Learning curve for uniportal video-assisted thoracoscopic anatomical segmentectomy

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Background: Anatomical segmentectomy by uniportal video-assisted thoracoscopic surgery (U-VATS) is a delicate surgical procedure. Hitherto, only few studies have assessed the learning curves of anatomical segmentectomy by U-VATS, with varying data available. The present study aimed to investigate the learning curve and clinical advantages for U-VATS segmentectomy.

Methods: The medical records of patients who underwent U-VATS or non-U-VATS segmentectomy between August 2017 and May 2020 were retrospectively reviewed. Cumulative sum (CUSUM) analysis was employed to illustrate the learning curve of U-VATS segmentectomy. Perioperative parameters were used to determine the structural intervals of the learning curve, and to compare U-VATS and non-U-VATS segmentectomy.

Results: In total, 122 patients receiving U-VATS segmentectomy and 98 patients receiving non-VATS segmentectomy were included. Of these, 116 patients underwent successful U-VATS segmentectomy, while the other six patients underwent conversions. The structural intervals of 20–29 cases and 58–63 cases were determined as the threshold according to the CUSUM analyses. The learning process of U-VATS segmentectomy was therefore divided into three phases. Interestingly, the perioperative parameters differed significantly between Phases 1 and 3, including operative time (Op-T), postoperative hospital stays (Po-Hst), postoperative thoracic drainage (Po-D), and operative failure (Po-F) rates (P<0.05). Moreover, U-VATS segmentectomy in Phase 3 was associated with significantly shorter Po-Hst and Op-T, less Po-D, and reduced postoperative pain compared with non-U-VATS (P<0.05).

Conclusions: U-VATS segmentectomy is an ideal alternative to non-U-VATS segmentectomy. Surgeons can preliminarily complete U-VATS anatomical segmentectomy after performing 20–29 cases, and can master the surgical techniques after completing 58–63 cases.

Keywords: Uniportal video-assisted thoracoscopic surgery (U-VATS); anatomical segmentectomy; learning curve; cumulative sum analysis

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Introduction

Since it was first performed in a pulmonary lobectomy by the Spanish scholar Gonzalez in in 2011 (1), the uniportal video-assisted thoracic surgery (U-VATS) technology has been widely applied in surgical treatment of lung diseases. Compared to traditional multiport VATS, U-VATS has the advantage of significantly reducing incision pain as using a single small incision could effectively minimizes intercostal nerve injury during the operation (2). However, Surgeons who performed U-VATS segmentectomy may undergo a harder learning curve of pulmonary segmentectomy as the U-VATS segmentectomy is a complex and time-consuming procedure. A considerable learning curve must be overcome before a surgeon is proficient in using this technique in pulmonary resections (3). Interestingly, previous studies have provided different findings regarding the learning curves of U-VATS segmentectomy and robotic segmentectomy (3-6). Chen *et al.* concluded that the inflection point for completing the learning curve was reached after the considerable number of 57 cases (5), whereas Cheng *et al.* found that an experienced surgeon could achieve a relatively stable level after 33 cases (3). In other words, the learning curve of this complex procedure has not been fully clarified. Therefore, we speculate that the inflection point may not be an exact number because of the complexity of U-VATS anatomical segmentectomy. In the present study, we will explore a novel form to describe the inflection point.

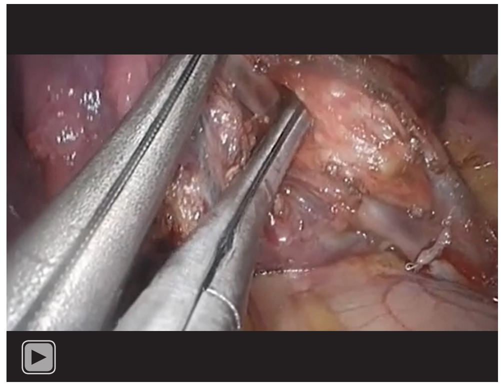
In our institution, surgeons performed 3-port or 2-port VATS segmentectomy between 2014 and 2018, and anatomical segmentectomy by U-VATS has been attempted and completed since the beginning of 2019. The present study aimed to reassess the inflection point for the learning curve of U-VATS anatomical segmentectomy in a novel approach and to demonstrate the clinical advantages of U-VATS anatomical segmentectomy compared with non-U-VATS.

We present the following article in accordance with the STROBE reporting checklist (available at https://dx.doi.org/10.21037/atm-21-6113).

Methods

Patients and data collection

We retrospectively reviewed 122 consecutive patients who underwent U-VATS anatomical segmentectomy (*Video 1*) and 98 consecutive patients receiving 2- or 3-port VATS anatomical segmentectomy by the same surgeon from August 2017 to May 2020.



Video 1 Uniportal thoracoscopic anatomical segmentectomy (right pulmonary segmentectomy 9+10).

The inclusion criteria for U-VATS segmentectomy are listed as follows: (I) clinical stage 0 or IA patients with a ground glass opacity-dominant tumor ≤3 cm or a solid-dominant tumor ≤2 cm on preoperative high-resolution computed tomography (HRCT) (7); and (II) patients with intraoperatively identified benign lesions, which were unsuitable for wedge resection due to inaccessible locations. The exclusion criteria were as follows: (I) patients who had received neoadjuvant treatment; (II) patients with more than one surgical site, and those who received ipsilateral reoperation or synchronous bilateral VATS; (III) patients on whom intraoperative pathology confirmed the presence of pleural or mediastinal metastasis; and (IV) those with severe and extensive adhesions of the entire pleural cavity. For all patients, blood routine examination, blood biochemistry, arterial blood gas analysis, coagulation function, electrocardiogram, pulmonary function, echocardiography, chest enhanced CT, abdominal and adrenal ultrasound, and pulmonary function were routinely performed before surgery.

Among the 122 patients receiving U-VATS segmentectomy, 116 received successful U-VATS pulmonary segmentectomy, while the other six patients underwent conversions to non-U-VATS (*Table 1*). Based on the previously reported experience in anatomical segmentectomy (8), we classified the procedure by U-VATS into three categories by the degree of difficulty of the segmentectomy (Table S1). Postoperative complications were divided into four levels according to the Clavien-Dindo classification (9), in which levels III and IV indicate serious complications. Postoperative pain scores were obtained using visual

Table 1 Characteristics and perioperative outcomes of the included patients

Characteristics	Overall (n=116)	Phase 1 (n=29)	Phase 2 (n=34)	Phase 3 (n=53)	P
Age (years)	53.9±12.6	55.1±11.2	54.5±12.1	52.8±13.8	0.68
Sex (male/female)	37/79	10/19	14/20	15/38	0.46
Tumor size (mm)	9.4±5.3	10.4±5.7	10.3±6.6	8.4±3.8	0.13
Hookwire localization	24	3	9	12	0.26
Operative time (minutes)	179.2±65.9	204.5±73.7	204.7±70.3	145.0±42.8	<0.001
Blood loss (mL)	37.6±91.7	61.7±181.4	27.1±12.9	31.1±18.0	0.26
Conversion*	6	3	1	2	0.48
Wedge resection#	30	10	10	10	0.26
No. of lymph nodes removed	3.9±3.7	4.2±3.8	3.9±3.4	3.8±3.8	0.89
Compromised segmentectomy	11	2	5	4	0.51
Pathology (malignant/benign)	102/14	26/3	29/5	47/6	0.87
Pathological stage (Tis/pT1(a/b) N0M0)	17/85	2/24	9/20	6/41	0.06
Thoracic drainage (mL)	613.2±498.8	816.5±547.8	619.8±539.4	497.7±409.0	0.04
Drainage time (days)					
Upper chest tube	2.7±1.9	2.7±1.2	3.0±3.6	2.5±0.7	0.53
Lower chest tube	4.5±2.4	4.9±2.0	4.8±3.7	4.0±1.5	0.21
Clavien-Dindo Classification					0.14
Grades I–II	18	5	7	6	
Grades III–IV	14	6	5	3	
Postoperative hospital stays (days)	7.3±3.5	8.9±4.6	7.2±3.5	6.5±2.4	0.01
30-d mortality	0	0	0	0	–
6-m recurrence	0	0	0	0	–

*, the relevant parameters were selected to evaluate conversion: conversion to non-U-VATS due to bleeding, unplanned additional resection due to insufficient surgical edge or improper operating procedure, except pathology; #, wedge resection before segmentectomy.

analogue scale (VAS), and nurses evaluated the VAS every 8 hours after surgery. Operative failure (Op-F) included intraoperative conversions, unplanned additional resection, or severe postoperative complications (Clavien ≥ III).

All procedures performed in this study involving human participants were in accordance with the Declaration of Helsinki (as revised in 2013). This retrospective clinical study has been approved by the Ethics Committee of the Second Affiliated Hospital of Soochow University (No. JD-HG-2020-19). Individual consent for this retrospective analysis was waived.

Treatment

Before determining the surgical procedure, the blood vessels and bronchus of the target segment were evaluated based on enhanced chest CT. Three-dimensional reconstruction was performed to evaluate the resection distance of combined segments when the nodule was adjacent to multiple lung segments (10).

The patient was placed on surgeon's side with double-lumen endotracheal intubation and combined intravenous-inhalation anaesthesia. The incisions of the upper lobe segmentectomy and the lower lobe segmentectomy were made at the 4^{th} and 5^{th} intercostal space of the anterior

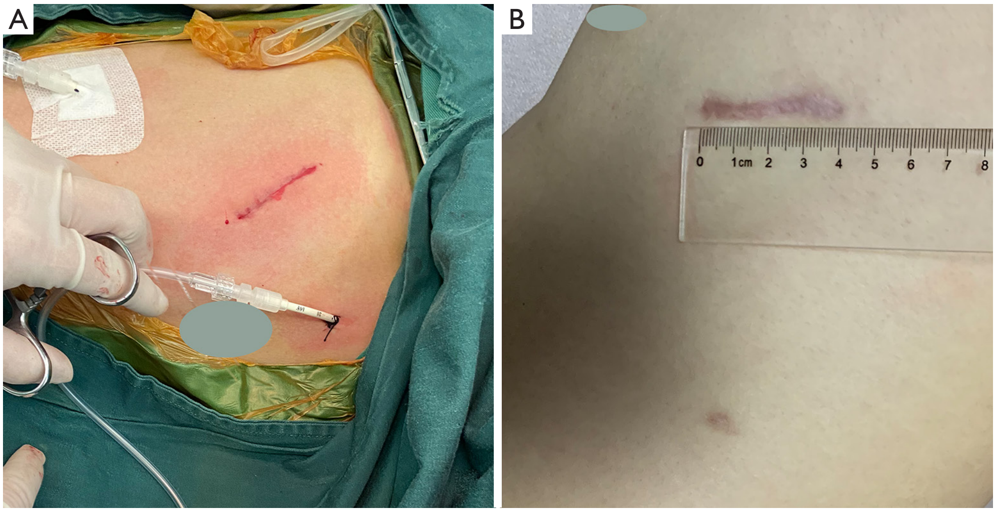


Figure 1 The surgical incision. (A) A patient with two pigtail tubes (10 F, Copper, China) whose surgical incision was sutured intracutaneously; (B) the surgical incision was healing well.

axillary line, respectively. The single incision was about 3–4 cm in length, and incision protector of a medium size was used routinely. The surgeon usually stood on the patient's ventral side, while the assistant was on the opposite side of the surgeon. All procedures were performed using single-direction U-VATS under the guidance of a 10-mm, 30-degree, angled thoracoscopic video camera. The locations of the lesions were confirmed preoperatively using a hookwire, or were indicated according to the interrelated anatomical site intraoperatively.

The arteries and veins of the target lung segment were incised in different ways depending on the diameter of the vessel. The target bronchus was dissociated using an endoscopic stapler. The inflation-deflation method was used to identify the intersegment planes. When the intersegment planes were unclear, it was necessary to evaluate according to the venous trend. Finally, continuous suture with 4-0 polypropylene was performed if air leakage or severe bleeding at the cutting edge was encountered. In the event of malignancy, lymph node dissection was performed in accordance with accepted international general guidelines (11,12). During the operation, a pigtail tube (10F, Copper, China) or traditional thoracic drainage tube (24F, PAHSCO, China) was used for drainage according to the intraoperative conditions. The surgical incision was routinely sutured intracutaneously (*Figure 1*, Figure S1).

Statistical analysis

Statistical analysis was performed using SPSS26.0 software (IBM Corp., Chicago, IL, USA). Measurement data are presented as mean ± standard deviation. Comparison between groups was performed by analysis of variance. The Student's *t*-test was applied to compare the distributions of continuous variables. And the χ^2 test and Fisher's exact test were adopted to compare the frequencies of categorical variables between groups. A two-tailed P value <0.05 was considered statistically significant. Cumulative sum (CUSUM) analysis was employed to analyze the learning curves of anatomical segmentectomy by U-VATS.

Results

An interval might be a more appropriate substitute for an absolute value as the breakpoint of the CUSUM curve

The CUSUM curve analyses on the operative time (Op-T) (*Figure 2*), postoperative hospital stays (Po-Hst) (*Figure 3*), and postoperative thoracic drainage (Po-D) (*Figure 4*) revealed two structural intervals of 20–29 cases and 58–63 cases. We selected the maximum of the two intervals as the breakpoints to divide 116 patients into three phases: Phase 1 (29 cases), Phase 2 (34 cases), and Phase 3 (53 cases). According to the distribution of the phases, three cases in Phase, one case in Phase 2, and two

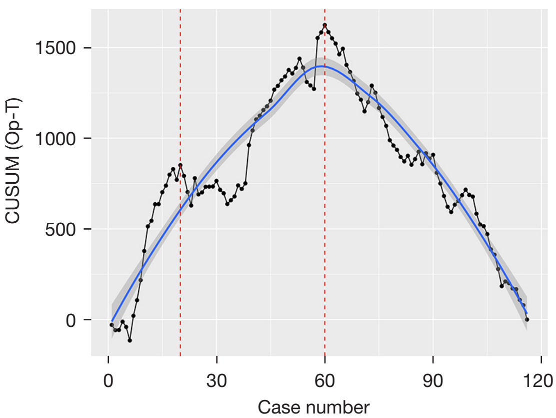


Figure 2 Learning curve for uniportal thoracoscopic anatomical pulmonary segmentectomy (CUSUM analysis of Op-T). CUSUM (Op-T) plotted against case number (solid line). The two structural intervals of the CUSUM (Op-T) were 20 and 60 cases. CUSUM, cumulative sum; Op-T, operative time.

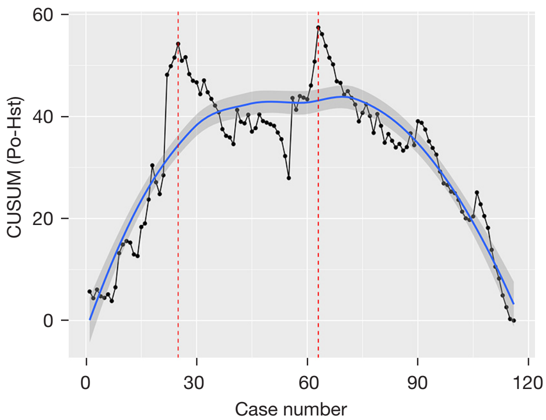


Figure 3 Learning curve for uniportal thoracoscopic anatomical pulmonary segmentectomy (CUSUM analysis of Po-Hst). CUSUM (Po-Hst) plotted against case number (solid line). The two structural intervals of the CUSUM (Po-Hst) were 25 and 63 cases. Po-Hst, postoperative hospital stay.

cases in Phase 3 underwent intraoperative conversions, respectively. As shown in *Table 1*, there was no significant difference in baseline characteristics among the three phases. The proportion of level 1 segmentectomy in Phase 1 was significantly higher than that in Phase 3 (P=0.03). Meanwhile, even with increase in level 3 segmentectomy in Phase 3, the perioperative parameters in Phase 3 indicated an impressive improvement compared to those in Phase 1, including Op-T, Po-Hst, and Po-D (P<0.05) (*Table 2*).

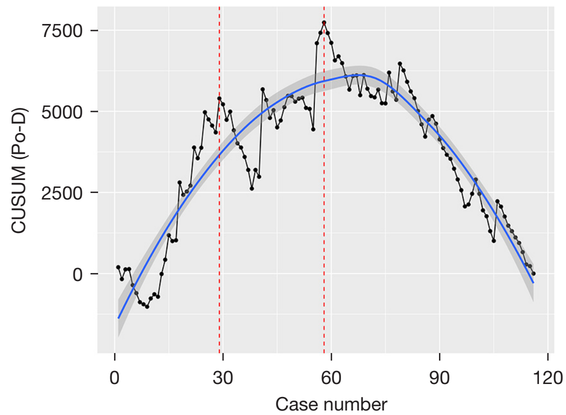


Figure 4 Learning curve for uniportal thoracoscopic anatomical pulmonary segmentectomy (CUSUM analysis of Po-D). CUSUM (Po-D) plotted against case number (solid line). The two structural intervals of the CUSUM (Po-D) were 29 and 58 cases. CUSUM, cumulative sum; Po-D, postoperative thoracic drainage.

We further analyzed multiple types of Op-F: conversion, unplanned additional resection, and serious postoperative complications (Clavien ≥ III). Interestingly, the occurrence rate of Op-F in Phase 2 (17.6%) was not significantly lower than that in Phase 1 (31.0%) (P=0.214). Nevertheless, there was a notable decrease in the occurrence rate of Op-F in Phase 3 (9.4%) compared with that in Phase 1 (31.0%) (P=0.03) (*Table 2*).

U-VATS anatomical segmentectomy is an alternative to non-U-VATS anatomical segmentectomy for early-stage lung cancer

As shown in *Table 3*, there was no significant difference in baseline characteristics and perioperative outcomes of anatomical segmentectomy by U-VATS and non-U-VATS. Interestingly, it was revealed that U-VATS segmentectomy in Phase 3 was associated with significantly shorter Po-Hst (P=0.04), shorter Op-T (P=0.03), and less Po-D (P=0.046), as well as reduced postoperative VAS_2 (P=0.002) and VAS_3 (P=0.004) compared with non-U-VATS anatomical segmentectomy (*Table 3*).

Discussion

Anatomical segmentectomy is a safe and feasible surgical technique for early lung cancer, which can reserve more lung function than lobectomy (13-15). The VATS pulmonary segmentectomy technology has gradually

Table 2 Perioperative outcomes in different phases of learning uniportal thoracoscopic segmentectomy

	Operative time	Postoperative hospital stays	Thoracic drainage	Blood loss	Operative failure*
P_1 (Phase 1 *vs.* 2)	0.99	0.09	0.36	0.27	0.21
P_2 (Phase 1 *vs.* 3)	0.001	0.01	0.005	0.37	0.03
P_3 (Phase 2 *vs.* 3)	<0.001	0.30	0.16	0.22	0.43

*, the relevant parameters were selected to evaluate operative failure: conversion, postoperative complications (Clavien ≥ III).

Table 3 Comparison of baseline characteristics and perioperative outcomes between U-VATS and non-U-VATS anatomical segmentectomy (2- and 3-port VATS)

Characteristics	U-VATS (all phases, n=116)	U-VATS (phase 3, n=53)	Non-U-VATS (n=98)	P_1	P_2
Age (years)	53.6±12.6	52.8±13.8	56.6±14.2	0.13	0.11
Sex (male/female)	37/79	15/38	37/61	0.37	0.46
Tumor size (mm)	9.4±5.3	8.4±3.8	8.5±3.7	0.14	0.83
Pathology (malignant/benign)	102/14	47/6	87/11	0.85	0.99
Pathological stage (Tis/pT1(a/b) N0M0)	17/85	6/41	9/78	0.21	0.67
Operative time (minutes)	179.2±65.9	149.0±42.8	166.8±58.4	0.15	0.03
Blood loss (mL)	37.6±91.7	31.1±18.0	38.7±47.7	0.92	0.27
No. of lymph nodes removed	3.9±3.7	3.8±3.9	3.5±3.1	0.32	0.56
Thoracic drainage (mL)	613.2±498.8	497.7±409.0	676.7±571.3	0.39	0.046
Drainage time (days)					
Upper chest tube	2.7±2.0	2.5±0.7	3.0±1.7	0.28	0.02
Lower chest tube	4.5±2.4	4.0±1.5	5.1±2.5	0.05	0.001
Postoperative hospital duration (days)	7.3±3.5	6.5±2.4	7.6±3.3	0.58	0.04
Conversion*	6	2	4	0.96	0.89
Postoperative pain level[&]					
VAS_1	3.1±0.9	3.0±1.0	3.4±1.1	0.09	0.08
VAS_2	2.8±0.9	2.7±0.9	3.2±0.9	0.001	0.002
VAS_3	2.6±1.2	2.6±1.1	3.1±1.2	<0.001	0.004
30-d mortality	0	0	1	0.93	0.42
6-m recurrence	0	0	0	–	–

*, the relevant parameters were selected to evaluate conversion: conversion of U-VATS to non-U-VATS, conversion of 2-port VATS to 3-port VATS or open surgery, and conversion of 3-port VATS to open surgery due to bleeding, unplanned additional resection due to insufficient surgical edge or improper operating procedure, except pathology; [&], postoperative pain scores were obtained using visual analogue scale (VAS), and nurses evaluated VAS every 8 hours after surgery. VAS_1 (VAS of the first 8 hours after surgery); VAS_2 (VAS of the second 8 hours after surgery); and VAS_3 (VAS of the third 8 hours after surgery). P_1 [U-VATS (all phases) versus non-U-VATS); P_2 [U-VATS (phases 3) versus non-U-VATS].

changed from 4-, 3- and 2-port to uniport. The challenge with uniportal VATS was choosing appropriate angle and path when cutting off the vessels, the bronchus and the lung segments. However, these difficulties can be overcome by rationally selecting the incision position, sufficiently dissecting lung segments and properly using a rotating or a wisdom stapler (4). Despite the narrow space of a single surgical incision, Bertolaccini *et al.* (16) and Gonzalez-Rivas (17) believed that U-VATS can provide the same view as open segmentectomy for thoracic surgeons, especially in displaying the superior mediastinum and the local area. U-VATS has the advantage of significantly reducing incision pain as using a single small incision could effectively minimizes intercostal nerve injury during the operation (2). According to previous studies (4,18,19), U-VATS anatomical segmentectomy is an alternative to non-U-VATS anatomical segmentectomy for early-stage lung cancer, and is associated with less intraoperative blood loss (Op-B), shorter Op-T, and faster recovery. Similarly, in our study, we found that U-VATS segmentectomy could bring shorter Po-Hst, shorter Op-T, and less Po-D, as well as reduced postoperative pain, especially in Phase 3 (*Table 3*).

In this study, the main indicators for learning curve analysis were as follows: Op-T, conversion, Op-B, removal of lymph nodes, postoperative complications, and Po-Hsts (20). Op-F was defined as not only intraoperative conversions but also serious postoperative complications (16). As reported by Chen *et al.* (5), thoracic surgeons could preliminarily acquire the surgical techniques of U-VATS segmentectomy in Phase 1, while their additional experience might accumulate gradually in Phase 2, and Phase 3 represented an experienced period. Notably, the two transition intervals among the three phases should be evaluated by multiple perioperative characteristics. In this study, the CUSUM curve was assessed in different aspects, including Op-T, Op-B, Po-D, and Po-Hst. The structural intervals were thereby generated, based on which three phases of the CUSUM curve were divided and subsequently compared. As expected, significant differences in the aforementioned perioperative characteristics could be found among the three phases.

In terms of the structural intervals, we employed an interval instead of an absolute value in the current study. As mentioned above, previous studies (3,5) focused on providing a specific number as an indicator of achieving technical maturity. However, their conflicting results might be due to the diversity of anatomical structures of different segments. Therefore, we believed that an interval might be a more appropriate substitute for an absolute value as the breakpoint of the CUSUM curve. A surgeon could perform perfectly U-VATS segmentectomy in the treatment of lung cancer after the phase 3 of learning curve. Notably, only one breakpoint was available in both the CUSUM curve of Op-B (Figure S2) and that of Op-F (Figure S3), which might be explained by the abundant experience of our surgeons in VATS. Meanwhile, two structural intervals were observed in the CUSUM curves of Op-T and that of Po-Hst, with a similar result being observed in that of Po-D. Furthermore, the maximum of the two intervals was used as the breakpoint to divide the 116 cases into three phases, which exhibited an excellent distinguishing ability, as significant differences in Op-T, Po-Hst, Po-D and Op-F were observed between the initial and final phases.

Taking the complexity of U-VATS anatomical segmentectomy into consideration, we summarized several technical factors that might contribute to the learning curve of U-VATS segmentectomy. Firstly, preoperative CT-guided hookwire localization is an advisable technique to reduce the difficulty for surgeons to locate the lesions, which can therefore avoid intraoperative unplanned additional resection. Secondly, an experienced assistant is helpful to handle intraoperative emergencies, especially unexpected bleeding, which can likely occur in conversions. In addition, it is crucial for a surgeon to obtain standardized training in VATS, including selection of surgical incision, use of uniportal surgical instruments, and management of intraoperative emergencies, before performing U-VATS anatomical segmentectomy.

Several limitations need to be considered for this study. Firstly, the number of included patients was moderate, which limited our CUSUM curve analysis in different subgroups stratified by the degree of difficulty of the segmentectomy. Secondly, this report was composed of the learning process of a single surgeon, who had extensive experience with VATS lobectomy before initiating U-VATS segmentectomy, which limits the generalizability of our results. Moreover, previous surgeon experience and hospital volume may affect the learning process.

Conclusions

U-VATS anatomical segmentectomy is an ideal alternative to non-U-VATS anatomical segmentectomy, with advantages in shorter Po-Hst and Op-T, less Po-D, and reduced postoperative pain. Surgeons can preliminarily acquire the surgical techniques of U-VATS anatomical segmentectomy after completing 20 to 29 cases, and can master the procedure after completing 58 to 63 cases.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://dx.doi.org/10.21037/atm-21-6113

Data Sharing Statement: Available at https://dx.doi.org/10.21037/atm-21-6113

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://dx.doi.org/10.21037/atm-21-6113). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All procedures performed in this study involving human participants were in accordance with the Declaration of Helsinki (as revised in 2013). This retrospective clinical study has been approved by the Ethics Committee of the Second Affiliated Hospital of Soochow University (No. JD-HG-2020-19). Individual consent for this retrospective analysis was waived.

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Supplementary

Table S1 Distribution of uniportal thoracoscopic anatomical segmentectomy

	Overall	Phase 1	Phase 2	Phase 3	P
Level 1, simple	36	14	8	13	
LS*4 + 5	8	1	1	6	
LS6	11	6	2	3	
RS6	17	7	5	4	
Level 2, moderate	69	14	22	32	
LS1	2	0	1	1	
LS1+2	4	1	2	1	
LS1+2+3	20	5	6	9	
LS3	1	0	0	1	
LS8	1	0	0	1	
LS8+9+10	3	1	1	1	
RS1	14	2	4	8	0.142
RS2	9	2	2	5	
RS5	1	0	0	0	
RS1+2	3	0	1	2	
RS7+8+9+10	2	0	2	0	
RS3	6	2	3	1	
RS8	3	1	0	2	
Level 3, complex	13	1	4	8	
LS9+10	4	1	1	2	
RS7+8	1	0	1	3	
RS9+10	6	0	2	1	
RS6+9+10	1	0	0	1	
RS7+9+10	1	0	0	1	

LS, left pulmonary segmentectomy; RS, right pulmonary segmentectomy.

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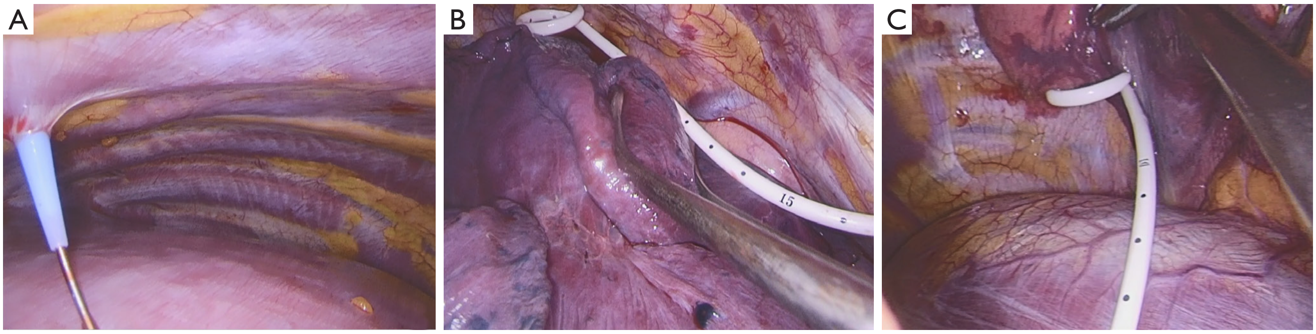

Figure S1 Using pigtail tubes for postoperative thoracic drainage. (A) The guidewire was placed into the chest as a seeker; (B) the upper drainage tube was placed in the second intercostal nearby the mid-clavicular line; (C) while the lower drainage tube was placed in the seventh intercostal between the middle axillary line and the posterior axillary line.

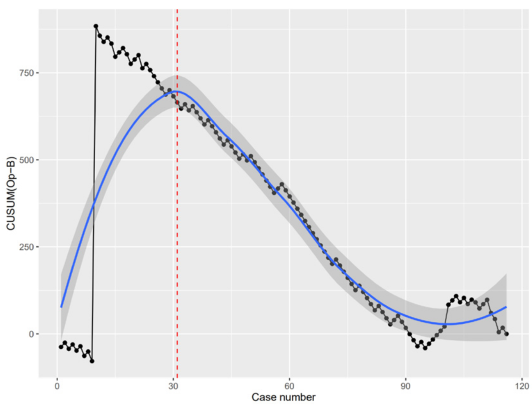

Figure S2 Learning curve for uniportal thoracoscopic anatomical segmentectomy (CUSUM analysis of Op-B). CUSUM (Op-B) plotted against case number (solid line). The structural breakpoint of the CUSUM (Op-B) was 30 cases. CUSUM, cumulative sum; Op-B, intraoperative blood loss.

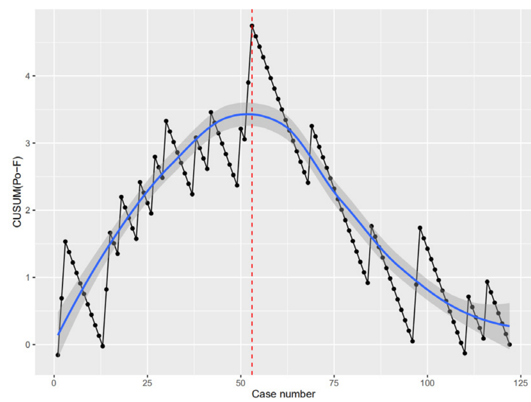

Figure S3 Learning curve for uniportal thoracoscopic anatomical segmentectomy (CUSUM analysis of Op-F). CUSUM (Po-C) plotted against case number (solid line). The structural breakpoint of the CUSUM (Op-F) was 53 cases. The relevant parameters were selected to evaluate Op-F: conversion and postoperative complications (Clavien ≥ III). CUSUM, cumulative sum; Op-F, operative failure.

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