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Learning Curve and Patient-Specific Determinants of Operative Time in Unilateral Biportal Endoscopic Lumbar Decompression by an Endoscopy-Naïve Surgeon: Analysis of the First 100 Cases

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Abstract

Unilateral biportal endoscopy (UBE) has rapidly gained global popularity as a minimally invasive technique for lumbar decompression. However, data regarding the learning curve of UBE performed by surgeons without prior spinal endoscopic experience, as well as patient- or anatomy-related determinants of operative time, remain limited. This study aimed to evaluate the learning curve of unilateral biportal endoscopic unilateral laminotomy for bilateral decompression (UBE-ULBD) performed by an endoscopy-naïve surgeon and to identify factors influencing operative time after technical proficiency was achieved. This retrospective study included the first 100 consecutive patients who underwent UBE-ULBD for lumbar central canal stenosis. Operative time per decompressed level was analyzed using cumulative summation (CUSUM) analysis to determine the proficiency threshold. Patient-related and anatomical variables were first examined for patients after the learning curve threshold using univariate analysis, and factors with $p < 0.20$ were subsequently entered into multivariate regression models. CUSUM analysis demonstrated a clear learning curve, with procedural proficiency achieved after approximately 26 cases. Mean operative time significantly decreased from 64.4 ± 21.4 minutes before proficiency to 47.5 ± 9.1 minutes thereafter ($p < 0.001$). Multivariate analysis identified surgery at the L5/S1 level, a high flavum canal ratio, and the presence of ligamentum flavum calcification as independent predictors of prolonged operative time. UBE-ULBD can be safely adopted by surgeons without prior spinal endoscopic experience. After overcoming the learning curve, operative time is influenced by specific anatomical and pathological factors, which may aid in preoperative risk stratification and more informed case selection during early adoption.

Introduction

Unilateral biportal endoscopy (UBE) has gained increasing popularity in recent years as an attractive minimally invasive technique for lumbar decompression [1–4]. This approach provides a highly magnified and clear operative field under continuous irrigation, and the separation of the viewing and working portals affords greater maneuverability compared with conventional endoscopic systems. Consequently, the indications for UBE have rapidly expanded across a broad range of spinal degenerative pathologies. Although its adoption initially grew predominantly in East Asia, UBE has more recently achieved widespread global adoption. As a newer-generation endoscopic platform, UBE has been embraced not only by surgeons with prior training in microendoscopic or full-endoscopic spine surgery (FESS), but also by those without previous familiarity with spinal endoscopy. This trend is partly attributable to the biportal configuration, which replicates the ergonomics of open surgery, allows flexible use of conventional spinal instruments, and is associated with a relatively shorter learning curve compared with FESS [5–9].

Previous investigations of the learning curve for UBE have reported that proficiency generally requires approximately 11–45 cases for lumbar discectomy [5–7, 10–12], 31–58 cases for lumbar decompression [10, 13–15], and 19–29 cases for lumbar interbody fusion [16, 17]. However, most of these studies have involved surgeons with prior spinal endoscopic experience, whereas reports

specifically evaluating the learning process of surgeons without any endoscopic background remain scarce [13]. Moreover, no studies have systematically investigated patient- and anatomy-related factors associated with operative time in UBE decompression procedures.

In light of the worldwide expansion of UBE and the need to promote its safe and effective dissemination, the present study aimed to (1) evaluate the initial learning curve of a spinal endoscopy-naïve surgeon performing lumbar decompression using UBE, and (2) identify patient-related and anatomical factors influencing operative time during UBE decompression.

Methods

Study Population

Institutional review board approval was obtained, and informed consent was secured using an opt-out approach because the study was retrospective in nature and all clinical and radiographic assessments followed routine institutional protocols. 105 consecutive patients who underwent unilateral biportal endoscopic unilateral laminotomy for bilateral decompression (UBE-ULBD) for lumbar decompression performed by a single surgeon over a 2-year period beginning in August 2023 were included. The operating surgeon had no prior experience with spinal endoscopic surgery but had more than 15 years of experience in open and microscopic spinal procedures, as well as prior experience with arthroscopic surgery. Exclusion criteria were: (1) previous surgery at the affected segment, and (2) radiographic evidence of dynamic instability, for which fusion surgery was indicated. Additionally, five patients with lumbar disc herniation and foraminal stenosis were excluded because they required combined herniotomy and lateral decompression in addition to UBE-ULBD. The final study cohort consisted of 100 patients (64 men and 36 women; mean age, 73.2 ± 8.9 years). The underlying diagnoses included lumbar spinal stenosis in 76 patients, degenerative spondylolisthesis in 19 patients, and degenerative scoliosis in 5 patients. The mean number of decompressed levels was 1.57 ± 0.70, comprising 55 single-level, 33 two-level, and 12 three-level decompressions. To minimize selection bias, UBE-ULBD was performed for all patients presenting with central canal stenosis during the study period, and no cases were treated with open or microscopic decompression. All patients were followed for at least 6 months after surgery (average, 13.8 months; range, 6–24 months).

Surgical technique

Surgical procedures were performed following previously described UBE techniques [3, 4]. After induction of general anesthesia, the patient was positioned prone, and two longitudinal incisions (5 mm for the viewing portal and 8 mm for the working portal) were made along the medial border of the left pedicle at the target level. Decompression began with drilling of the spinolaminar junction, followed by removal of the ipsilateral lamina, contralateral lamina, and the cranial margin of the inferior lamina toward the lateral recess. The ligamentum flavum was circumferentially detached from its bony attachments and then split at the midline. After confirming the absence of adhesions, the ligamentum flavum was removed in two parts on each side. Adequate neural decompression was confirmed by

visualization of the dural sac and the lateral border of the traversing nerve root. A closed-suction drain was placed in the epidural space at the conclusion of the procedure. Patients were mobilized on postoperative day 1, and the drain was removed on postoperative day 2.

Clinical evaluation

Operative time per decompressed level, as well as the number of complications and reoperations, was recorded for all cases. Clinical outcomes were assessed preoperatively and at the final follow-up using the visual analog scale (VAS) for low back pain and leg pain and the modified MacNab criteria.

Learning curve evaluation

Operative time per decompressed level was assessed using a cumulative summation (CUSUM) analysis to determine the number of cases required to achieve procedural proficiency. CUSUM analysis quantifies performance trends by sequentially summing the difference between each individual operative time and the overall mean operative time of the cohort [5–7, 10–17]. When plotted against case sequence, the resulting CUSUM curve reflects changes in operative efficiency over time: an upward slope indicates longer-than-average operative times, whereas a downward inflection signifies improved performance. In this study, the learning curve was defined based on the point at which the CUSUM curve reached its peak and subsequently began to decline, consistent with methods described in previous reports.

Other evaluations

To assess factors influencing operative time, we analyzed single-level decompression cases performed after the surgeon had surpassed the initial learning curve, as determined by the CUSUM analysis. The following patient- and anatomy-related variables were evaluated: (1) age, (2) sex, (3) body mass index (BMI), (4) bone mineral density (BMD), (5) patient pathologies, (6) operated level, (7) depth from the skin to the laminar surface, (8) subcutaneous tissue thickness, (9) paraspinal muscle thickness, (10) laminar thickness, (11) axial laminar opening angle, (12) flavum canal ratio (FCR), and (13) presence of ligamentum flavum calcification. BMD was measured in Hounsfield units (HU) for each vertebral body according to the protocol described by Schreiber et al. [18], and the HU values of the vertebrae above and below the decompressed level were averaged to determine the representative BMD for each patient. Thickness-related parameters were measured on axial CT images obtained at the level corresponding to the lower edge of the upper lamina, aligned parallel to the caudal endplate of the vertebral body (Fig. 1) [19]. All measurements were referenced to the plane corresponding to the lateral boundary of decompression on the ipsilateral lamina. The laminar opening angle was defined as the angle between the lines representing the planes of the right and left laminae at the same level. FCR was assessed on axial T2-weighted MRI at the most stenotic level and defined as the ratio of the cross-sectional area of the ligamentum flavum to that of the spinal canal (Fig. 2) [20].

Statistical analysis

Continuous and categorical variables are presented as mean ± standard deviation and number, respectively. After assessing the normality of continuous variables using the Shapiro–Wilk tests, the unpaired t-test or one-way analysis of variance were used to analyze the differences between groups. The chi-square test was applied for categorical variables, and Fisher's exact test was used when the expected cell count was fewer than five. Each variable was first examined using univariate analysis. Then, variables with a p value < 0.20 in the univariate analysis were entered into the multivariate regression models using a stepwise variable selection method to identify independent factors influencing operative time. All statistical analyses were performed using JMP version 18.0 (SAS Institute, Cary, NC, USA), and a p value < 0.05 was considered statistically significant.

Results

The mean operative time per level was 51.9 ± 15.2 minutes. Perioperative complications included incidental durotomy in 4 patients (4.0%). Among these cases, one patient required immediate open surgical repair, and two patients were successfully managed using a patch technique. In the remaining patient, a delayed herniation of the cauda equina root associated with an occult dural tear without cerebrospinal fluid leakage was identified 3 weeks postoperatively, necessitating secondary open surgical repair. Postoperative epidural hematoma occurred in 3 patients (3.0%); one patient underwent surgical evacuation, while the other two resolved spontaneously within 2 weeks. One patient (1.0%) experienced transient postoperative motor weakness, which resolved without additional intervention.

Clinical outcomes demonstrated significant improvement. The VAS scores for low back pain and leg pain improved significantly from 45 ± 21 mm and 69 ± 23 mm preoperatively to 14 ± 18 mm and 11 ± 14 mm at the final follow-up, respectively (p < 0.001). According to the modified Macnab criteria, the rate of excellent or good outcomes was 97.0%, including 46 patients classified as excellent and 51 as good. Three patients were rated as fair, and no patients were rated as poor.

CUSUM analysis of operative time per decompressed level demonstrated a clear learning pattern. The fitted polynomial curve ($y = 1.0\times10^{-8}x^5 - 3.0\times10^{-5}x^4 + 6.8\times10^{-3}x^3 - 0.66x^2 + 22.29x + 56.78$; $R^2 = 0.958$) reached its peak at case 26, indicating the cutoff point for achieving procedural proficiency in UBE-ULBD (Fig. 3). The mean operative time before this cutoff (learning phase) was 64.4 ± 21.4 minutes, which decreased significantly to 47.5 ± 9.1 minutes after the cutoff (mastery phase) (p < 0.001). No significant differences were observed between the learning and mastery phases with respect to baseline patient characteristics or surgical outcomes (Table 1).

Table 1
Comparison of patient characteristics and surgical outcomes between learning and mastery phases

Parameters	**Learning phase (N = 26)**	**Mastery phase (N = 74)**	**P-value**
Age (years)	74.3 ± 6.8	72.8 ± 9.5	0.469
Sex (M : F)	20 : 6	44 : 30	0.154
Body mass index (kg/m^2)	24.3 ± 4.1	24.6 ± 4.0	0.863
Pathologies (cases)	22	54	0.480
Lumbar canal stenosis	3	16	
Degenerative spondylolisthesis	1	4	
Degenerative scoliosis			
Number of decompressed level	1.54 ± 0.58	1.58 ± 0.70	0.933
Operative time (min)	64.4 ± 21.4	47.5 ± 9.1	< 0.001*
VAS (low back pain) (mm) Pre	43 ± 29	46 ± 24	0.748
Post	15 ± 21	14 ± 23	0.903
VAS (leg pain) (mm) Pre	66 ± 31	70 ± 28	0.695
Post	13 ± 18	10 ± 18	0.914
MacNab criteria	11 : 14 : 1 : 0	35 : 37 : 2 : 0	0.885
Excellent : Good : Fair : Poor			
Complications (cases) Dural tear	1	3	0.801
Hematoma	1	2	
Transient paralysis	0	1	
Follow-up (months)	14.8 ± 5.8	13.4 ± 4.6	0.316
VAS: visual analog scale.			
*: $p < 0.05$.			

Among the 74 cases performed after the learning curve threshold, 41 patients underwent single-level decompression and were included in the analysis of factors influencing operative time. In this cohort, univariate analysis demonstrated that operated level ($p = 0.046$), FCR ($p < 0.001$) (Fig. 4), and the presence of ligamentum flavum calcification ($p < 0.001$) were significantly associated with prolonged operative time. The mean FCR in this cohort was 0.57 ± 0.12. Additionally, although patient pathologies

did not reach statistical significance, they met the inclusion threshold for multivariate analysis (p = 0.055). Obesity-related parameters were not significant contributors to operative time (p = 0.381–0.749) (Tables 2 and 3). Multivariate regression analysis was subsequently performed using variables with p < 0.20 in the univariate analysis, and the following independent predictors of prolonged operative time were identified: the L5/S1 level (standardized regression coefficient [β] = 0.23, p = 0.045), FCR (β = 0.36, p = 0.009), and the presence of ligamentum flavum calcification (β = 0.31, p = 0.022) (Table 4).

Table 2
Univariate analysis of categorical variables with operative time

Parameters	**Number (cases)**	**Operative time (min)**	**P-value**
Sex			
Male	25	48.2 ± 7.9	0.419
Female	16	50.8 ± 12.3	
Pathologies			
LCS	28	47.3 ± 9.5	0.055
DS	13	53.5 ± 9.3	
Operated level			
L2/3	3	45.7 ± 5.0	0.046*
L3/4	10	45.4 ± 9.4	
L4/5	25	49.2 ± 9.0	
L5/S1	3	65.6 ± 6.0	
Flavum calcification			
with	5	62.6 ± 6.3	< 0.001*
without	36	47.4 ± 8.7	
LCS: lumbar canal stenosis, and DS: degenerative spondylolisthesis.			
*: p < 0.05.			

Table 3
Univariate analysis of continuous variables with operative time

Parameters	R^2	P-value
Age	0.029	0.287
Body mass index	0.004	0.678
Bone mineral density	0.017	0.413
Depth from skin to lamina	0.013	0.474
Subcutaneous tissue thickness	0.020	0.381
Paraspinal muscle thickness	0.003	0.749
Laminar thickness	0.035	0.242
Laminar opening angle	0.014	0.455
Flavum canal ratio	0.277	< 0.001*
*: $p < 0.05$.		

Table 4
Multivariate regression analysis with operative time

Parameters	B	95% Confidence interval		β	P-value
		Lower	Upper		
Pathologies (DS)	1.41	-0.84	4.65	0.17	0.168
L5/S1	5.24	0.76	11.23	0.23	0.045*
Flavum canal ratio	30.12	8.14	52.12	0.36	0.009*
Flavum calcification	4.60	0.69	8.50	0.31	0.022*
B: unstandardized regression coefficient, β: standardized regression coefficient, and DS: degenerative spondylolisthesis.					
*: $p < 0.05$.					

Discussion

With the rapid global expansion of UBE, the safe dissemination of this technique has become increasingly important. In this study, we investigated the learning curve of UBE-ULBD performed by a

surgeon without prior endoscopic experience, with a particular focus on factors influencing operative time. Using CUSUM analysis, the proficiency cutoff for UBE-ULBD was identified at 26 cases. Furthermore, multivariate analysis of cases performed after this proficiency threshold demonstrated that surgery at the L5/S1 level, marked hypertrophy of the ligamentum flavum as reflected by a high FCR, and the presence of ligamentum flavum calcification were independently associated with prolonged operative time, whereas BMI and skin-to-lamina depth had minimal influence.

Previous CUSUM-based analyses of the learning curve for UBE-ULBD have reported that surgical proficiency requires approximately 31–58 cases [10, 13–15]. In these studies, operative time has consistently been used as a surrogate marker of technical proficiency. However, it is highly plausible that the length of the learning curve varies substantially according to surgeon-specific factors, particularly prior training in endoscopic techniques [11]. Several recent studies have suggested that prior endoscopic experience shortens the learning curve for UBE procedures [7, 9].This effect is likely attributable to greater familiarity with the restricted endoscopic field of view and the unique hand–eye coordination required for endoscopic manipulation. Despite this, investigations focusing specifically on surgeons without any prior spinal endoscopic experience remain limited. A key strength of the present study lies in its focus on learning curve characteristics in a spine endoscopy–naïve surgeon, evaluated using CUSUM methodology. Park et al. examined their initial 60 cases and defined surgical proficiency as an operative time comparable to their average time for microscopic decompression (75 minutes), reporting that approximately 58 cases were required to achieve proficiency [13]. In contrast, the present study evaluated the learning curve using the mean operative time of the first 100 cases as the reference benchmark and identified a proficiency threshold at 26 cases. Direct comparisons between studies are inherently challenging due to differences in the definition of proficiency, surgeon background, and heterogeneity of underlying pathologies. Nevertheless, the relatively shorter learning curve observed in the present study may be partly explained by the operator's extensive experience in open and microscopic spinal surgery, as well as prior experience in arthroscopic procedures [12]. Although further multicenter studies involving multiple surgeons are warranted to more precisely characterize the learning curve of UBE-ULBD, the findings of this study suggest that technical proficiency with UBE-ULBD is clinically achievable even for surgeons without a prior endoscopic surgical background.

To our knowledge, this study is the first report to systematically evaluate patient-related and anatomical factors that influence the procedural complexity of UBE-ULBD, which constitutes a key strength of the present investigation. In this study, surgery at the L5/S1 level, marked hypertrophy of the ligamentum flavum, and the presence of ligamentum flavum calcification were independently associated with prolonged operative time after the learning curve had been surpassed. Yoshimizu et al. reported that BMI and spinal level were significant determinants of operative time in UBE discectomy based on multivariate analysis [12]. Theoretically, patients with elevated BMI may be predisposed to insufficient irrigation due to thick soft tissue layers, and technical difficulties in triangulation have also been proposed. The discrepancy between their findings and ours may be explained by methodological differences: our analysis was restricted to cases performed after the surgeon had overcome the learning curve in order to minimize the confounding effect of technical immaturity, whereas their analysis included the entire

early experience. Olson et al. compared clinical outcomes of UBE decompression across different degrees of obesity and reported no significant differences in operative time or perioperative complications [21], which is consistent with our results. Taken together, the influence of BMI on operative time may diminish with increasing technical proficiency, suggesting that UBE may represent a favorable minimally invasive option for obese patients compared with conventional open procedures.

Regarding spinal level, previous studies of UBE discectomy have demonstrated shorter operative times at the L5/S1 level than at more cranial levels [12], primarily because of the wider interlaminar space, larger working corridor, and reduced need for bone resection. In contrast, our study demonstrated that the L5/S1 level was an independent predictor of prolonged operative time in UBE-ULBD. This apparent paradox can be explained by fundamental technical differences between UBE discectomy and UBE-ULBD. Unlike discectomy, UBE-ULBD requires extensive contralateral decompression through a unilateral corridor. Anatomically, the L5/S1 level is characterized by a deep and capacious spinal canal, a steeper contralateral working angle, and a longer laminar length from the midline to the lateral recess, as previously described [22]. These features likely increase the time required for contralateral bony drilling and flavectomy. In addition, during contralateral manipulation, temporary obstruction of the working portal and deterioration of irrigation flow are more likely to occur, further compromising visualization and ultimately resulting in prolonged operative time.

Another important finding of this study is the strong association between hypertrophied or calcified ligamentum flavum and prolonged operative time. Severe flavum hypertrophy and calcification may act as a critical technical bottleneck during UBE-ULBD because these pathological tissues tend to adhere firmly to the underlying dura, require meticulous circumferential detachment, and often necessitate piecemeal resection rather than en bloc removal. Furthermore, calcified ligamentum flavum reduces tissue elasticity and increases the risk of incidental durotomy [23], compelling surgeons to proceed more cautiously and thereby extending operative duration. These pathological features therefore represent key anatomical constraints that limit surgical efficiency even after technical proficiency has been achieved.

From a practical standpoint, the factors identified as determinants of operative time in this study may serve as useful preoperative imaging–based risk stratification markers, enabling more appropriate case selection and surgical planning. Safe implementation of UBE-ULBD requires structured training, including cadaver-based workshops and appropriate mentorship; however, careful case selection remains equally critical. During the early adoption phase, surgeons should prioritize cases with minimal ligamentum flavum hypertrophy, absence of flavum calcification, and avoidance of the L5/S1 level. Although obesity did not significantly prolong operative time after proficiency was achieved, it may represent an additional technical challenge during the early learning phase and should therefore be interpreted with caution [12].

The present study has several limitations that should be acknowledged. First, operative time was used as a surrogate marker of technical proficiency. Although operative time is a practical and objective parameter, it reflects only one dimension of surgical skill. The definition of “proficiency” in UBE-ULBD remains inherently complex and multifactorial, and additional parameters, such as perioperative

complications, clinical outcomes, and quantitative radiographic assessments of decompression completeness, may offer complementary and more comprehensive measures of procedural proficiency. Furthermore, future studies incorporating video-based skill assessment, motion analysis, or objective structured technical evaluations may offer deeper insights into procedural performance and learning dynamics. Second, this was a single-center study performed by a single surgeon, which limits the generalizability of the findings. Although the surgeon had no prior experience in spinal endoscopic surgery, extensive experience in open and microscopic spinal surgery, as well as arthroscopic techniques, may have favorably influenced the observed learning curve. Therefore, surgeons with less overall surgical experience may require a longer learning period, and the present results should be interpreted with caution. Third, the analysis was limited to the initial 100 consecutive cases. As surgical experience accumulates, the definition and threshold of “proficiency” may evolve, and longer-term evaluations are necessary to further validate the learning curve findings over time. Finally, despite the consecutive nature of the cohort, there was unavoidable heterogeneity among cases with respect to individual patient pathologies. These factors may have introduced unmeasured confounding effects and could not be fully accounted for in this retrospective design. In addition, operative efficiency may have been influenced by time-dependent confounding factors, including increasing familiarity of the surgical team, gradual optimization of perioperative workflow, and minor refinements in equipment setup or surgical technique over time. These effects are difficult to fully disentangle from individual surgeon learning and may have partially contributed to the observed reduction in operative time.

Conclusions

UBE-ULBD can be performed safely by surgeons without prior spinal endoscopic experience, with procedural proficiency achieved after approximately 26 cases based on CUSUM analysis. After overcoming the learning curve, operative time was independently prolonged by surgery at the L5/S1 level, severe hypertrophy of the ligamentum flavum, and the presence of flavum calcification, whereas obesity-related parameters had minimal influence. Preoperative recognition of these factors may facilitate risk stratification, more appropriate case selection, and optimized surgical planning during the learning process of UBE-ULBD.

Declarations

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Author’s Contributions: All authors contributed to the study conception and design. Data collection and analysis were performed by Keitaro Matsukawa. The first draft of the manuscript was written by Keitaro Matsukawa and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethical Approval and Consent to participate: This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of National Hospital

Organization, Murayama Medical Center (ID:12-10), and informed consent was secured using an opt-out approach because the study was retrospective in nature and all clinical and radiographic assessments followed routine institutional protocols.

Human and Animal Ethics: All procedures performed in studies involving human participants were in accordance with the ethical standards of our institutional (National Hospital Organization, Murayama Medical Center) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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24. Statements & Declarations

Figures

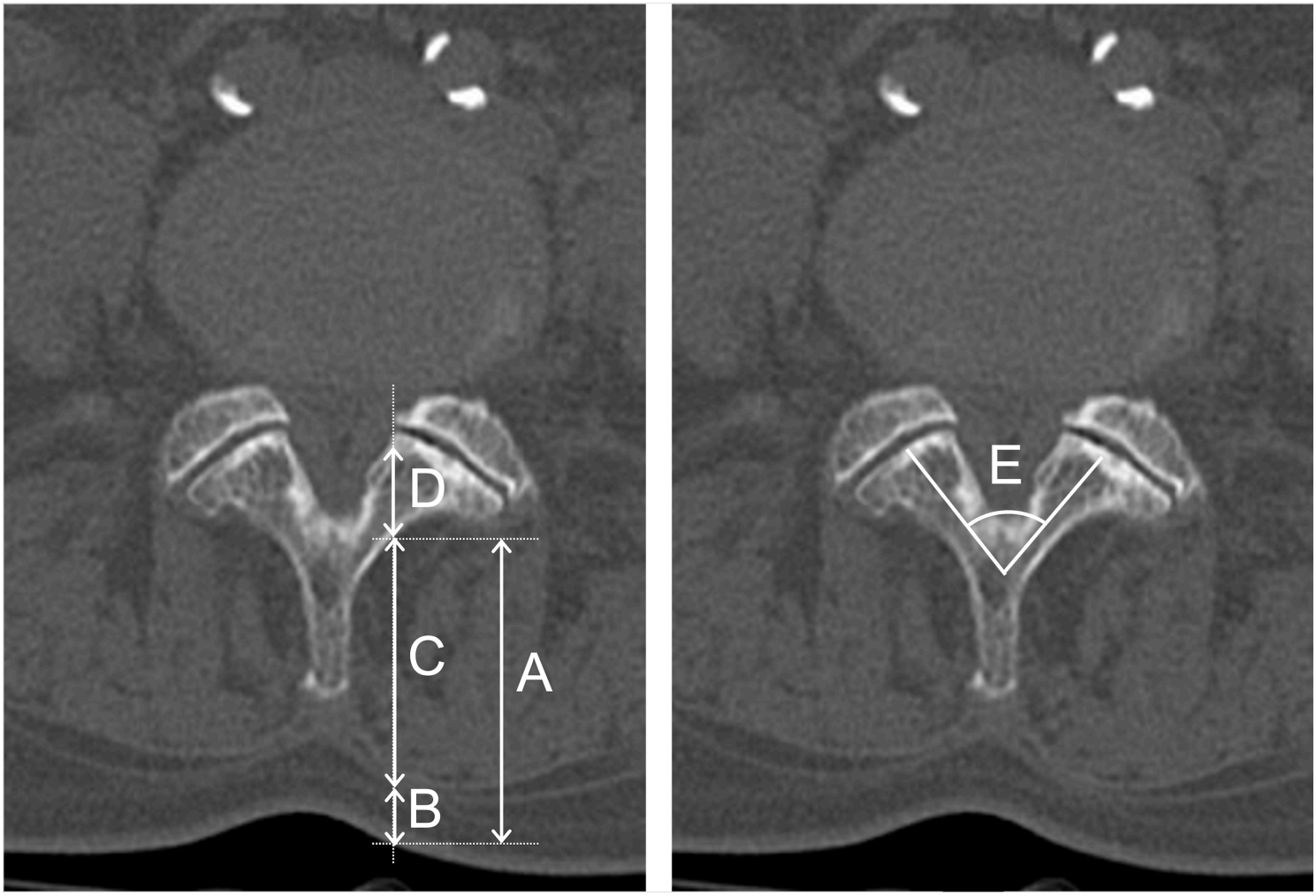


Figure 1

Representation of radiographical measurements of parameters.

Thickness-related parameters were measured on the plane corresponding to the lateral boundary of decompression on the ipsilateral lamina. The laminar opening angle was defined as the angle between lines representing the planes of the right and left laminae.

A: depth from the skin to the laminar surface; B: subcutaneous tissue thickness; C: paraspinal muscle thickness; D: laminar thickness; E: axial laminar opening angle.



Figure 2

Measurement of the flavum canal ratio.

The flavum canal ratio was assessed on axial T2-weighted MRI at the most stenotic level and defined as the ratio of the cross-sectional area of the ligamentum flavum to that of the spinal canal.

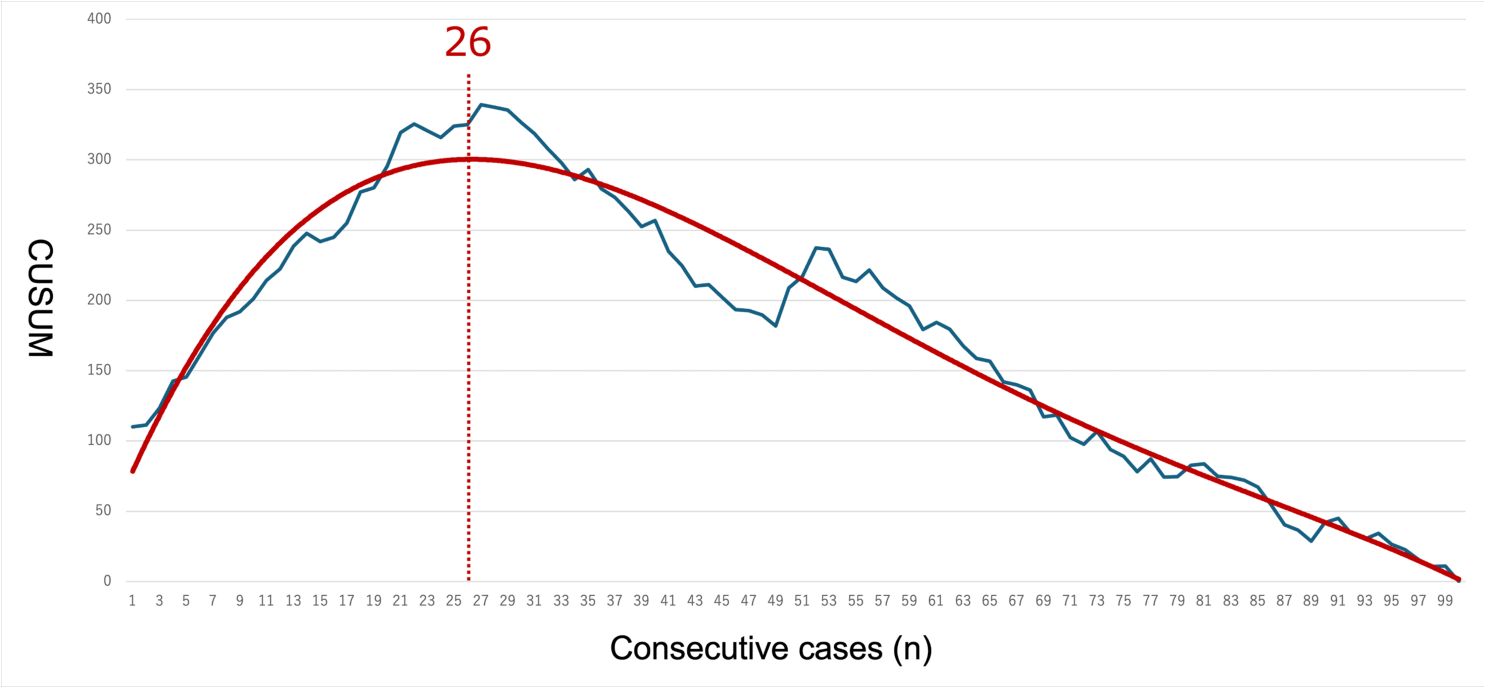


Figure 3

Cumulative summation analysis of operative time.

The fitted polynomial curve ($y = 1.0\times10^{-8}x^5 - 3.0\times10^{-5}x^4 + 6.8\times10^{-3}x^3 - 0.66x^2 + 22.29x + 56.78$; $R^2 = 0.958$) reached its peak at case 26, indicating the cutoff point for achieving procedural proficiency.

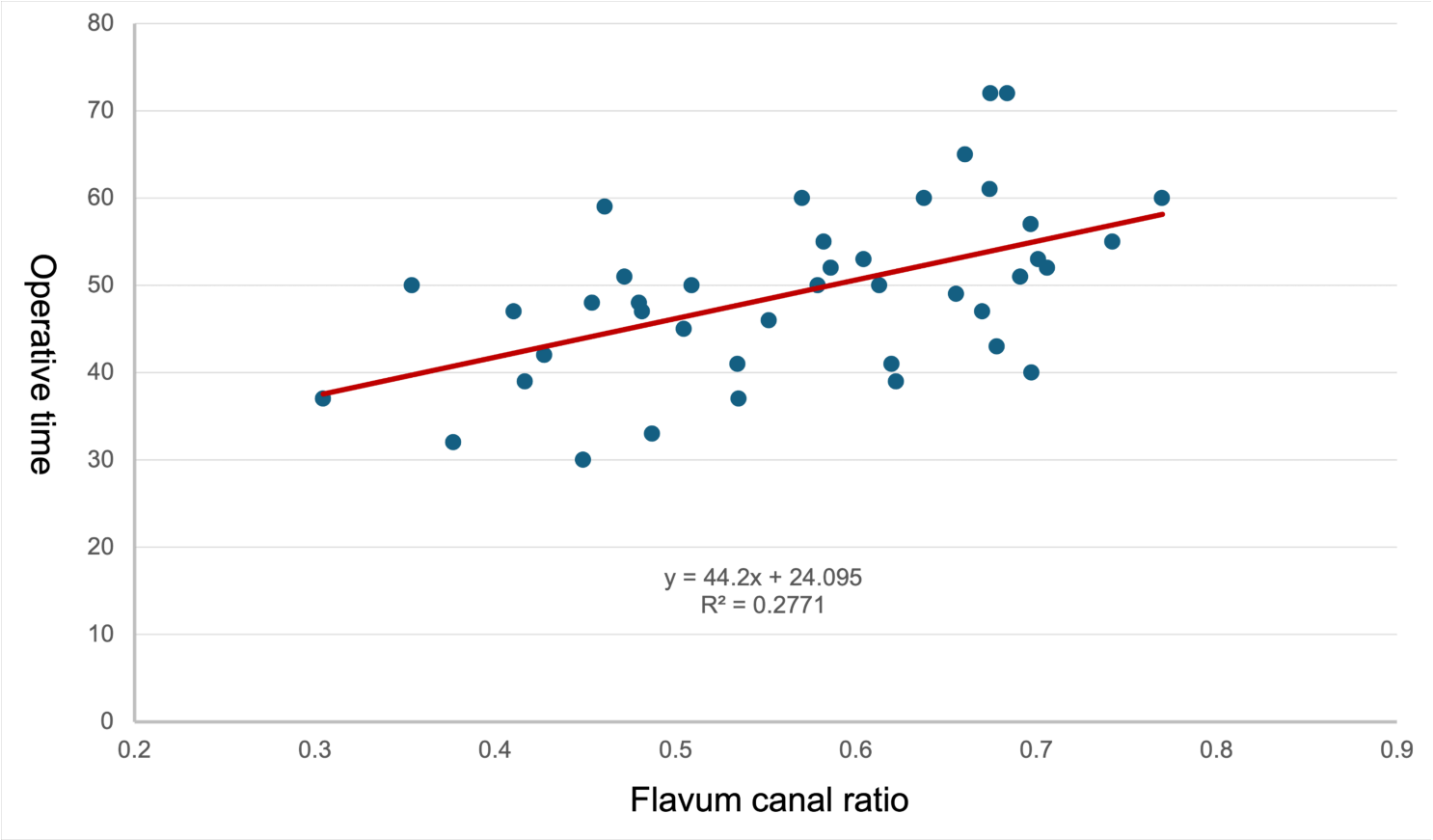


Figure 4

Correlation between flavum canal ratio and operative time.

Scatter plot demonstrating the relationship between the flavum canal ratio (FCR) and operative time in single-level UBE-ULBD cases performed after the learning curve threshold. A positive correlation was observed, indicating that higher FCR values were associated with longer operative times.