Interactive CardioVascular and Thoracic Surgery 34 (2022) 799–807
https://doi.org/10.1093/icvts/ivab378 Advance Access publication 7 January 2022

ORIGINAL ARTICLE

Cite this article as: Li W-H, Cheng H, Gan X-F, Li X-J, Wang X-J, Wu X-W *et al*. Learning curve of uniportal video-assisted thoracoscopic lobectomy: an analysis of the proficiency of 538 cases from a single centre. Interact CardioVasc Thorac Surg 2022;34:799–807.

Learning curve of uniportal video-assisted thoracoscopic lobectomy: an analysis of the proficiency of 538 cases from a single centre

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Received 4 October 2021; received in revised form 1 November 2021; accepted 20 November 2021

THORACIC

Key question

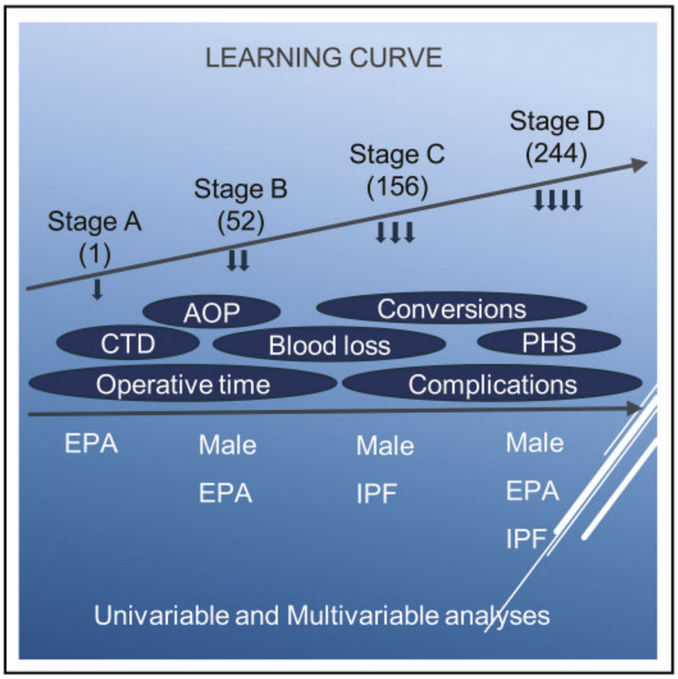
How does length of experience with the uniportal video-assisted thoracoscopic surgery (UniVATS) lobectomy affect the learning curve?

Key finding(s)

4th proficiency stage in UniVATS lobectomy learning curve entered at ~ 244th procedure; influences other than surgical experience become more significant.

Take-home message

These results should be of great value for surgeons wishing to evaluate the learning process and for the next generation of surgeons learning this procedure.



Abstract

OBJECTIVES: Uniportal video-assisted thoracoscopic surgery (UniVATS) is widely used as a minimally invasive thoracic operation. The goal of our study was to analyse the effect of long-term experience with the UniVATS lobectomy on the learning curve.

METHODS: The learning curves were quantitatively evaluated by the unadjusted cumulative sum, and they were segmented using joinpoint linear regression analysis. The variables were compared between subgroups using trend analysis, and linear regression analysis was applied to correlate clinical characteristics at different stages of the learning curve with the duration of the operation.

RESULTS: The learning curve for the UniVATS lobectomy can be divided into 3 phases of proficiency at ∼200–300 procedures, with a fourth phase as the number of procedures increases. The 1st–52nd, 52nd–156th, 156th–244th and 244th–538th procedures comprised the preliminary learning stage, preliminary proficiency stage, proficiency stage and advanced proficiency stage, respectively.

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Surgical outcomes and their variability between stages improved with increasing case numbers, with the most significant addition of an auxiliary operating port and conversions. In multivariable analysis, as stages progressed, influences other than surgical experience increased the operative time, with male and extensive pleural adhesions in the preliminary proficiency stage; male and incomplete pulmonary fissures in the proficiency stage; and male, extensive pleural adhesions and incomplete pulmonary fissures in the advanced proficiency stage.

CONCLUSIONS: As the number of procedures increases, there may be 4 different proficiency stages in the UniVATS lobectomy learning curve. The surgeon enters the fourth stage at approximately the 244th procedure. Moreover, at stage 4, the perioperative indicators tend to stabilize, and influences other than surgical experience become more significant.

Keywords: UniVATS • Learning curve • Lobectomy • Operative time

ABBREVIATIONS

aCCI	Age-adjusted Charlson Comorbidity Index
AOP	Auxiliary operating port
CI	Confidence interval
CTD	Chest tube duration
CUSUM	Cumulative sum
EPA	Extensive pleural adhesion
IPF	Incomplete pulmonary fissures
PHS	Postoperative hospital stay
UniVATS	Uniportal video-assisted thoracoscopic surgery

INTRODUCTION

Uniportal video-assisted thoracoscopic surgery (UniVATS) is a widely used minimally invasive thoracic surgical procedure. UniVATS lobectomy is defined as an unmonitored operation without rib dilatation and a single incision <4 cm [1]. However, UniVATS lobectomy is still a challenging procedure, and surgeons in the early phases of the learning curve might have more incidences of intraoperative bleeding and complications [2]. The learning curve is not only an important way to show the relationship between the surgeon's experience and the patient's perioperative outcome, but also a way for the surgeon to measure the number of operations needed to reach a certain technical level in the learning process. At present, there is a consensus that at least 50 consecutive operations are required to overcome the learning curve and that at least 40 operations per year are required to maintain this skill [3].

Learning curve studies of UniVATS lobectomy in several centres have been reported [4–9]. Although the learning curve represents the learning process for a surgical technique well, different centres have reported different learning curves and different surgical strategies. Previous studies [6, 7, 9] have indicated that the surgeon's position on the learning curve has matured when the number of cases is <300. In our clinical practice, we found that the results can be better optimized and stabilized as the number of cases increases further, which may have a further impact on the learning curve. Therefore, we summarized the experience of 538 consecutive UniVATS lobectomies performed by the same surgeon in our centre from June 2016 to October 2020 to analyse in detail the changing process in the learning curve over the short and the long term and to compare the factors influencing the learning curve at different learning stages to improve the surgeons' understanding of the long-term learning process of surgical techniques.

METHODS

Ethical statement

The study was approved by the institutional review committee and the ethics committee of the Fifth Hospital affiliated with Sun Yat-Sen University. All patients were exempted from informed consent because of the retrospective nature of the study [IRB # 2021—Lun Zi No. (K235-1)].

Data collection

Inclusion criteria for patients who had a UniVATS lobectomy in this study were as follows: non-small-cell lung cancer with a preoperative pathologically confirmed or undiagnosed clinical stage of T1-3N0-2M0 requiring a lobectomy; preoperative diagnosis of oligometastases requiring lobectomy; benign lesions including pulmonary sequestration, bronchiectasis and benign lung tumours requiring lobectomy; preoperative assessment of patients with good cardiac, pulmonary, hepatic and renal function able to tolerate an operation while under general anaesthesia. Exclusion criteria were as follows: patients with preoperative evaluation of tumour stage T4N0-3M0-1, any N3 or M1; patients proposed for open lobectomy, sleeve resection, double lobectomies and sublobar resection; any unstable systemic disease, including uncontrolled hypertension, unstable angina, cardiac function class II or higher, severe arrhythmias, severe liver or kidney disease, and so forth. The types of diseases included primary malignant tumours of the lung, benign tumours of the lung, bronchiectasis, pulmonary sequestration and oligometastases of the lung.

All data were collected from the patients' medical records in the centre from June 2016 to October 2020. Data on age, sex, age-adjusted Charlson Comorbidity Index (aCCI) [10] scores, lesion location, maximum tumour diameter, incomplete pulmonary fissures (IPF), extensive pleural adhesions (EPA), operative time, blood loss, auxiliary operating port (AOP), conversions, postoperative hospital stay (PHS), chest tube duration (CTD), complications and other clinical features were collected. The operative time was recorded from the beginning of the skin incision to the end of the suture incision. The blood loss was defined as the amount of blood loss recorded from the beginning of the operation to the end of the operation. Conversion was defined as a procedure that could be completed only if the thoracotomy was converted or if the incision was temporarily enlarged to be longer than 8 cm. IPF were defined as grades 2 and 3 according to the fissure development grading system advocated by Lee *et al.*

[11]. EPA were defined as pleural adhesions that required sharp dissection and adhesiolysis for 30 min or longer [12]. All complications were classified into 11 grades according to the modified Clavien–Dindo operation complication classification system [13].

Operative technique

All procedures were performed by the same surgeon, QingDong Cao, who had sufficient experience, having performed approximately 70 open-heart procedures and >260 multiportal VATS operations per year. The patient was placed in the lateral recumbent position, and the folding knife position was maintained (head side up, tail side down). During the operation, the chief surgeon and an assistant stood at the patient's abdomen so that the assistant could help the surgeon dissect and expose the organ. Another assistant stood at the back of the patient, helping to hold the thoracoscope (Karl Storz, GmbH & Co. Tuttlingen, Germany). One could observe the whole operation through the observation screen.

During the UniVATS lobectomy, the upper lobes were resected using a single 3- to 4-cm incision between the anterior and mid-axillary lines at the fourth intercostal space; the middle and lower lobes were resected in the same way at the fifth intercostal incision. A soft plastic cutting protector was used in the incision without spreading the ribs. During the operation, a 10-mm 30° thoracoscope was placed on the dorsal side of the incision. An ultrasonic knife (Ethicon Endo-Surgery Inc., Cincinnati, OH, USA) or hook electrocautery was used to carry out the procedure. During the operation, the anatomical order varied according to the development of pulmonary fissures and the location of the tumour. Specifically, the anatomical order of the right lower lobe, left upper lobe and left lower lobe is usually the artery, vein and bronchus and that of the right upper lobe is usually the artery, bronchus and vein. Additionally, the anatomical order of the right middle lobe lesions is usually veins, bronchi and arteries. We use the 'single-direction thoracoscopic lobectomy' [14] when we encounter dense fissures that make it difficult to complete the operation using the conventional surgical procedure. After resection of the target lung, the specimen was removed with a specimen bag. Patients with malignant lesions continued to undergo systematic lymph node dissection. The incision was sutured layer by layer at the end of the operation. A 22- or 24-FR thoracic drainage tube was placed in the original incision and connected to a closed thoracic drainage bottle. The indications for removal of the thoracic drainage tube after the operation were as follows: 24-h thoracic drainage volume <200 ml, clear respiratory sounds in both lungs during auscultation, a chest X-ray showing that the lung recovered well on the operative side and no bubbles escaping when the patient coughed.

Statistical analysis of data

All collected clinical data were sorted sequentially according to the date of the operation, and the operative time was used as the efficiency index. The learning curve was quantitatively evaluated by the unadjusted cumulative sum (CUSUM) [7, 15–17], which was the continuous sum of the difference between a single data point and the average of all data points. The CUSUM of variables of interest in the first patient was the difference between the value of the first patient and the average of all patients. The CUSUM of the second patient and subsequent patients was the CUSUM of the previous patient plus the difference of the second patient. This recursive process was continued until the CUSUM of the last patient was calculated to be zero.

Scatter plots of CUSUM values with straight lines were plotted for 218, 298, 378, 458 and 538 patients using Microsoft Excel (Microsoft Excel 2019, Microsoft, Redmond, WA, USA), named CUSUM 5, CUSUM 4, CUSUM 3, CUSUM 2 and CUSUM 1, and the CUSUM curves were segmented using joinpoint linear regression analysis (Joinpoint Regression Program 4.9.0.0, March, 2021, Bethesda, MD; Statistical Research and Applications Branch, National Cancer Institute, Bethesda, MD, USA). Finally, the data of each group were analysed and compared using SPSS software (version 25.0, IBM-SPSS, Armonk, NY, USA). The Kolmogorov–Smirnov test and the Shapiro–Wilk test were used to test normality for continuous variables. Data are shown as mean (standard deviation) or median (interquartile range) for continuous variables and *n* (%) for categorical variables. Trend analysis was performed using the one-way analysis of variance test or the Kruskal–Wallis test for comparisons between groups of continuous variables and the χ^2 test for comparisons between groups of categorical variables or hierarchical information. Linear regression analysis was applied to correlate the clinical characteristics in the learning curves at different stages with the duration of the operation. Significance values were adjusted for multiple testing using the Bonferroni test, and two-tailed *P*-value <0.05 was considered to be statistically significant.

RESULTS

Patient characteristics

Between June 2016 and October 2020, a total of 538 patients (Table 1), including 304 women [56.5%] and 234 men [43.5%], with an average age of 56.3 [11.2] years, underwent UniVATS lobectomy by the same surgeon at the centre. Comorbidities were evaluated by means of aCCI, and the median score was 1.0 [0.0–2.0] points. Among the cases, the surgical locations of 187, 58, 109, 95 and 89 cases were the right upper lobe, right middle lobe, right lower lobe, left upper lobe and left lower lobe, respectively. The pathological types included benign lesions in 36 cases [6.7%] and malignant lesions in 502 cases [93.3%], of which the most common histological types were adenocarcinoma [453, 84.2%]. According to the eighth edition of the International Union against Cancer TNM staging criteria for lung cancer [18], there were 384 cases [71.4%] of IA, 27 cases [5.0%] of IB, 9 cases [1.2%] of IIA, 26 cases [4.8%] of IIB, 38 cases [7.1%] of IIIA and 8 cases [1.5%] of IIIB. Although we had 4 [0.7%] patients with IVA tumours, they were all distant oligometastases. Among the neoplastic lesions, there were 239 cases [44.4%] of solid lesions and 292 cases [54.3%] of subsolid lesions, with a median diameter of 17.0 [11.5–26.0] mm. Intraoperative exploration identified 76 cases [14.1%] with EPA and 236 cases [43.9%] with IPF. Due to difficulties encountered during the operation or with completing the operation with a single incision, 47 cases [8.7%] received an AOP, and 38 cases [7.1%] were converted. Although there were significant differences in sex and maximum tumour diameter between stages ($P < 0.05$), there were no significant differences in other features ($P > 0.05$), so the clinical results were comparable between stages.

Table 1: Baseline characteristics according to the learning curve stages

Characteristic		UniVATS lobectomy				*P*-Value
	Total (*n* = 538)	Stage A (1–52)	Stage B (52–156)	Stage C (156–244)	Stage D (244–538)	
Age, years						0.722
Mean [SD]	56.3 [11.2]	57.9 [12.0]	56.1 [10.3]	56.4 [11.7]	56.0 [11.4]	
Sex, *n* [%]						0.047
Female	304 [56.5]	26 [50.0]	48 [45.7]	54 [60.7]	177 [60.0]	
Male	234 [43.5]	26 [50.0]	57 [54.3]	35 [39.3]	118 [40.0]	
aCCI						0.913
Median [IQR]	1.0 [0.0–2.0]	2 [1.0–2.0]	1.0 [0.0–2.0]	1.0 [1.0–2.0]	1.0 [0.0–2.0]	
MTD, mm						<0.001
Median [IQR]	17.0 [11.5–26.0]	21.5 [13.0–38.0]	20.0 [14.4–30.0]	18.0 [12.8–28.0]	15.0 [10.0–23.0]	
Density, *n* [%]						0.059
Solid	239 [44.4]	36 [69.2]	57 [54.3]	44 [49.4]	103 [34.9]	
Subsolid	292 [54.3]	16 [30.8]	44 [41.9]	42 [47.2]	181 [61.4]	
Pathology, *n* [%]						0.195
Benign	36 [6.7]	5 [9.6]	10 [9.5]	7 [7.9]	14 [4.7]	
Malignant	502 [93.3]	47 [90.4]	95 [90.5]	113 [90.4]	281 [95.3]	
Adenocarcinoma	453 [84.2]	39 [75.0]	78 [74.3]	73 [82.0]	265 [89.8]	
Squamous	30 [5.6]	4 [7.7]	12 [11.4]	6 [6.7]	8 [2.7]	
Others	19 [3.5]	4 [7.7]	5 [4.8]	3 [3.4]	8 [2.7]	
Pathological stage, *n* [%]						0.091
IA	384 [71.4]	32 [61.5]	66 [62.9]	63 [70.8]	226 [76.6]	
IB	27 [5.0]	4 [7.7]	2 [1.9]	5 [5.6]	16 [5.4]	
IIA	9 [1.2]	1 [1.9]	2 [1.9]	1 [1.1]	5 [1.7]	
IIB	26 [4.8]	3 [5.8]	7 [6.7]	5 [5.6]	11 [3.7]	
IIIA	38 [7.1]	4 [7.7]	12 [11.4]	5 [5.6]	17 [5.8]	
IIIB	8 [1.5]	1 [1.9]	3 [2.9]	2 [2.2]	2 [0.7]	
IVA	4 [0.7]	0 [0.0]	1 [1.0]	1 [1.1]	2 [0.7]	
Others	42 [7.8]	7 [13.5]	12 [11.4]	7 [7.9]	16 [5.4]	
Location, *n* [%]						0.527
RUL	187 [34.8]	16 [30.8]	35 [33.3]	28 [31.5]	109 [36.9]	
RML	58 [10.8]	4 [7.7]	14 [13.3]	6 [6.7]	34 [11.5]	
RLL	109 [20.3]	10 [19.2]	23 [21.9]	15 [16.9]	62 [21.0]	
LUL	95 [17.7]	11 [21.2]	20 [19.0]	21 [23.6]	44 [14.9]	
LLL	89 [16.5]	11 [21.2]	13 [12.4]	19 [21.3]	46 [15.6]	
EPA, *n* [%]	76 [14.1]	11 [21.2]	15 [14.3]	13 [14.6]	37 [12.5]	0.431
IPF, *n* [%]	236 [43.9]	24 [46.2]	56 [53.7]	41 [46.1]	117 [39.7]	0.101

aCCI: age-adjusted Charlson Comorbidity Index; EPA: extensive pleural adhesion; IPF: incomplete pulmonary fissure; IQR: interquartile range; LLL: left lower lobe; LUL: left upper lobe; MTD: maximum tumour diameter; RLL: right lower lobe; RML: right middle lobe; RUL: right upper lobe; SD: standard deviation; UniVATS: uniportal video-assisted thoracoscopic.

CUSUM analysis

This study found that in CUSUM 5 (Fig. 1), the learning curve could be divided into 3 stages: the ascending stage, the plateau and the descending stage. The CUSUM values showed significant changes at the 52nd and 151st cases, which became the 2 cut-off points of the learning curve of CUMSUM 5. The curve for the 1st–52nd cases comprised the ascending stage, that for the 52–151st cases comprised the plateau and the 151st–218th cases comprised the descending stage.

As the case numbers increased further, the CUSUM value continued to change but the phases of the CUSUM curve also changed significantly (Fig. 2). The change in the curve from CUMSUM 5 to CUMSUM 3 shows that the slope of the platform segment of CUMSUM 5 increased rapidly as the number of cases increased further, and the learning curve adds a new significant change point, thus showing the characteristics of 4 stages. As seen through CUMSUM 3 to CUMSUM 2, as the case numbers increased, the slope of stage 2 of CUMSUM 3 increased at a decreasing rate, and the slope of the platform part of CUMSUM 3 increased rapidly to form the platform segment of CUMSUM 2. From CUMSUM 2 to CUMSUM 1, the learning curve still showed the characteristics of 4 stages of change, but the slope of its platform part did not increase significantly as case number increased further, and its change was extremely small. Therefore, according to the rate of phase change of the learning curve at different numbers of cases, the surgical technique proficiency reflected by the learning curve CUSUM 1 can be divided into 4 phases of change (Fig. 3). The 1st–52nd, 52nd–156th, 156th–244th and 244th–538th cases comprised the preliminary learning stage (stage A), the preliminary proficiency stage (stage B), the proficiency stage (stage C) and the advanced proficiency stage (stage D), respectively.

Clinical results

According to the analysis of the difference in clinical results between the stages (Table 2 and Supplementary Material, Appendices S3–S5), the intraoperative indicators greatly improved from the preliminary learning stage or the preliminary proficiency stage to the proficiency stage and then to the advanced proficiency stage, and the technology tended to be more stable: the operative time (261.9 [63.3] vs 208.7 [52.0] vs 171.2 [39.4] vs 144.4 [32.9] min, $P < 0.001$), the blood loss (100

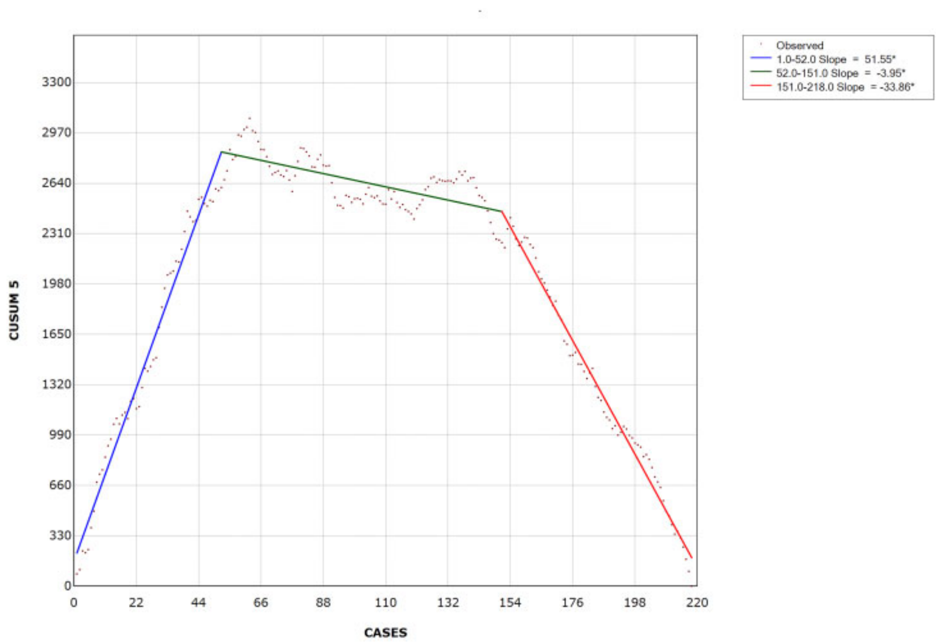

Figure 1: Joinpoint linear regression analysis of cumulative sum values for operative time in 218 patients indicates that the slope is significantly different from zero at alpha = 0.05 level. CUMSUM: cumulative sum.

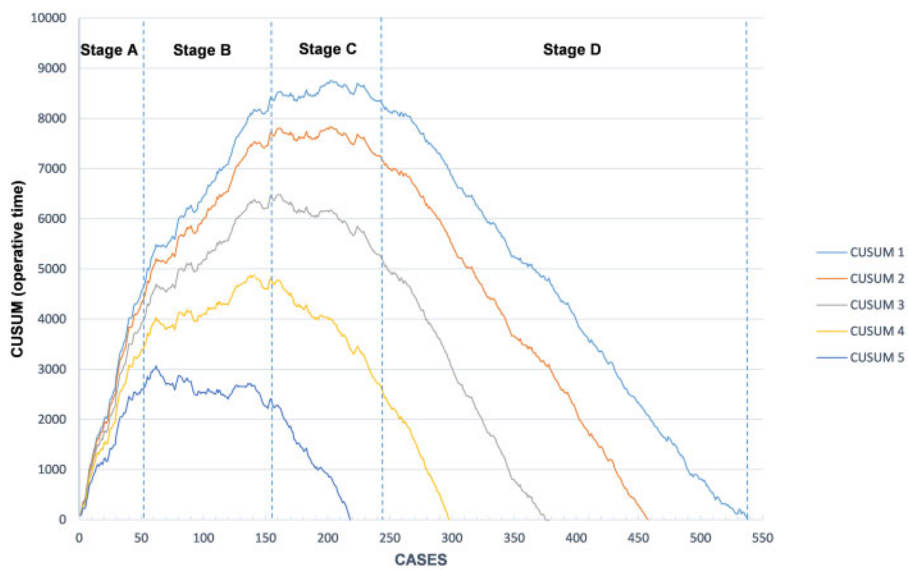

Figure 2: The cumulative sum plot for a uniportal video-assisted thoracoscopic surgery lobectomy performed by a surgeon in 218, 298, 378, 458 and 538 cases. The cumulative sum curve of the operative time: The 1st–52nd, 52nd–156th, 156th–244th and 244th–538th cases constituted the preliminary learning stage (stage A), preliminary proficiency stage (stage B), proficiency stage (stage C) and advanced proficiency stage (stage D), respectively. UniVATS: uniportal video-assisted thoracoscopic surgery; CUMSUM: cumulative sum.

[50.0–225.0] or 90.5 [50–130] vs 50.0 [20.0–80.0] vs 20.0 [20.0–50.0] ml, $P < 0.05$) and the PHS (10.0 [7.0–13.0] or 9.0 [7.0–12.0] vs 6.0 [5.0–8.0] vs 5.0 [4.0–6.0] days, $P < 0.001$) were significantly reduced. The number of dissected lymph nodes increased from the preliminary learning stage to the proficiency stage or the advanced proficiency stage (11.4 [6.5] vs 13.9 [6.8] or 12.9 [5.8], $P = 0.010$). In addition, with the proficiency of the technology, the decline was more obvious with the addition of AOP (26.9% or 16.2% vs 2.7%, $P < 0.001$) and the conversions (28.8% or 15.2% vs 0.7%, $P < 0.001$) from the preliminary learning stage or preliminary proficiency stage to the advanced proficiency stage. Besides, from the preliminary learning stage to the proficiency stage or the advanced proficiency stage, the CTD (5.0 [4.0–8.0] vs 4.0[3.0–4.0] days or 3.0 [2.0–4.0] days, $P < 0.001$) and the incidence of postoperative complications (36.5% vs 7.9% or 7.1%, $P < 0.001$) also decreased. However, the difference was that there was no significant difference in the common complication prolonged air leaks [4] at any stage ($P = 0.263$).

Univariable and multivariable analysis

Univariable analysis (Table 3) showed that EPA ($P = 0.005$) was the only factor that affected the operative time in the preliminary

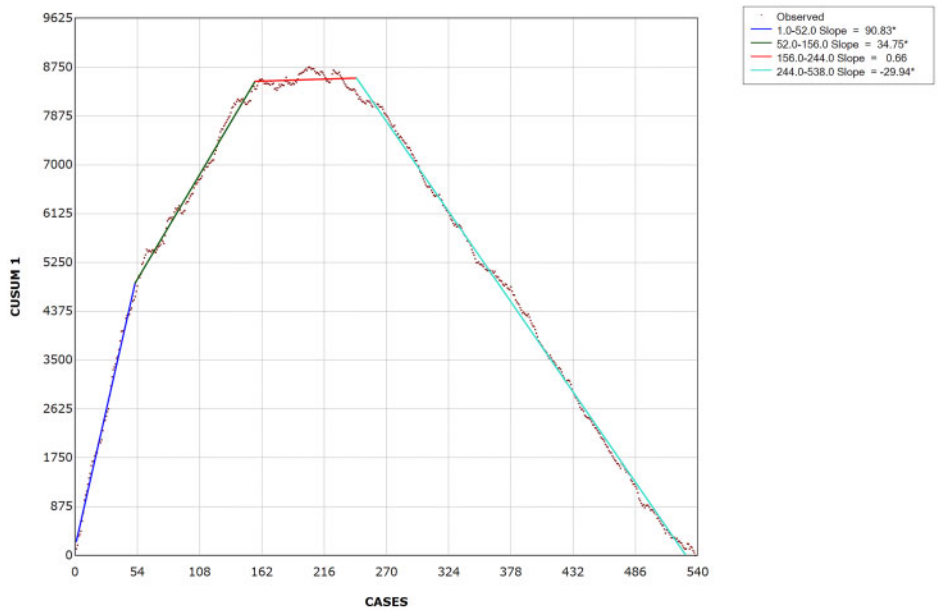

Figure 3: Joinpoint regression analysis of cumulative sum values for operative time in 538 patients indicates that the slope is significantly different from zero at the alpha = 0.05 level. CUMSUM: cumulative sum.

Table 2: Results according to the learning curve stages

Variable	UniVATS lobectomy					*P*-Value
	Total (*n* = 538)	Stage A (1–52)	Stage B (52–156)	Stage C (156–244)	Stage D (244–538)	
Operative time (min)						<0.001
Mean [SD]	172.7 [56.5]	261.9 [63.3]	208.7 [52.0]	171.2 [39.4]	144.4 [32.9]	
Blood loss (ml)						<0.001
Median [IQR]	50.0 [20.0–85.0]	100.0 [50.0–225.0]	90.0 [50.0–130.0]	50.0 [20.0–80.0]	20.0 [20.0–50.0]	
AOP, *n* [%]	47 [8.7]	14 [26.9]	17 [16.2]	8 [9.0]	8 [2.7]	<0.001
Conversions, *n* [%]	38 [7.1]	15 [28.8]	16 [15.2]	6 [6.7]	2 [0.7]	<0.001
Lymph nodes, *n*						0.010
Mean [SD]	12.6 [6.2]	11.4 [6.5]	11.2 [6.1]	13.9 [6.8]	12.9 [5.8]	
CTD (days)						<0.001
Median [IQR]	3.0 [3.0–5.0]	5.0 [4.0–8.0]	4.0 [3.0–6.0]	4.0 [3.0–4.0]	3.0 [2.0–4.0]	
PHS (days)						<0.001
Median [IQR]	6.0 [4.0–8.0]	10.0 [7.0–13.0]	9.0 [7.0–12.0]	6.0 [5.0–8.0]	5.0 [4.0–6.0]	
Complications, *n* [%]	74 [13.8]	19 [36.5]	27 [25.7]	7 [7.9]	21 [7.1]	<0.001
PAL	41 [7.6]	6 [11.5]	9 [8.6]	3 [3.4]	23 [8.5]	0.263
Arrhythmia	14 [2.6]	4 [7.7]	5 [4.8]	1 [1.1]	4 [1.4]	0.018
Vascular	3 [0.6]	0 [0.0]	2 [1.9]	0 [0.0]	1 [0.3]	0.327
Pneumonia, *n* [%]	20 [3.7]	8 [15.4]	6 [5.7]	1 [1.1]	6 [2.0]	<0.001
Pneumo-oedema	1 [0.2]	0 [0.0]	0 [0.0]	1 [0.4]	0 [0.0]	
Chylothorax	5 [0.9]	3 [5.8]	2 [1.9]	0 [0.0]	0 [0.0]	0.001
Wound infection	10 [1.9]	2 [3.8]	6 [5.7]	1 [1.1]	1 [0.3]	0.002
Operative mortality	0 [0.0]	0 [0.0]	0 [0.0]	0 [0.0]	0 [0.0]	

AOP: auxiliary operating port; CTD: chest tube duration; IQR: interquartile range; PAL: prolonged air leaks; PHS: postoperative hospital stay; SD: standard deviation; UniVATS: uniportal video-assisted thoracoscopic surgery.

learning stage. The factors that influenced the operative time in the preliminary proficiency stage included sex (*P* = 0.006) and EPA (*P* = 0.003). The factors related to the increase in operative time in the proficiency stage were sex (*P* = 0.023), EPA (*P* = 0.013) and IPF (*P* = 0.005). In the advanced proficiency stage, the factors leading to the increase in operative time were sex (*P* = 0.040), aCCI (*P* = 0.028), pathological stage (*P* = 0.038), EPA (*P* < 0.001) and IPF (*P* = 0.010).

Multivariable analysis (Table 4) showed that males [*B* = 26.208 min, 95% confidence interval (CI) 7.356–45.059, *P* = 0.007] and EPA (*B* = 40.953 min, 95% CI 14.115–67.790, *P* = 0.003) increased the operative time of the preliminary proficiency stage; males (*B* = 19.592 min, 95% CI 3.929–35.256, *P* = 0.015) and IPF (*B* = 20.664 min, 95% CI 4.811–36.517, *P* = 0.011) increased the operative time of the proficiency stage. Additionally, males (*B* = 7.598 min, 95% CI 0.253–14.943, *P* = 0.043), EPA (*B* = 22.770 min, 95% CI -11.745 to 33.795, *P* < 0.001) and IPF (*B* = 7.437 min, 95% CI -0.003 to 14.876, *P* = 0.040) increased the operative time in the advanced proficiency stage. One phenomenon is that the factor that has the

Table 3: Univariable analysis for risk factors for operative time

Independent variable	Stage A			Stage B			Stage C			Stage D		
	B	95% CI	*P*-Value	*B*	95% CI	*P*-Value	*B*	95% CI	*P*-Value	*B*	95% CI	*P*-Value
Age	-0.051	[-1.551, 1.449]	0.946	0.802	[-0.168, 1.772]	0.104	0.326	[-0.390, 1.042]	0.368	0.320	[-0.011, 0.651]	0.058
Sex	-7.615	[-43.137, 27.906]	0.669	27.555	[7.994, 47.115]	0.006	19.340	[2.771, 35.910]	0.023	8.028	[0.379, 15.677]	0.040
aCCI	-2.607	[-19.018, 13.805]	0.751	7.866	[-0.820, 16.552]	0.075	4.248	[-3.538, 12.034]	0.281	3.358	[0.359, 6.358]	0.028
MTD	0.548	[-0.427, 1.523]	0.265	0.036	[-0.662, 0.733]	0.919	0.244	[-0.405, 0.892]	0.457	0.207	[-0.140, 0.553]	0.241
Density	10.547	[-19.499, 40.593]	0.484	-4.978	[-17.296, 7.340]	0.425	-2.265	[-12.059, 7.530]	0.647	-0.905	[-5.306, 3.495]	0.686
Pathology	-10.532	[-29.007, 7.944]	0.258	-9.983	[-21.704, 1.738]	0.094	-4.796	[-15.707, 6.115]	0.385	-4.550	[-10.353, 1.253]	0.124
Pathological stage	6.284	[-6.172, 18.739]	0.315	1.996	[-4.345, 8.337]	0.533	3.600	[-2.199, 9.400]	0.220	3.210	[0.176, 6.245]	0.038
Location	-9.332	[-20.602, 1.938]	0.103	-2.274	[-9.369, 4.821]	0.193	1.282	[-4.078, 6.643]	0.636	-0.843	[-3.380, 1.693]	0.513
EPA	58.785	[18.543, 99.027]	0.005	42.700	[15.049, 70.351]	0.003	29.156	[6.372, 51.939]	0.013	25.366	[14.349, 36.383]	<0.001
IPF	17.244	[-18.111, 52.599]	0.332	13.801	[-6.277, 33.879]	0.176	23.319	[7.341, 39.296]	0.005	10.111	[2.484, 17.739]	0.010

aCCI: age-adjusted Charlson Comorbidity Index; *B*: partial regression coefficient; CI: confidence interval; EPA: extensive pleural adhesion; IPF: incomplete pulmonary fissure; MTD: maximum tumour diameter.

greatest impact on the programme time is the EPA in the preliminary and advanced proficiency stages, whereas in the proficiency stage it is the IPF. This finding may due to the fact that in the preliminary learning stage, the operative time is seriously affected by surgical experience, and the role of other influencing factors was masked. As surgical experience accumulated during the process of reaching the preliminary proficiency stage, the influence of surgical experience gradually decreased, and the effects of other influencing factors began to appear and became increasingly significant.

DISCUSSION

The European Association of Thoracic Physicians released the consensus report [3], and the Chinese Society for Thoracic and Cardiovascular Surgery and the Chinese Association of Thoracic Surgeons consensus report [1] clearly defined UniVATS and described in detail the safety, feasibility, surgical techniques and short- and long-term results of the operation. These experts agreed that UniVATS is suitable for patients with T1-3N0-2 tumours, systematic lymph node dissection, lobectomy, segmental and bronchial sleeve resection and pneumonectomy. Other recommendations are that the upper lobes should be incised in the fourth intercostal space and that the middle and lower lobes should be cut in the fifth intercostal space, among other details. The patient selection criteria and surgical procedures used in this study are highly consistent with these new expert consensus recommendations.

Previous researchers [6, 7, 9] have suggested that the UniVATS lobectomy learning curve can be divided into 3 stages when the number of cases is in the range of 52–274 cases, representing different levels of mastery of the technique, all reaching proficiency in the 3rd stage. The same results were obtained in the present study when the number of cases was within the first 218 cases (CUSUM 5 in Fig. 1). In this study, we analysed the different cycle learning curves of 538 consecutive UniVATS lobectomies. The research showed that as the number of procedures increased and further experience was gained in surgery, the learning curve gradually stabilized (CUSUM 2– 4 in Fig. 2). There may be 4 different proficiency stages in the UniVATS lobectomy learning curve and that one enters the fourth stage at approximately the 244th procedure (CUSUM 1 in Fig. 3). Complete proficiency is defined as the surgeon's surgical experience reaching a steady state where the surgical outcome is minimally influenced by the surgical experience and where the operation can be performed independently with the highest quality. Moreover, a comparative analysis of the surgical results and of the factors influencing each of these stages revealed that with the phased progress of the learning curve and the maturation of the surgical technique, there were substantial decreases in operative time, blood loss, AOP, conversions, CTD, PHS and complications, with the most significant decrease occurring in AOP and conversions (Table 2); influencing factors other than surgical experience became increasingly significant (Tables 3 and 4).

In 2015, Fossati *et al.* [19] analysed the surgical learning curve for the single-stage pre-urethra procedure using 641 samples and showed that, even after the 600th case, the learning curve continued to rise without reaching a plateau, and the learning curve seemed to be infinite. In our study, a similar phenomenon was observed. Therefore, we defined the highest stage of the learning curve in the study as the advanced proficiency stage,

Table 4: Multivariable analysis for risk factors for operative time

Independent variable	Stage B				Stage C				Stage D			
	B	Beta	95% CI	*P*-Value	*B*	Beta	95% CI	*P*-Value	*B*	Beta	95% CI	*P*-Value
Male	26.208	0.252	[7.356, 45.059]	0.007	19.592	0.245	[3.929, 35.256]	0.015	7.598	0.113	[0.253, 14.943]	0.043
aCCI									2.650	0.101	[-0.244, 5.544]	0.073
Pathological stage									2.403	0.093	[-0.556, 5.361]	0.111
EPA	40.953	0.277	[14.115, 67.790]	0.003	20.123	0.182	[-2.259, 42.504]	0.077	22.770	0.230	[11.745, 33.795]	<0.001
IPF					20.664	0.263	[4.811, 36.517]	0.011	7.437	0.111	[-0.003, 14.876]	0.040

aCCI: age-adjusted Charlson Comorbidity Index; *B*: partial regression coefficient; Beta: standardized partial regression coefficient; CI: confidence interval; EPA: extensive pleural adhesion; IPF: incomplete pulmonary fissure.

but this did not mean complete proficiency. Because there are a variety of indicators for measuring the learning curve, the phased clinical results of our indicators are also changing continuously, and a long-term constant trend has not been found.

In addition, Liu *et al.* [7] used the CUSUM method to analyse the learning curve of 120 UniVATS lobectomies performed by a surgeon from October 2013 to September 2014. They determined pure lobectomy time as an indicator of efficiency by reviewing surgical videos, dividing the learning curve into 3 stages and then comparing the clinical characteristics of each stage. They found that from the ascending phase to the descending period, the average operative time, the number of repeat operations with staples and the conversion rate decreased significantly, whereas the morbidity, mortality and length of hospital stay for complications were basically similar. The difference of this research is that there may be 4 stages in the learning curve, with significant improvements in indicators including the incidence of complications and PHS as the stages progress.

In 2020, Vieira *et al.* [9] published their experience with UniVATS lobectomy in 274 patients from 2014 to 2017, using cubic splines to divide the learning curve of operative times into 3 different learning stages. Their results show that 60 consecutive operations are needed to overcome the initial stage and a total of 140 operations are needed to reach proficiency. This finding is similar to that for the first 3 learning curve stages in our study. Our result is that ∼52 cases are needed to overcome the preliminary learning stage and that ∼156 cases are needed to reach the proficiency stage; however, ∼88 operations are still needed to reach the advanced proficiency stage. Even so, some of our surgical results, such as the operative time, are generally higher than those reported by Vieira *et al.* [9] This finding may be due to the lack of preoperative histological diagnosis in most of our samples and the need for intraoperative frozen sections, which usually take ∼30 ± 10 min in our centre.

In addition, Vieira *et al.* [9] predicted that the effect of additional cases on operative time varied at each stage by using a multivariate regression model using age, sex, aCCI and tumour size, with additional cases increasing the operative time the most at the initial stage and less frequently at the skilled stage. However, we found that in addition to the preceding indicators, the other 2 very important indicators, namely, EPA and IPF development, can also significantly increase the operative time. Our results also show that the number of influencing factors for non-operative experience after reaching the technical proficiency stage is significantly higher than before.

An analysis of the experience of other centres may help to understand the safety, feasibility and effectiveness of a single-hole VATS lobectomy [20]. Our experience suggests that the new generation of surgeons should be prepared for long-term learning. By observing excellent cases in other centres and our own surgical videos, and by regularly summarizing the perioperative and postoperative results, we can better understand the steps that can be improved to speed up the improvement of our skills. Shortening the learning curve of each stage as much as possible brings more benefits to our patients.

Limitations

This study is a single-centre retrospective study. Its main limitation is its retrospective design and its inability to accurately evaluate the surgeon's previous surgical experience. Moreover, it is not clear how new equipment and different surgical nurses or assistants may affect the learning curve.

CONCLUSIONS

In this analysis, as the number of procedures increases and further experience is gained in performing the operation, there may be 4 different proficiency stages in the UniVATS lobectomy learning curve, and one enters the fourth stage at approximately the 244th case. Moreover, as the learning curve enters stage 4, factors other than surgical experience become more significant.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *ICVTS* online.

Conflict of interest: none declared.

Data Availability Statement

All relevant data are within the manuscript and its supporting information files. The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Author contributions

Wen-Hao Li: Conceptualization; Formal analysis; Investigation; Resources; Writing—original draft; Writing—review & editing. **Hua Cheng:** Conceptualization; Investigation; Resources; Writing—review & editing. **Xiang-Feng Gan:** Conceptualization; Supervision; Writing—original draft. **Xiao-Jian Li:**

Resources. **Xiao-Jin Wang:** Resources. **Xiang-Wen Wu:** Resources. **Hong-Cheng Zhong:** Resources. **Tian-Chi Wu:** Resources. **Wen-Wen Huo:** Resources. **Shao-Long Ju:** Resources. **Liang-Zhan Lv:** Resources. **Qing-Dong Cao:** Conceptualization; Project administration; Resources; Supervision; Validation; Writing—review & editing.

Reviewer information

Interactive CardioVascular and Thoracic Surgery thanks Cheng-Long Huang and the other, anonymous reviewer(s) for their contribution to the peer review process of this article.

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