperative outcomes such as operative time, blood loss, hospital stay, and complication rates between UBE-TLIF and MIS-TLIF.
3. To determine the number of surgical cases required to achieve technical proficiency in UBE-TLIF compared with MIS-TLIF.

MATERIALS AND METHODS

Source of Data

The data for this study were obtained from patients who underwent lumbar interbody fusion surgery for degenerative lumbar spine disorders at the Department of Neurosurgery/Orthopaedics in a tertiary care teaching hospital. All relevant clinical, operative, and postoperative information was collected from hospital medical records, operative notes, and follow-up documentation.

Study Design

The present study was conducted as a comparative observational analytical study evaluating the learning curve and perioperative outcomes of two minimally invasive spinal fusion techniques: Unilateral Biportal Endoscopic TLIF (UBE-TLIF) and Minimally Invasive TLIF (MIS-TLIF).

Study Location

The study was conducted in the Department of Neurosurgery/Spine Surgery at a tertiary care teaching hospital equipped with facilities for minimally invasive spine surgery and endoscopic spinal procedures.

Study Duration

The study was conducted over a two-year period, during which all eligible patients undergoing TLIF surgery were included in the analysis.

Sample Size

A total of 120 patients were included in the study. These patients were divided into two groups:

- Group A: Patients undergoing Unilateral Biportal Endoscopic TLIF (UBE-TLIF) (n = 60)
- Group B: Patients undergoing Minimally Invasive TLIF (MIS-TLIF) (n = 60)

Inclusion Criteria

- Patients aged 18-70 years.
- Patients diagnosed with lumbar degenerative diseases such as lumbar disc herniation, lumbar spinal stenosis, or degenerative spondylolisthesis requiring TLIF.
- Patients who failed conservative treatment for at least 6 weeks.
- Patients who provided informed written consent for participation in the study.

Exclusion Criteria

- Patients with previous lumbar spine surgery at the same level.
- Patients with spinal infections, tumors, or traumatic spinal injuries.
- Patients with severe spinal deformities requiring multilevel fusion.
- Patients with systemic conditions contraindicating surgery.

Procedure and Methodology

Eligible patients who met the inclusion criteria were enrolled in the study after obtaining informed consent. All patients underwent detailed clinical evaluation including medical history, neurological examination, and radiological investigations such as MRI and CT scans to confirm the diagnosis and determine the surgical level.

Patients were allocated into two groups based on the surgical technique performed. In Group A, surgery was performed using the unilateral biportal endoscopic approach, which involved the creation of two portals one for endoscopic visualization and the other for surgical instruments. Continuous saline irrigation was maintained throughout the procedure to improve visualization. Decompression of neural elements was achieved, followed by discectomy, endplate preparation, cage insertion, and pedicle screw fixation.

In Group B, surgery was performed using the conventional minimally invasive TLIF technique utilizing tubular retractors and microscopic guidance. After muscle dilation and placement of the tubular retractor, decompression and discectomy were performed followed by interbody cage insertion and pedicle screw fixation.

Perioperative parameters such as operative time, intraoperative blood loss, hospital stay, and perioperative complications were recorded. Sequential operative cases were analyzed to evaluate the learning curve.

Sample Processing

All collected data were verified and compiled in a structured data sheet. Operative time, complication rates, and perioperative variables were recorded for each consecutive surgical case. These data were used for CUSUM analysis to determine the learning curve pattern and proficiency threshold for UBE-TLIF compared with MIS-TLIF.

Statistical Methods

Data were entered into Microsoft Excel and analyzed using SPSS software version 26.0. Continuous variables such as operative time and blood loss were expressed as mean ± standard deviation, while categorical variables such as complication rates were expressed as frequency and percentage.

Comparisons between the two groups were performed using the Independent t-test for continuous variables and Chi-square test for categorical variables. A p-value < 0.05 was considered statistically significant.

CUSUM (Cumulative Sum) analysis was applied to sequential operative cases to assess the learning curve and identify the point of surgical proficiency.

Data Collection

Patient demographic details, clinical characteristics, operative findings, and postoperative outcomes were collected using a structured data collection proforma. Information was obtained from patient records, operative notes, and follow-up visits. Data were anonymized to maintain patient confidentiality and were analyzed collectively for research purposes.

RESULTS

Table 1 presents the baseline clinicodemographic and preoperative characteristics of the study population comprising 120 patients who underwent TLIF procedures, including 59 patients in the UBE-TLIF group and 61 patients in the MIS-TLIF group. The mean age of patients in the UBE-TLIF group was 52.7 ± 9.8 years, while the MIS-TLIF group had a mean age of 54.1 ± 10.4 years, with no statistically significant difference between the groups (mean difference -1.4 years; 95% CI: -5.05 to 2.25; p = 0.449). The gender distribution was also comparable between the groups, with 33 males (55.9%) in the UBE-TLIF group and 35 males (57.4%) in the MIS-TLIF group, showing no significant association (OR 0.94; 95% CI: 0.46-1.94; p = 1.000).

The mean body mass index (BMI) was 26.1 ± 3.2 kg/m² in the UBE-TLIF group and 26.8 ± 3.6 kg/m² in the MIS-TLIF group, which did not differ significantly (mean difference -0.7; 95% CI: -1.94 to 0.54; p = 0.267). Similarly, the duration of symptoms before surgery was comparable between groups, with a mean duration of 10.6 ± 4.8 months in the UBE-TLIF group and 11.1 ± 5.2 months in the MIS-TLIF group (mean difference -0.5; 95% CI: -2.31 to 1.31; p = 0.589).

TABLE 1: Baseline Clinicodemographic Profile and Preoperative Characteristics (N = 120)

Variable	UBE-TLIF (n=59)	MIS-TLIF (n=61)	Test of significance	Effect size (95% CI)	P value
Age (years)	52.7 ± 9.8	54.1 ± 10.4	Welch t-test	Mean diff = -1.4 (-5.05 to 2.25)	0.449
Male sex	33 (55.9)	35 (57.4)	Fisher's exact	OR = 0.94 (0.46 to 1.94)	1.000
BMI (kg/m²)	26.1 ± 3.2	26.8 ± 3.6	Welch t-test	Mean diff = -0.7 (-1.94 to 0.54)	0.267
Symptom duration (months)	10.6 ± 4.8	11.1 ± 5.2	Welch t-test	Mean diff = -0.5 (-2.31 to 1.31)	0.589
Diagnosis (stenosis / DLS / disc+instability)	22/27/10	24/28/9	Chi-square		0.940
Operated level (L4-L5 / L5-S1)	41/18	43/18	Chi-square		1.000
Diabetes mellitus	14 (23.7)	15 (24.6)	Fisher's exact	OR = 0.95 (0.41 to 2.20)	1.000
Hypertension	19 (32.2)	21 (34.4)	Fisher's exact	OR = 0.90 (0.42 to 1.93)	0.848
Preop ODI (%)	46.2 ± 8.9	47.5 ± 9.4	Welch t-test	Mean diff = -1.3 (-4.62 to 1.99)	0.430
Preop VAS back (0-10)	7.1 ± 1.1	7.0 ± 1.2	Welch t-test	Mean diff = 0.1 (-0.32 to 0.52)	0.646

Regarding diagnosis, lumbar degenerative conditions including spinal stenosis, degenerative spondylolisthesis, and disc herniation with instability were similarly distributed across the groups (22/27/10 in UBE-TLIF vs 24/28/9 in MIS-TLIF, $p = 0.940$). The majority of surgeries were performed at the L4-L5 level, accounting for 41 cases in the UBE-TLIF group and 43 cases in the MIS-TLIF group, while 18 cases in each group involved the L5-S1 level, showing identical distribution ($p = 1.000$).

Comorbid conditions were also comparable between the groups. Diabetes mellitus was present in 23.7% of UBE-TLIF patients and 24.6% of MIS-TLIF patients (OR 0.95; 95% CI: 0.41-2.20; $p = 1.000$), while hypertension was observed in 32.2% and 34.4% of patients, respectively (OR 0.90; 95% CI: 0.42-1.93; $p = 0.848$). Preoperative functional status was similar, with a mean Oswestry Disability Index (ODI) score of 46.2 ± 8.9 in the UBE-TLIF group and 47.5 ± 9.4 in the MIS-TLIF group (mean difference -1.3; 95% CI: -4.62 to 1.99; $p = 0.430$). The preoperative VAS score for back pain was also comparable (7.1 ± 1.1 vs 7.0 ± 1.2, mean difference 0.1; 95% CI: -0.32 to 0.52; $p = 0.646$).

TABLE 2: UBE-TLIF Learning Curve by CUSUM Phase (Operative Time + Complications) (n = 59)
CUSUM-defined proficiency inflection for UBE-TLIF: Case #24
(Phase-1: cases 1-24; Phase-2: cases 25-59)

Variable	Phase-1 Early (n=24)	Phase-2 Late (n=35)	Test of significance	Effect size (95% CI)	P value
Operative time (min)	192 ± 28	154 ± 22	Welch t-test	Mean diff = 38 (24.23 to 51.77)	<0.001*
Blood loss (mL)	220 ± 90	150 ± 70	Welch t-test	Mean diff = 70 (25.88 to 114.12)	0.003*
Hospital stay (days)	4.2 ± 1.6	3.0 ± 1.0	Welch t-test	Mean diff = 1.2 (0.45 to 1.95)	0.002*
Any perioperative complication	7 (29.2)	4 (11.4)	Fisher's exact	OR = 3.19 (0.82 to 12.48)	0.102
Dural tear	3 (12.5)	1 (2.9)	Fisher's exact	OR = 4.86 (0.47 to 49.80)	0.294
Conversion to open	2 (8.3)	0 (0.0)	Fisher's exact	OR = 7.89 (0.36 to 171.99)	0.161

* statistically significant at $p < 0.05$

Table 2 demonstrates the learning curve associated with the UBE-TLIF procedure using CUSUM analysis. The analysis identified a proficiency inflection point at case number 24, dividing the procedures into an early phase (cases 1-24) and a late phase (cases 25-59). During the early phase, the mean operative time was 192 ± 28 minutes, which significantly decreased to 154 ± 22 minutes in the late phase. This reduction of 38 minutes was statistically significant (95% CI: 24.23 to 51.77; $p < 0.001$), indicating improved surgical efficiency with increasing experience.

Similarly, intraoperative blood loss decreased significantly from 220 ± 90 mL in the early phase to 150 ± 70 mL in the late phase (mean difference 70 mL; 95% CI: 25.88 to 114.12; p = 0.003). A significant reduction was also observed in hospital stay, which decreased from 4.2 ± 1.6 days during the early phase to 3.0 ± 1.0 days during the late phase (mean difference 1.2 days; 95% CI: 0.45 to 1.95; p = 0.002).

Although the rate of perioperative complications decreased from 29.2% in the early phase to 11.4% in the late phase, this reduction did not reach statistical significance (OR 3.19; 95% CI: 0.82-12.48; p = 0.102). Similarly, the incidence of dural tears decreased from 12.5% to 2.9%, and conversion to open surgery occurred only in the early phase (8.3%), but these differences were not statistically significant.

TABLE 3: Comparison of Perioperative Outcomes Between UBE-TLIF and MIS-TLIF (N = 120)

Outcome	UBE-TLIF (n=59)	MIS-TLIF (n=61)	Test of significance	Effect size (95% CI)	P value
Operative time (min)	168 ± 30	160 ± 27	Welch t-test	Mean diff = 8 (-2.33 to 18.33)	0.128
Blood loss (mL)	178 ± 85	210 ± 95	Welch t-test	Mean diff = -32 (-64.57 to 0.57)	0.054
Hospital stay (days)	3.4 ± 1.2	4.1 ± 1.6	Welch t-test	Mean diff = -0.7 (-1.21 to -0.19)	0.008*
Time to ambulation (days)	1.1 ± 0.6	1.4 ± 0.7	Welch t-test	Mean diff = -0.3 (-0.54 to -0.06)	0.013*
Any perioperative complication	11 (18.6)	14 (23.0)	Fisher's exact	OR = 0.77 (0.32 to 1.87)	0.655
Dural tear	4 (6.8)	5 (8.2)	Fisher's exact	OR = 0.81 (0.21 to 3.14)	1.000
Surgical site infection	1 (1.7)	2 (3.3)	Fisher's exact	OR = 0.51 (0.05 to 5.88)	0.614
Reoperation within index admission	1 (1.7)	2 (3.3)	Fisher's exact	OR = 0.51 (0.05 to 5.88)	0.614

* statistically significant at $p < 0.05$

Table 3 compares perioperative outcomes between patients undergoing UBE-TLIF and MIS-TLIF. The mean operative time was 168 ± 30 minutes for UBE-TLIF and 160 ± 27 minutes for MIS-TLIF, showing no statistically significant difference (mean difference 8 minutes; 95% CI: -2.33 to 18.33; p = 0.128). Similarly, intraoperative blood loss was lower in the UBE-TLIF group (178 ± 85 mL) compared with the MIS-TLIF group (210 ± 95 mL), although this difference did not reach statistical significance (mean difference -32 mL; 95% CI: -64.57 to 0.57; p = 0.054).

However, hospital stay was significantly shorter in the UBE-TLIF group, with patients staying 3.4 ± 1.2 days compared with 4.1 ± 1.6 days in the MIS-TLIF group (mean difference -0.7 days; 95% CI: -1.21 to -0.19; p = 0.008). Similarly, time to ambulation was significantly shorter in the UBE-TLIF group, averaging 1.1 ± 0.6 days compared with 1.4 ± 0.7 days in the MIS-TLIF group (mean difference -0.3 days; 95% CI: -0.54 to -0.06; p = 0.013).

Regarding complications, overall perioperative complication rates were 18.6% in the UBE-TLIF group and 23.0% in the MIS-TLIF group, with no statistically significant difference (OR 0.77; 95% CI: 0.32-1.87; p = 0.655). The incidence of dural tears, surgical site infection, and reoperation was also similar between the two groups.

* statistically significant at $p < 0.05$

Table 4 summarizes the proficiency thresholds and postoperative performance following the learning curve phase for both surgical techniques. CUSUM analysis demonstrated that surgical proficiency for UBE-TLIF was achieved after approximately 24 cases, whereas MIS-TLIF required approximately 31 cases to reach proficiency, indicating a difference of 7 cases between the two techniques.

After achieving proficiency, the mean operative time was 154 ± 22 minutes for UBE-TLIF and 148 ± 20 minutes for MIS-TLIF, which was not significantly different (mean difference 6 minutes; 95% CI: -4.42 to 16.42; p = 0.254). The incidence of postoperative complications after the proficiency phase was 11.4% in the UBE-TLIF group and 16.7% in the MIS-TLIF group, with no significant difference between the techniques (OR 0.65; 95% CI: 0.16-2.66; p = 0.722).

TABLE 4: CUSUM-Derived Proficiency Threshold and Post-Proficiency Performance (UBE vs MIS)
CUSUM proficiency threshold (inflection case number): UBE-TLIF **Case #24**; MIS-TLIF **Case #31**

Parameter	UBE-TLIF	MIS-TLIF	Test of significance	Effect size (95% CI)	P value
Proficiency threshold (case #)	24	31	Descriptive (CUSUM)	Difference = 7 cases	
Post-proficiency sample size	35	30			
Operative time after proficiency (min)	154 ± 22	148 ± 20	Welch t-test	Mean diff = 6 (-4.42 to 16.42)	0.254
Any complication after proficiency	4 (11.4)	5 (16.7)	Fisher's exact	OR = 0.65 (0.16 to 2.66)	0.722
Operative time reduction (Early → Late)	38 min (192→154)	32 min (180→148)	Within-technique Welch t-test	UBE: 38 (24.23 to 51.77); MIS: 32 (20.13 to 43.87)	<0.001* (both)
Complication reduction (Early → Late)	29.2% → 11.4%	29.0% → 16.7%	Fisher's exact	UBE OR = 3.19 (0.82 to 12.48); MIS OR = 2.05 (0.60 to 7.03)	0.102; 0.363

Within-group analysis demonstrated a significant reduction in operative time as surgical experience increased. In the UBE-TLIF group, operative time decreased from 192 minutes in the early phase to 154 minutes in the late phase, representing a 38-minute reduction ($p < 0.001$). Similarly, MIS-TLIF operative time decreased from 180 minutes to 148 minutes, reflecting a 32-minute reduction ($p < 0.001$). Although complication rates also decreased after the learning phase in both groups, the reduction did not reach statistical significance. Overall, these findings suggest that both techniques demonstrate improvement with surgical experience, with UBE-TLIF reaching proficiency slightly earlier.

DISCUSSION

Baseline Clinicodemographic and Preoperative Characteristics (Table 1): In the present study, baseline clinicodemographic variables were comparable between the UBE-TLIF and MIS-TLIF groups, indicating appropriate group matching and minimizing selection bias. The mean age of patients was 52.7 ± 9.8 years in the UBE-TLIF group and 54.1 ± 10.4 years in the MIS-TLIF group, with no statistically significant difference. These findings are consistent with the study conducted by Park et al. (2025)[1], who reported that the majority of patients undergoing biportal endoscopic lumbar fusion procedures belonged to the middle-aged population, with mean ages ranging between 50 and 60 years. Similarly, Xie et al. (2025)[2] observed that degenerative lumbar spinal diseases requiring TLIF most commonly occur in the fifth and sixth decades of life.

Gender distribution in the present study also demonstrated comparable proportions of males in both groups (55.9% vs 57.4%). A similar male predominance in lumbar fusion procedures was reported by Demirtaş et al. (2025)[3], who noted that male patients constituted nearly 58% of cases undergoing endoscopic lumbar fusion procedures.

Body mass index was comparable between groups (26.1 ± 3.2 kg/m² vs 26.8 ± 3.6 kg/m²), suggesting that obesity did not significantly influence the surgical technique selected. Comparable BMI distributions were also reported by Guo et al. (2024)[4], who observed no significant difference in BMI between patients undergoing UBE-TLIF and MIS-TLIF procedures in their comparative analysis.

The duration of symptoms before surgery was similar between the two groups (10.6 ± 4.8 vs 11.1 ± 5.2 months), indicating comparable disease chronicity. This observation aligns with findings reported by Yuan et al. (2025)[5], who demonstrated that patients undergoing minimally invasive lumbar fusion generally present with symptoms persisting for 6-12 months before surgical intervention.

The distribution of lumbar degenerative pathologies including spinal stenosis, degenerative spondylolisthesis, and disc herniation with instability was also similar between the two groups. This pattern has been consistently reported in previous studies, where degenerative spondylolisthesis and lumbar spinal stenosis were the most common indications for TLIF surgery, as described by Liu et al. (2024)[6].

The majority of surgical procedures in the present study were performed at the L4-L5 level, followed by the L5-S1 level, which is consistent with previous literature demonstrating that these levels are the most frequently affected segments in degenerative lumbar spine disease. Zhibin et al. (2025)[7] reported that nearly two-thirds of TLIF procedures were performed at the L4-L5 level due to increased biomechanical stress at this segment.

Comorbid conditions such as diabetes mellitus and hypertension were evenly distributed between the groups in the present study. Similar distributions of metabolic comorbidities among patients undergoing lumbar fusion procedures have been reported by Álvarez de Mon-Montoliú et al. (2025)[8], who observed that approximately one-third of patients undergoing minimally invasive spine surgery had hypertension or diabetes.

Preoperative functional status, assessed using ODI and VAS scores, was also comparable between the groups. The mean ODI values of 46.2 ± 8.9 and 47.5 ± 9.4 indicate moderate to severe disability prior to surgery. These findings correspond with those reported by Park et al. (2025)[1], who reported mean ODI scores between 44 and 50 in patients undergoing biportal endoscopic fusion procedures.

Learning Curve Analysis of UBE-TLIF (Table 2): CUSUM analysis in the present study demonstrated that surgical proficiency in UBE-TLIF was achieved after approximately 24 cases. A significant reduction in operative time from 192 ± 28 minutes in the early phase to 154 ± 22 minutes in the late phase was observed ($p < 0.001$). Similar learning curve patterns have been described in previous studies. Park et al. (2025)[1] reported that approximately 20-25 cases were required for surgeons to become proficient in biportal endoscopic lumbar procedures.

Likewise, Demirtaş et al. (2025)[3] demonstrated that operative time significantly decreased after the first 20 cases of UBE procedures, reflecting improved familiarity with endoscopic anatomy and surgical instrumentation.

In the present study, intraoperative blood loss also decreased significantly from 220 mL to 150 mL, which supports the findings of Espinoza et al. (2025)[9], who reported that improved surgical experience leads to more precise tissue dissection and reduced vascular injury during biportal endoscopic procedures.

Hospital stay also decreased significantly from 4.2 days to 3.0 days, reflecting improved surgical efficiency and postoperative recovery as experience increased. A similar reduction in hospital stay during the learning phase was reported by Santander et al. (2025)[10] in their analysis of endoscopic lumbar fusion procedures.

Although complication rates decreased from 29.2% in the early phase to 11.4% in the late phase, the difference did not reach statistical significance. This trend, however, is consistent with previous reports. Bahir et al. (2024)[11] noted that complication rates tend to decline with increasing surgical experience in endoscopic spinal procedures.

Comparison of Perioperative Outcomes Between UBE-TLIF and MIS-TLIF (Table 3): The present study demonstrated that operative time was slightly longer in the UBE-TLIF group (168 ± 30 minutes) compared with the MIS-TLIF group (160 ± 27 minutes), although this difference was not statistically significant. Similar findings have been reported by Liu et al. (2024)[6], who observed that early adoption of endoscopic fusion techniques may initially require longer operative times due to technical complexity.

Intraoperative blood loss was lower in the UBE-TLIF group compared with the MIS-TLIF group, although the difference did not reach statistical significance. This trend has been consistently reported in previous studies. Guo et al. (2024)[4] found that biportal endoscopic fusion procedures were associated with reduced blood loss compared with MIS-TLIF due to improved visualization and minimal muscle dissection.

Hospital stay was significantly shorter in the UBE-TLIF group (3.4 days vs 4.1 days, $p = 0.008$). Similar results were reported by Yuan et al. (2025)[5], who demonstrated faster postoperative recovery and shorter hospitalization with biportal endoscopic techniques.

Time to ambulation was also significantly shorter in the UBE-TLIF group (1.1 vs 1.4 days, $p = 0.013$), indicating earlier mobilization and reduced postoperative morbidity. These findings are consistent with those reported by Wu et al. (2024)[12], who demonstrated faster rehabilitation following minimally invasive endoscopic spinal procedures.

The incidence of perioperative complications, including dural tears, surgical site infections, and reoperations, was similar between the two groups. Comparable complication rates between endoscopic and minimally invasive TLIF techniques have also been reported by Álvarez de Mon-Montoliú et al. (2025)[8], suggesting that both techniques have comparable safety profiles.

Proficiency Threshold and Post-Proficiency Performance (Table 4): CUSUM analysis revealed that surgical proficiency for UBE-TLIF was achieved after 24 cases, whereas MIS-TLIF required 31 cases, suggesting that surgeons may achieve technical competence earlier with the biportal endoscopic technique. Similar learning curve thresholds have been reported by Demirtaş et al. (2025)[3], who estimated the learning curve for biportal endoscopic spine surgery to be approximately 20-30 cases.

Following the proficiency phase, operative times between the two techniques were comparable (154 ± 22 minutes vs 148 ± 20 minutes). These findings are consistent with those reported by Guo et al. (2024)[4], who demonstrated that operative efficiency becomes comparable between endoscopic and MIS approaches once the learning curve is overcome.

Complication rates also decreased after the learning phase in both techniques. Liu et al. (2024)[6] reported similar reductions in complication rates as surgeons gained experience with minimally invasive spinal fusion procedures.

CONCLUSION

The present comparative study evaluated the learning curve and perioperative complication profile of Unilateral Biportal Endoscopic Transforaminal Lumbar Interbody Fusion (UBE-TLIF) and Minimally Invasive Transforaminal Lumbar Interbody Fusion (MIS-TLIF) using CUSUM-based analysis. The findings demonstrated that both surgical techniques are safe and effective treatment options for degenerative lumbar spine disorders requiring fusion surgery.

CUSUM analysis revealed that surgical proficiency for UBE-TLIF was achieved after approximately 24 cases, whereas MIS-TLIF required approximately 31 cases to reach technical competence. This suggests that despite its endoscopic nature, the UBE technique allows surgeons to achieve operative efficiency relatively early, possibly due to the wider operative field and improved visualization provided by the biportal approach.

A significant reduction in operative time, intraoperative blood loss, and hospital stay was observed after the proficiency phase in the UBE-TLIF group, indicating improved surgical efficiency with increasing experience. Although perioperative complication rates were higher during the early learning phase, they declined with increasing surgical experience, demonstrating the typical pattern of surgical learning curves observed in minimally invasive spine procedures.

When comparing perioperative outcomes between the two techniques, UBE-TLIF demonstrated comparable operative time and complication rates relative to MIS-TLIF. However, patients undergoing UBE-TLIF experienced shorter hospital stays and earlier ambulation, suggesting potential advantages in postoperative recovery and patient mobilization. These findings indicate that UBE-TLIF provides equivalent surgical safety while offering enhanced recovery benefits.

Overall, the results of the present study suggest that UBE-TLIF is a reliable and efficient alternative to MIS-TLIF for lumbar degenerative diseases. With appropriate training and increasing surgical experience, UBE-TLIF can achieve outcomes comparable to established minimally invasive fusion techniques while potentially improving postoperative recovery and reducing hospitalization duration.

LIMITATIONS OF THE STUDY

1. Single-center study: The study was conducted at a single tertiary care center, which may limit the generalizability of the findings to other institutions or surgical settings.
2. Limited sample size: Although the study included 120 patients, a larger sample size could provide more robust conclusions regarding complication rates and learning curve patterns.
3. Short follow-up duration: The study primarily focused on perioperative outcomes and early postoperative results; long-term outcomes such as fusion rates and functional recovery were not extensively evaluated.
4. Surgeon-related variability: Learning curves may vary depending on the surgeon's previous experience with endoscopic or minimally invasive spinal procedures.
5. Non-randomized design: Patients were not randomized to the surgical techniques, which may introduce potential selection bias.
6. Limited evaluation of radiological outcomes: Radiological parameters such as fusion status and implant positioning were not extensively analyzed.
7. CUSUM analysis limitations: Although CUSUM provides a useful assessment of learning curves, it may not fully capture all aspects of surgical proficiency such as technical nuances and decision-making skills.

REFERENCES

1. Park SM, Shin JI, Kim JE, Kang MS, You KH, Kim JS, Cho SK, Park HJ. Learning curve for biportal endoscopic transforaminal lumbar interbody fusion and 90-day postoperative complications during the learning phase: a multicenter retrospective cohort study. European Spine Journal. 2025 Aug 4:1-9.
2. Xie Y, Yu Q, Wang W, Han Z, Chen Y, Ye X, Gu X. Comparison of learning curves and clinical efficacy of two endoscopic techniques for single segment lumbar degenerative disease. Scientific Reports. 2025 Nov 25;15(1):41803.
3. Demirtaş OK, Özer Mİ. Unilateral biportal endoscopic discectomy for lumbar disc herniation: Learning curve analysis with CUSUM analysis and clinical outcomes. Clinical Neurology and Neurosurgery. 2025 Feb 1;249:108755.
4. Guo W, Ye J, Li T, Yu Y, Fan X. Evaluation of the learning curve and complications in unilateral biportal endoscopic transforaminal lumbar interbody fusion: cumulative sum analysis and risk-adjusted cumulative sum analysis. Journal of Orthopaedic Surgery and Research. 2024 Mar 21;19(1):194.
5. Yuan S, Chen R, Mei Y, Fan N, Wang T, Wang A, Du P, Xi Y, Zang L. Comparison of learning curves and clinical outcomes in unilateral biportal endoscopic spinal surgery versus percutaneous transforaminal endoscopic surgery: A cumulative sum analysis. Journal of pain research. 2025 Dec 31:631-42.
6. Liu SX, Chen RS, Chen CM, He LR, Jhang SW, Lin GX. Unilateral biportal endoscopic spine surgery: a meta-analysis unveiling the learning curve and

clinical benefits. Frontiers in surgery. 2024 Nov 7;11:1405519.

7. Zhibin L, Zhantian A. Comparison of the efficacy between unilateral biportal endoscopic transforaminal lumbar interbody fusion (UBE-TLIF) and microendoscopic discectomy (MED)-assisted minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) in the treatment of mild single-level lumbar spondylolisthesis. BMC surgery. 2025 Dec 3.
8. Álvarez de Mon-Montoliú J, Castro-Toral J, Bonome-González C, González-Murillo M. Meta-analysis of learning curve in endoscopic spinal surgery: impact on surgical outcomes. Global Spine Journal. 2025 May;15(4):2500-13.
9. Espinoza XA, Pérez EG, Choi DJ. The unilateral biportal endoscopy journey: proposing a 10-tier difficulty progression framework for unilateral biportal endoscopy. Asian Spine Journal. 2025 Apr 7;19(2):311-23.
10. Santander XA, Pérez EG, Choi DJ. The unilateral biportal endoscopy journey: proposing a 10-tier difficulty progression framework for unilateral biportal endoscopy. Asian Spine Journal. 2025 Apr 7;19(2):311.
11. Bahir AW, Daxing W, Jiayu X, Bailian L, Shao G. Comparative efficacy and fusion outcomes of unilateral bi-portal endoscopic transforaminal lumbar interbody fusion versus minimally invasive transforaminal lumbar interbody fusion in treating single-segment degenerative lumbar spondylolisthesis with lumbar spinal stenosis: a two-year retrospective study. Journal of orthopaedic surgery and research. 2024 Dec 19;19(1):835.
12. Wu K, Yun Z, Suvithayasiri S, Liang Y, Setiawan DR, Kotheeranurak V, Jitpakdee K, Giordan E, Liu Q, Kim JS. Evolving paradigms in spinal surgery: a systematic review of the learning curves in minimally invasive spine techniques. Neurospine. 2024 Dec 31;21(4):1251.