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The learning curve for lumbar discectomy in unilateral biportal endoscopic spine surgery using the cumulative summation method

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Abstract

Background Unilateral biportal endoscopy (UBE) is gaining popularity owing to its versatility as a spinal endoscopic procedure. However, the general value of the learning curve for discectomy by UBE is unknown. This retrospective study aimed to determine the learning curve of UBE for lumbar discectomy using a cumulative summation (CUSUM) method. We examined the learning curves of four surgeons at an institution and factors that shortened the learning curves.

Methods The study included 200 patients (mean age 44.2 years) who underwent lumbar discectomy by UBE at our hospital and four male orthopedic surgeons who had performed 50 UBE discectomies. An approximate curve using the CUSUM method was created using the mean operative time for each case as the target. All surgeons had performed lumbar discectomy and over 200 spinal surgeries before inducing UBE. Surgeon A received specialized training in shoulder arthroscopic surgery. The surgical times before and after the curve reached its maximum value were compared; a point of significant difference was defined as case to proficiency.

Results The mean operative times for surgeons A, B, C, and D were 48, 66, 90, and 87 min, respectively. The approximate curves obtained using the CUSUM method had maxima at $x = 22$, 20, 27, and 13. The operating times of Surgeons A and B showed significant differences before and after the maxima (59 vs. 39 and 75 vs. 60), whereas those of Surgeons C and D did not (96 vs. 84 and 95 vs. 85).

Conclusions UBE is generally considered to have a steep learning curve; in this study, the learning curve differed depending on the surgeon. The surgeon with the best learning curve was trained as an arthroscopic surgeon. Coordination for endoscopic surgery influenced the learning curve compared to the experience with spine surgery.

Keywords Learning curve, Cumulative sum analysis, Unilateral biportal endoscopy, Biportal endoscopic spine surgery, Lumbar discectomy, Interlaminar approach, Surgeon, Orthopedic, Specialized training, Retrospective study

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Background

Unilateral biportal endoscopic (UBE) spine surgery is an endoscopic surgery that creates two portals and is performed under perfusion. UBE creates two portals for better freedom and maneuverability, which increases the efficiency of securing the field of view and working with the endoscope. Therefore, it is easier to master than the conventional spinal endoscopic surgery [1].

Cumulative sum (CUSUM) analysis was first developed in the industrial field to assess performance and identify points of improvement. Doctors began using this analysis in the 1970s to study the learning curve of surgical procedures. CUSUM analysis converts raw data into a running total of data deviations from the group mean, allowing researchers to visually inspect the data for trends that are difficult to detect using other methods.

UBE is a relatively new technique that is rapidly gaining popularity worldwide owing to its versatility as a spinal endoscopic procedure. There are reports on the learning curve required to master this technique. In lumbar disc herniotomy with the UBE interlaminar approach, Xu et al. estimated learning curves using the CUSUM method based on the mean operative time and reported 12–32, 24, and 31 as the cases to proficiency (CP) [2–4]. However, because these studies were only discussions of single surgeons and essentially examined the learning curve of three surgeons in total, it may not be possible to provide a general value of the learning curve for discectomy by UBE. Herein, we examined the learning curve of four spine surgeons who started performing UBE at approximately the same time at the same institute. CUSUM analysis of the operating time was performed for each surgeon. To identify the factors that help shorten the learning curve, we examined the degree of step-by-step time reduction in UBE discectomy for the surgeon whose mean operating time was the shortest. This study aimed to identify the learning curve of UBE discectomy and the important steps for shortening the learning curve.

Methods

Materials

This study was approved by our Institutional Review Board. This retrospective study included 200 patients (mean age 44.2 years, 65 women and 135 men) who underwent single-level lumbar discectomy using the interlaminar approach at our hospital. Written informed consent was obtained in the form of opt-out on the institutional website. Four surgeons, A, B, C, and D, each operated on 50 of the 200 patients. These surgeons were spine surgeons who performed lumbar discectomies under a microscope before the introduction of UBE. All 200 patients underwent surgery at the same facility between 2019 and 2020. The surgeons were male orthopedic surgeons. Surgeon A was 32 years old at the time of introduction and had 3 years of experience in spine surgery; Surgeon B was 34 years old and had 4 years of experience; Surgeon C was 38 years old and had 5 years of experience; and Surgeon D was 40 years old and had 5 years of experience. The surgeons had performed over 200 spinal surgeries but performed lumbar discectomy mainly under a microscope and had limited experience with endoscopic spine surgery. However, Surgeon A differed from the other surgeons in that he received specialized training in shoulder arthroscopic surgery.

CUSUM plots and statistical analysis

We created a graph of the cumulative sum indicated by $Si = \sum{}_{j=1}^{i}\left(Yj - \bar{Y}\right)$ i =1, 2..., n. Y = operating time, n = 50 of the number of surgeons performed, and $\bar{Y} = \sum{}_{j=1}^{n} Yj/n$ referred to the average operating time of 50 cases. Specifically, the CUSUM value for the first case is the operating time minus the mean operation time, and the CUSUM value for the second case is the operation time minus the mean operation time plus the CUSUM value for the first case. The CUSUM value was positive and persisted until the 50th case. The CUSUM values were plotted against the case number. The plotted graph was used to calculate a polynomial curve-fitting model. The operating time was calculated from the skin incision to wound closure. A generalized linear mixed model with repeated measures was used. The fixed effects were case numbers, and the random effects were the surgeons. A single linear regression for each surgeon was computed as the independent variable to further investigate the effects on the operating time.

Graphs were plotted using Microsoft Excel. The R2 value was used to judge the fit of the model, and the model with the highest R2 value was used for subsequent analyses.

To analyze the calculated CUSUM curve, the cases were divided into two groups: one before the curve reached its maximum value and the other after. The number of cases where the form of the fitted curve changed from rising to dropping was also calculated. The two groups were compared using the Mann–Whitney U test (JMP software). A significant difference in the operating time of each group was defined as the CP.

Other evaluations

We examined the number of complications, recurrences, and reoperations between four surgeons who performed CP and those who did not. The incidence was compared between groups with and without CP. Comparisons were made using Fisher's exact tests.

We examined the effect of surgeon-related factors (arthroscopic training experience, age, and years of spinal surgery experience) on the learning speed. We fitted an exponential model to each surgeon's learning curve and extracted the learning speed parameter (b). We then performed a multiple regression analysis with learning speed as the dependent variable and the surgeon-related factors as independent variables. The exponential decay model used was as follows. $T(x) = a \cdot e^{-b \cdot x} + c$, where $T(x)$ represents the surgical time, x is the case number, a is the initial surgical time, b is the learning rate, and c is the final stabilized surgical time. For the regression analysis, learning speed was used as the dependent variable, with age and years of spinal surgery experience and arthroscopic training experience as independent variables. Statistical analyses were performed using Python.

To assess factors influencing operative time, we conducted multiple linear regression analyses. The independent variables included BMI, surgical level, and patient age. Surgical level was treated as a categorical variable, with L5/S as the reference. Regression coefficients (β) and 95% confidence intervals (CIs) were reported, with statistical significance set at $p < 0.05$.

The operating time required for each surgical step by Surgeon A was also investigated. The steps were as follows: step 1: space creation (after insertion of the endoscope, detachment of soft tissue, and resection on the dorsal side of the lamina and interlamina); step 2: bone resection (the interlamina space was enlarged by resection of the upper and lower lamina, inferior articular process, and superior articular process); step 3: yellow ligament resection (the yellow ligament was removed and the lateral border of the nerve root was identified); step 4: discectomy (the herniation was removed). CUSUM analysis was also performed for each surgical step.

Surgical procedure (Fig. 1)

Two portals were set up on the 1 cm cephalocaudal side of the lumbar disc in line with the interpedicular line. The cranial portal was used as the endoscope portal and the caudal portal as the working portal. To create a space for endoscopic insertion, the rotator muscle was peeled off from the caudal border of the upper lamina using a Cobb elevator. The spinolaminar junction was the initial target point, where the tip of the endoscope was inserted through the caudal portal. Surgery was performed under continuous perfusion. The caudal edge of the upper lamina and the inner edge of the inferior articular process were confirmed by peeling the soft tissue from the bone using a radiofrequency device. The dorsal surface of the lower lamina, superficial layer of the yellow ligament, and inner edge of the superior articular process were confirmed. The working space for discectomy was expanded by osteotomy using a high-speed drill, which was performed from the caudal margin of the lamina and inner edge of the inferior articular process to the inner edge of the superior articular process. The deep layer of the yellow ligament was excised, the nerve root was identified, and herniation was removed. After confirming nerve decompression, a suction drain was placed in the interlaminar space, and the wound was closed.

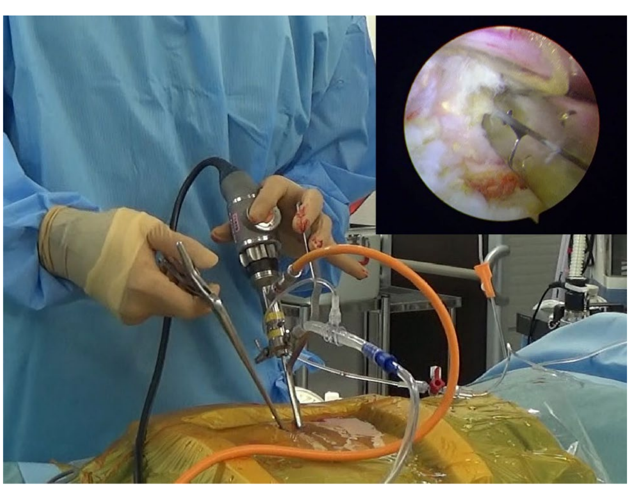

Fig. 1 Schematic of UBE lumbar discectomy

Results

The mean operative times for surgeons A, B, C, and D were 48, 66, 90, and 87 min, respectively (Fig. 2). The individual surgeons had a significant impact on the operating time (P value < 0.001) (Fig. 3). The approximate curves for Surgeons A, B, C, and D were maximal at $x = 22$, 20, 28, and 13. The operative times of Surgeons A and B significantly differed before and after the maximal operation. Therefore, 22 and 20 cases were defined as CP for Surgeons A and B, respectively. However, there was no significant difference in the operative time before and after the maximum of Surgeons C and D (Table 1).

Operative time was statistically compared between the cases before and after the function of the curve reached a maximum.

The complication rates for Surgeons A, B, C, and D were 2%, 0%, 4%, and 2%, respectively. The recurrence rates were 2%, 12%, 12%, and 6%, respectively, and the reoperation rates were 2%, 8%, 12%, and 4%, respectively. No significant differences were observed between the four surgeons (Table 2).

Analysis of surgeon-related factors suggested that younger surgeons tended to have a faster learning rate. In contrast, years of spinal surgery experience showed a negative correlation with learning speed. Interestingly, arthroscopic training experience was associated with enhanced learning speed. However, due to the small sample size of surgeons ($n = 4$), statistical significance could not be evaluated, and all p-values were returned as nan.

Regression analysis showed that surgical level and BMI significantly influenced operative time, while patient age had no significant effect. The operative time was

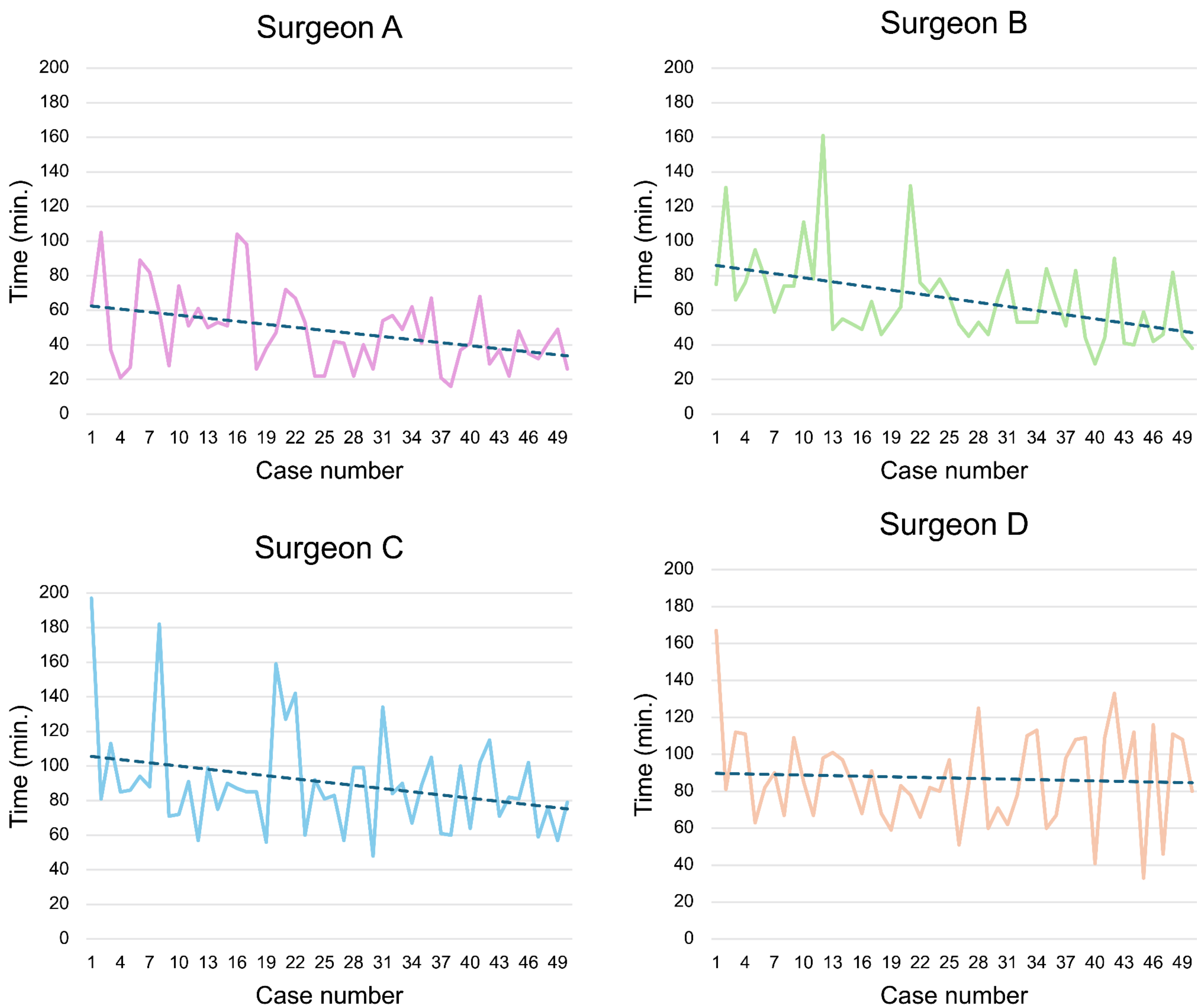

Fig. 2 Change in operating time for Surgeons **A**, **B**, **C**, and **D**

significantly longer for L2/3 and L3/4 than for L5/S. The operative time for L4/5 did not differ significantly from that for L5/S (Table 4).

For Surgeon A, the average operative times were 337 s, 392 s, 559 s, and 1005 s for steps 1, 2, 3, and 4, respectively (Fig. 4). The maximum values of the curve-fitting model plotted using CUSUM for each step were achieved at 15, 18, 14, and 21 cases (Fig. 5). The time for steps 1 and 2 was significantly shorter than that for step 3; however, no significant difference was observed for step 4 (Table 5).

Operative time was statistically compared between the cases before and after the function of the curve reached a maximum.

Discussion

UBE is an endoscopic procedure that makes it easy to secure the field of view and has a high operability because the endoscope and instrument operations are independent. UBE is considered to have a gentle learning curve due to its good operability [1]. However, UBE, which involves working with an endoscope on one hand and instruments on the other, requires a higher degree of coordination. Therefore, there are hurdles for spine surgeons who are accustomed to conventional or microscopic surgery to get started.

The learning curve was originally used to evaluate industrial work. Since Luft began using the learning curve to assess surgical proficiency, it has become popular in the surgical evaluation concept [5]. Woodall et al. reported that CUSUM plots and methods have been used in many healthcare applications from the perspective of surgical outcome quality [6].

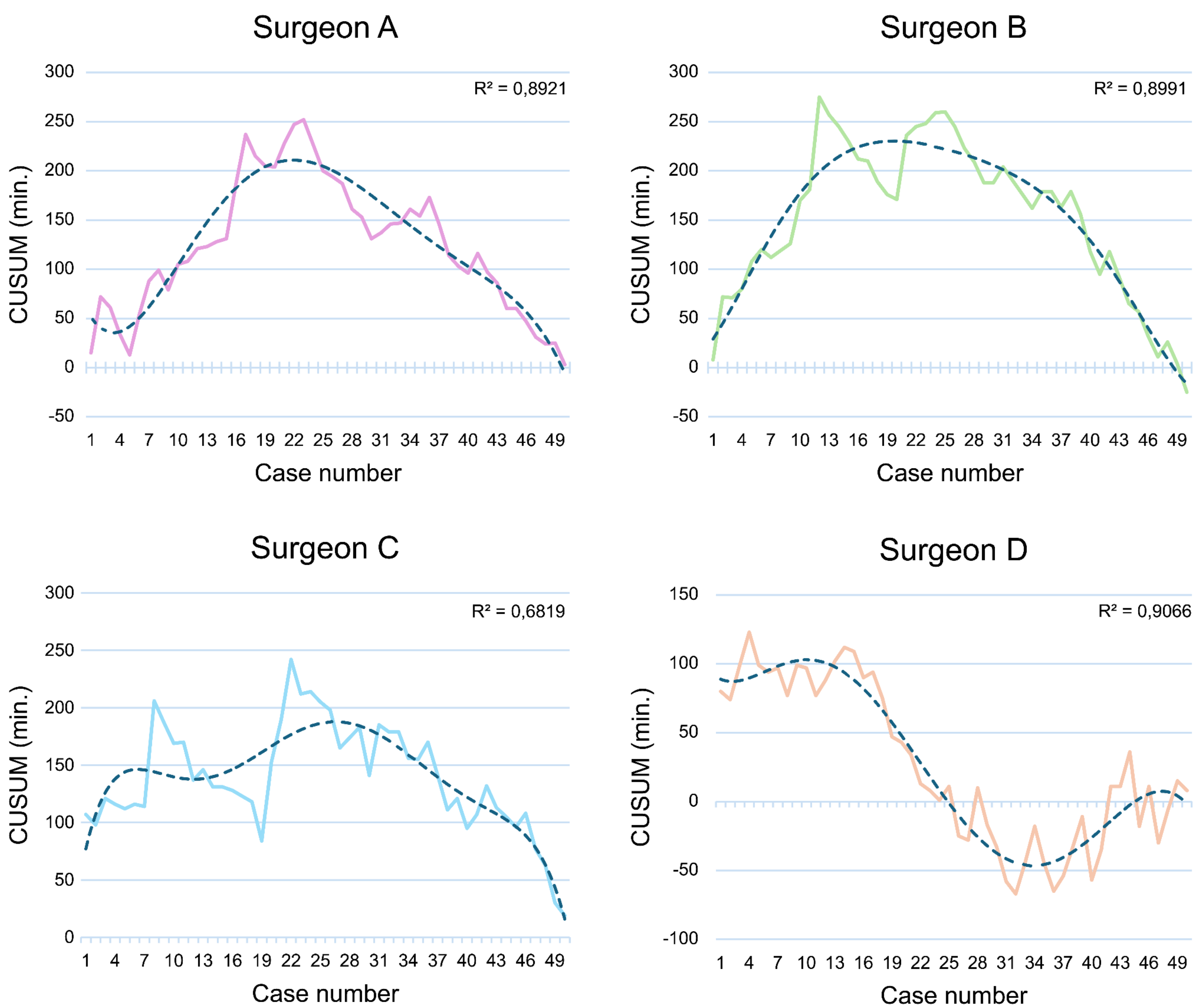

Fig. 3 Cumulative sum plots for Surgeons **A**, **B**, **C**, and **D**

Table 1 Analysis of curves created by CUSUM plot for each surgeon

		Before	After	*P* value
Surgeon A	n	22	28	0.004
	Operating time (minutes)	59.2 ± 25.3	39.2 ± 14.6	
Surgeon B	n	20	30	0.042
	Operating time (minutes)	75.6 ± 29.4	60.5 ± 21.4	
Surgeon C	n	27	23	0.419
	Operating time (minutes)	96.1 ± 36.1	83.7 ± 21.4	
Surgeon D	n	13	37	0.319
	Operating time (minutes)	94.8 ± 27.5	84.5 ± 24.6	

Table 2 Comparison of the incidence of complications, recurrence, and reoperation among four surgeons

	Surgeon A	Surgeon B	Surgeon C	Surgeon D	*P* value
Complications	2% (1/50)	0% (0/50)	4% (2/50)	2% (1/50)	0.903
Recurrence	2% (1/50)	12% (6/50)	12% (6/50)	6% (3/50)	0.153
Reoperation	2% (1/50)	8% (4/50)	12% (6/50)	4% (2/50)	0.214

Table 3 Multivariate regression results (L5/S as level reference)

Factor	Coefficient	*P* value
Age	49.22	nan
Years of spinal surgery experience	-125.58	nan
Arthroscopic training experience	-27.17	nan

Table 4 Multivariate regression results (L5/S as Lebel Reference)

Variable	Coefficient (β)	95% CI Lower	95% CI Upper	*P* value
const	36.02	11.75	60.30	0.004
Age	-0.08	-0.35	0.20	0.582
BMI	1.39	0.54	2.24	0.002
Level_L2/3	54.91	20.38	89.44	0.002
Level_L3/4	40.36	22.78	57.94	0.000
Level_L4/5	8.06	-0.40	16.53	0.062

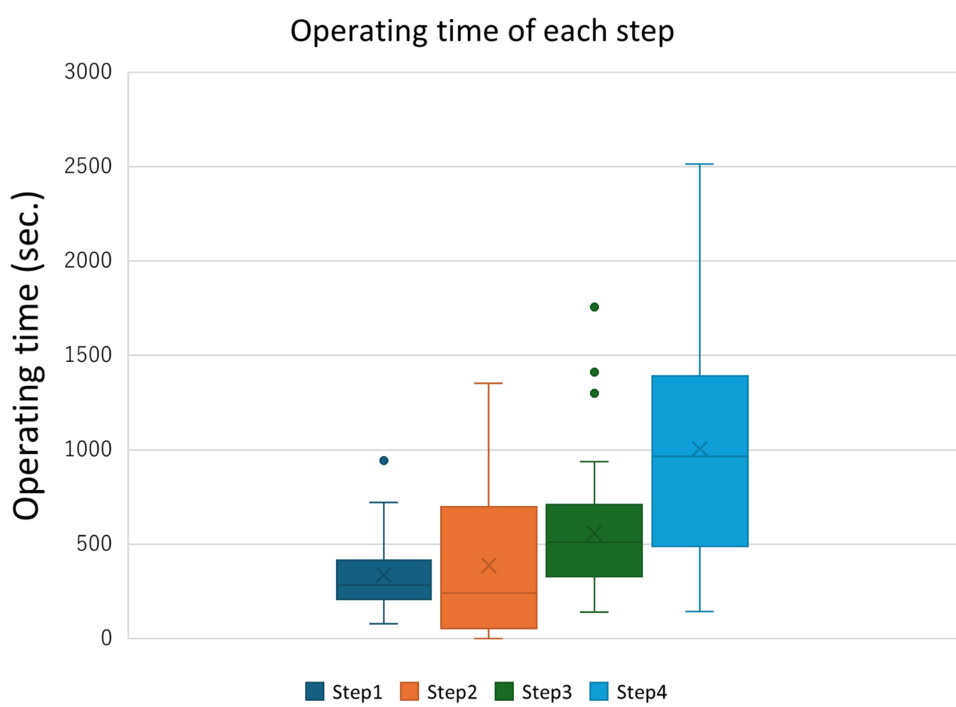

Fig. 4 Surgeon A operating time in steps 1–4

According to Woodall, the most popular way to examine the CUSUM learning curve for operative time is to retrospectively investigate the mean operating time as a reference. Dai reported that when graphs plotted by the CUSUM method showed a horizontal trend, a learning curve was achieved [7]. However, Woodall noted that it is difficult to determine CP based on the shape of the actual graph [6]. Using a curve-fitting model to reduce misleading results is recommended; in our study, we analyzed data based on this method.

Woodall stated that expert opinion is needed to interpret the plotted curves and assess whether the surgeon is skilled. To make interpretation easier and clearer, we divided the curve-fitting model into two groups at the point of transition from increase to decrease as a function, and if there was a significant difference in the operative time before and after the CUSUM maximal value, it was defined as CP. In this study, the operative time before and after the maximal value was significantly different between Surgeons A and B, and CP was defined in 22 and 23 cases, respectively; however, the CP of Surgeons C and D was not defined. UBE is reported to be relatively easy to learn; however, in our study, there were individual differences in the mastery of UBE.

In lumbar disc herniotomy using the UBE interlaminar approach, Chen et al.. found that 24 patients had CP using the CUSUM method based on a mean operative time of 98 min [2]. Xu et al. found that 12–32 patients had CP using the CUSUM method based on the mean operative time, including anesthesia, of 124 min [3].

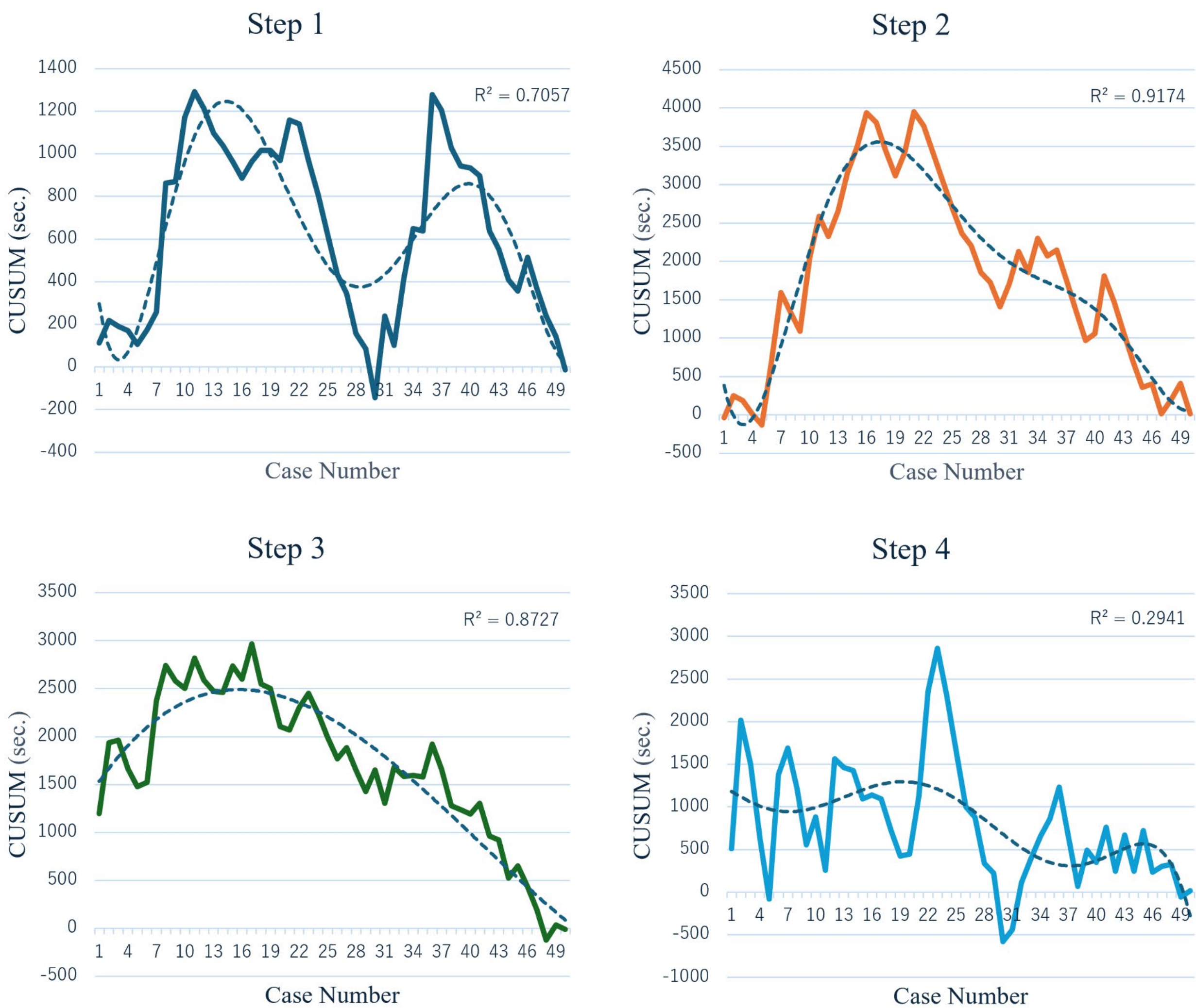

Fig. 5 Cumulative sum plots for Surgeon A operating time in steps 1–4

Table 5 Analysis of curves created using CUSUM plot for each step of operation

		Before	After	*P* value
Step 1	n	15	35	0.022
	Operating time (seconds)	401.2 ± 185.3	309.1 ± 189.3	
Step 2	n	18	32	0.005
	Operating time (seconds)	583.6 ± 432.7	284.8 ± 333.2	
Step 3	n	14	36	0.090
	Operating time (seconds)	733.9 ± 458.8	489.3 ± 235.7	
Step 4	n	21	29	0.906
	Operating time (seconds)	1058.5 ± 704.9	966.9 ± 493.2	

Easthardt et al. found that 32 patients had CP using the CUSUM method, based on a mean operative time of 70 min [4]. In our study, the CP of Surgeons A and B was 22 and 23 cases, respectively, which are close to those in the three previous reports.

Full endoscopic spine surgery (FESS) is a spinal endoscopic surgery performed through a single portal and should be compared with UBE. In a systematic review by Ahn on discectomy using the interlaminar approach with the FESS system, six papers were examined [8]; the cut-off values of the six reports were 10–43 for 22.17 ± 12.40 patients, with a significant reduction in surgical time. However, none of these reports examined CP using the CUSUM method, as Chen and Xu *et al.'s* UBE reports and

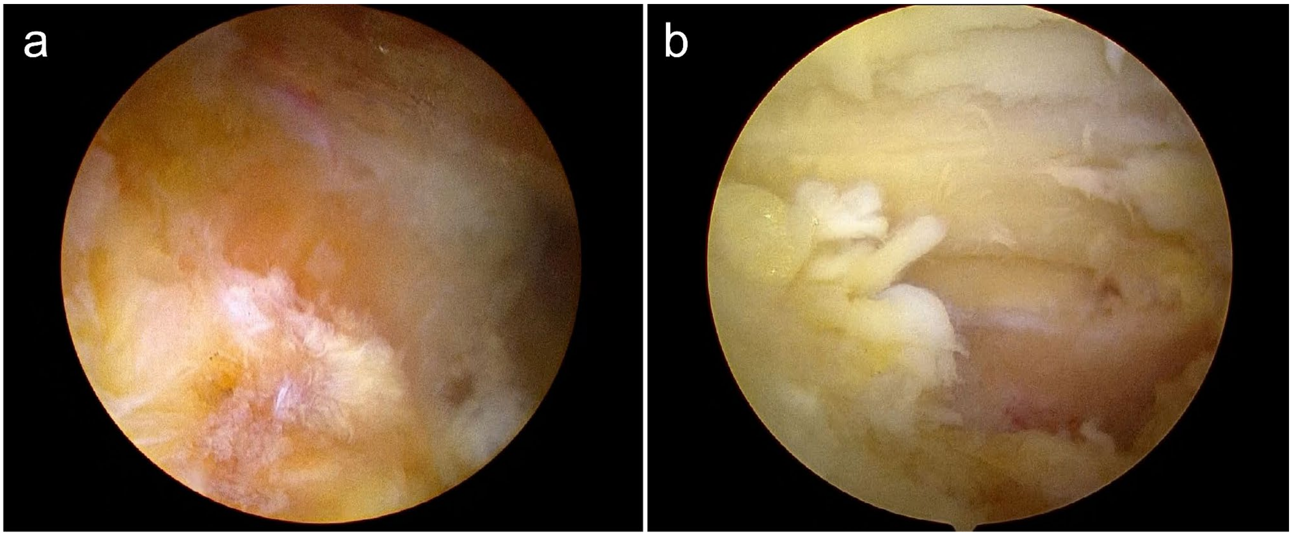

Fig. 6 Endoscopic findings of the yellow ligament. **A**. Surgical field image before excision of the superficial layer of the yellow ligament. **B**. Surgical field image after resection of the superficial layer of the yellow ligament

the present study did; therefore, it is difficult to make a simple comparison. However, in terms of numbers alone, it can be said that UBE and FESS require more than 20 cases of experience.

Surgeons A and B, who had clear CP, started UBE in their early 30s, suggesting that age was a factor that made it easier for them to learn about UBE. Unlike his peers, Surgeon A received training in shoulder arthroscopic surgery before UBE was introduced. Although the sample size was 4 and no significant difference was observed, caution should be exercised in interpreting the results; in this study, young age and arthroscopic training experience were factors associated with enhanced learning speed. On the other hand, it was suggested that years of spinal surgery experience do not necessarily contribute to improved learning speed. It has been argued that the biportal technique allows for swift adoption, given its similarity to the joint arthroscopy regularly practiced during orthopedic residency [4]. Experience in arthroscopy, which requires training in triangulation and coordination, may be more important than spinal surgery experience for shortening the UBE learning curve. Based on these results, it may be necessary to have a training program that takes into account age and past surgical age for smooth UBE acquisition.

BMI and surgical level were important factors influencing operating time. Patients with high BMI were at increased risk of Insufficient irrigation due to thick soft tissues, and difficulty in triangulation was also considered a factor. It is suggested that indications for such patients should be approached cautiously before CP. However, after CP, UBE may be a favorable option for high-BMI patients because it is minimally invasive even in obese patients. The higher the surgical position, the longer the operating time; in the upper lumbar region, the interlaminar space is narrow and the lamina is thick, so a large amount of bone resection is required, making it difficult to secure a working space for herniotomy. Before CP, it may be necessary to focus on patients with L4/5 or L5/S lesions.

We found differences in the reduction in operative time between surgeons; however, there were no differences in intraoperative complications, recurrence rates, or reoperation rates. The advantage of UBE is that surgeons who take a long time to become adept can increase the number of surgeries they have performed without many complications or recurrences.

Surgeon A, who had the shortest average operative time and was able to achieve smooth proficiency, was examined stepwise in terms of surgical time. Bone and soft tissue resection significantly reduced the treatment time in 18 and 19 cases, respectively. The time of yellow ligament resection tended to be shorter than that of the 14 cases. It was suggested that the ingenuity of handling the yellow ligament was the first barrier to reducing the operative time. The surgical time has been shortened since the procedure for stratifying and treating the yellow ligament was performed. Olszewski reported that the ligamentum flavum comprises superficial and deep layers and that the deep layer is a crucial surgical structure that prevents nerve damage [9]. It is possible to safely create the minimum necessary working space for discectomy by performing bone resection after careful excision of the superficial layer of the yellow ligament. (Fig. 6A, B) We believe that it is important as one of the ways to shorten the learning period.

The interpretation of the CUSUM method varies by study, and it is difficult to simply compare studies;

however, this study is unique in that it uses a certain interpretation of the learning curve of multiple surgeons at an institution. In the future, if the interpretation of the learning curve becomes consistent, it may be possible to examine the factors that affect it in more detail, as comparisons can be made between facilities.

In addition, since operative time is only one factor in surgery and its reduction is not necessarily the goal, the learning curve should be evaluated using additional criteria. It is hoped that accumulating such studies will clarify the factors that can shorten the UBE learning curve. A multi-center collaborative study is required to increase the sample size of surgeons with diverse backgrounds and patients from different regions and with varying disease severities.

Conclusions

The CUSUM method was used to investigate the learning curve of UBE discectomy for four spine surgeons working at the same facility. Two of the surgeons identified the CP in 22 and 23 cases, but the other two could not identify clear CP in 50 cases. Even before CP, the incidence of complications was not high. Thus, UBE can be considered a safe endoscopic surgery.

Abbreviations

CP	Cases to proficiency
CUSUM	Cumulative summation
FESS	Full endoscopic spine surgery
UBE	Unilateral biportal endoscopy

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Author contributions
TK analyzed and interpreted the patient data. All authors read and approved the final manuscript.

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Data availability
The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Institutional Review Board of Seirei Hamamatsu General Hospital (Approval Code No. 3895). Written informed consent was obtained in the form of an opt-out on the institutional website.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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