



# Three-dimensional reconstruction facilitates thoracoscopic anatomical partial lobectomy by an inexperienced surgeon: a single-institution retrospective review

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**Background:** This study aimed to evaluate the effect of three-dimensional (3D) interactive quantitative surgical planning on the outcome of video-assisted thoracoscopic surgery (VATS) anatomical partial lobectomy (APL), and to investigate the learning curve of 3D reconstruction-assisted VATS APL assisted.

**Methods:** We retrospectively analyzed 156 cases of solitary pulmonary ground-glass opacity (GGO) lesions in patients who underwent 3D interactive quantitative VATS APL. Digital imaging and communications in medicine data were recorded for each patient. We used Materialise 3-Matic software to make 3D reconstructed images. All surgeries were performed by the same thoracic surgeon at the Cardiothoracic Surgery Department of Yichang Central People's Hospital between February 28, 2018, and April 20, 2020. The learning curve was evaluated using operative time and the cumulative sum (CUSUM) value of operative time in all cases.

**Results:** VATS APL was performed in every patient successfully, and there were no conversions to thoracotomy or lobectomy. The median surgical margin distance was 2.2 (range, 2.0–2.8) cm. All patients had an R0 complete cancer resection on histology. The histological subtypes of the segmental lesions included 69 cases of minimally invasive adenocarcinoma (MIA), 61 cases of adenocarcinoma, one case of squamous cell carcinoma, 16 cases of adenocarcinoma in situ (AIS), and nine cases of atypical adenomatous hyperplasia (AAH). The median operation time was 119 (range, 57–245) min, and median intraoperative blood loss was 37 (range, 15–247) mL. The median duration of thoracic drainage tube insertion was 2.3 (range, 1–23) days after surgery. The median length of postoperative hospital stay was 3.7 (range, 3–25) days. There were no cases of perioperative death. During the median postoperative follow-up period of 11 (range, 2–26) months, no tumor recurrence or postoperative death was observed. 3D interactive quantitative surgical planning facilitates safe and efficient VATS APL with a learning curve of 30 cases.

**Conclusions:** 3D interactive quantitative surgical planning for VATS APL is a feasible option for inexperienced surgeons, with acceptable safety and complications.

**Keywords:** Anatomical partial lobectomy (APL); surgical planning; three-dimensional (3D); video-assisted thoracoscopic surgery (VATS)

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## Introduction

Owing to the widespread application of high-resolution computed tomography (HRCT) for health examinations in recent years, an increasing number of ground-glass opacity (GGO) lesions have been identified. For these lesions, particularly those with diameters of <2 cm and a consolidation ratio of <50%, lobectomy results in a greater loss of lung function. Numerous clinical studies have shown that there is no significant difference between segmentectomy and lobectomy in the treatment of early small focus lung cancer (1-4). Anatomical partial lobectomy (APL) is based on the anatomy of pulmonary segments and subsegments (5). The APL procedure comprehensively takes into account the individualized surgical differences of sublobectomy in different patients based on the tumor location. For patients with multiple pulmonary nodules, the advantages of APL are more obvious (6). These advantages have resulted in increased interest from both doctors and patients.

The National Comprehensive Cancer Network guidelines clearly states that, the indication for sublobar resection is a lesion around the lung with a diameter of  $\leq 2$  cm and with at least one of the following: pathologically confirmed adenocarcinoma in situ (AIS), nodule with  $\geq 50\%$  GGO on CT, and imaging-confirmed tumor doubling time of  $\geq 400$  days (7). Thoracoscopic APL is a very delicate technological procedure, and APL is technically more difficult than lobectomy. Anatomic complexity and many variations of segmental bronchi and vessels are other considerations (8). In three-dimensional (3D) reconstruction images, the intersegmental vein and its branches can be accurately identified, allowing the intersegmental plane to be easily recognized. 3D reconstruction is conducive to identify the lung segment structure, facilitate the localization of lung nodules and the determination of cutting plane (9-11), 3D digital anatomy models are useful in training inexperienced surgeons (12).

The objective of this study was to evaluate the effect of inexperienced surgeon perform 3D interactive quantitative surgical planning on the outcome of video-assisted thoracoscopic surgery (VATS) APL, and investigate the learning curve of inexperienced surgeon perform VATS APL with 3D reconstruction. We present the following article in accordance with the STROBE reporting checklist (available at <https://dx.doi.org/10.21037/jtd-21-1578>).

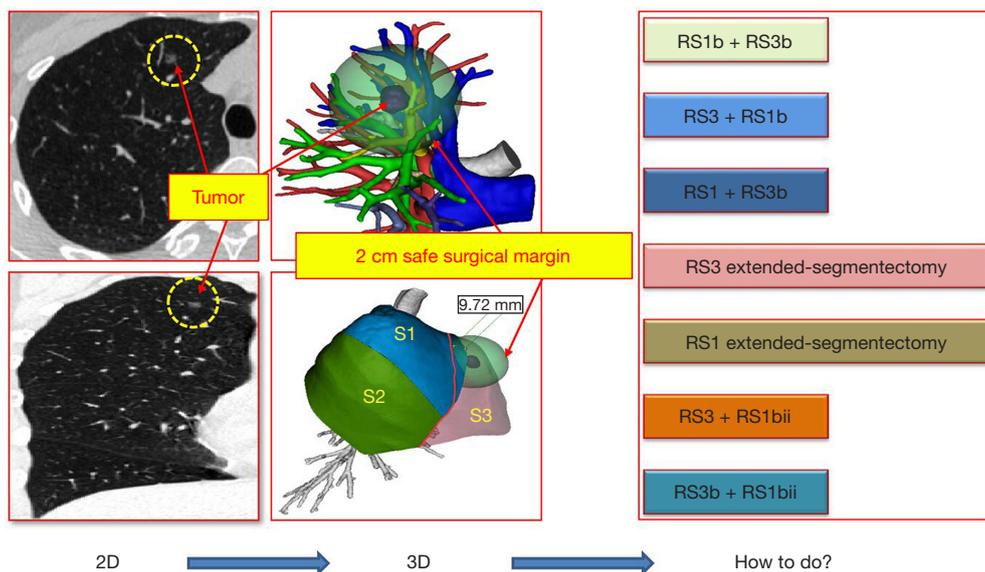
## Methods

### *Patients and methods*

A total of 156 patients underwent 3D interactive quantitative planned VATS APL at the Cardiothoracic Surgery Department of Yichang Central People's Hospital between February 28, 2018, and April 20, 2020. All surgeries were performed by the same thoracic surgeon (Dr. Yun Liu) with assistant surgeons. The inclusion criterion for VATS APL in the present study was CT indicating a single lesion around the lung (considered  $1/3$  outside the lung parenchyma) with a diameter of  $\leq 2$  cm and with at least one of the following: pathologically confirmed AIS, nodule with  $\geq 50\%$  GGO on CT, and imaging-confirmed tumor doubling time of  $\geq 400$  days. The preoperative workup of all patients included clinical history, physical examination, thin-slice CT of the chest, and routine preoperative examination. Brain magnetic resonance imaging, bone scintigraphy, or positron emission tomography/CT was also performed if necessary. All enrolled patients provided informed consent. The operation time, intraoperative blood loss, resection margin distance, postoperative complications, thoracic tube retention for drainage, length of postoperative hospital stay, and postoperative complications were analyzed, these data are relevant because of the clear statistical methodology and objective determination of the learning curve. The learning curve was analyzed using the cumulative sum (CUSUM) method. The learning curve was evaluated using operative time and the CUSUM value of operative time in all cases. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The protocol of this study was approved by the institutional review board of Yichang Central People's Hospital (No. HEC-KYJJ-2018-601-01). Informed consent was obtained from the patients before surgery.

### *3D interactive quantitative surgical planning*

All patients underwent preoperative chest thin-slice CT with a slice thickness of 0.625–1.5 mm. Digital imaging and communications in medicine data were recorded for each patient. 3D reconstruction images were generated for all patients using the Materialise 3-Matic software (developed by Materialise Nv Co., Materialise's interactive medical image control system, Belgium; serial number: A51D56D6-C3XE-0011-1F7605D216DF39D5). The



**Figure 1** According to each specific situation, we selected the most reasonable operation type and planned the surgical path. 2D, two-dimensional; 3D, three-dimensional; S1, apical segment; S2, posterior segment; S3, anterior segment.

pulmonary arteries, pulmonary veins, bronchi, and each pulmonary segment were reconstructed and marked with different colours. Accurate determination of the location of pulmonary nodules and 2 cm safe margin was conducted. The lung tissue involved in the safe resection margin was considered the target segment, and the corresponding segmentectomies were performed accordingly. The anatomic relationship between the nodule and adjacent structures was determined to design an appropriate surgical excision. According to each specific situation, we selected the most reasonable operation type and planned the surgical path (*Figure 1*).

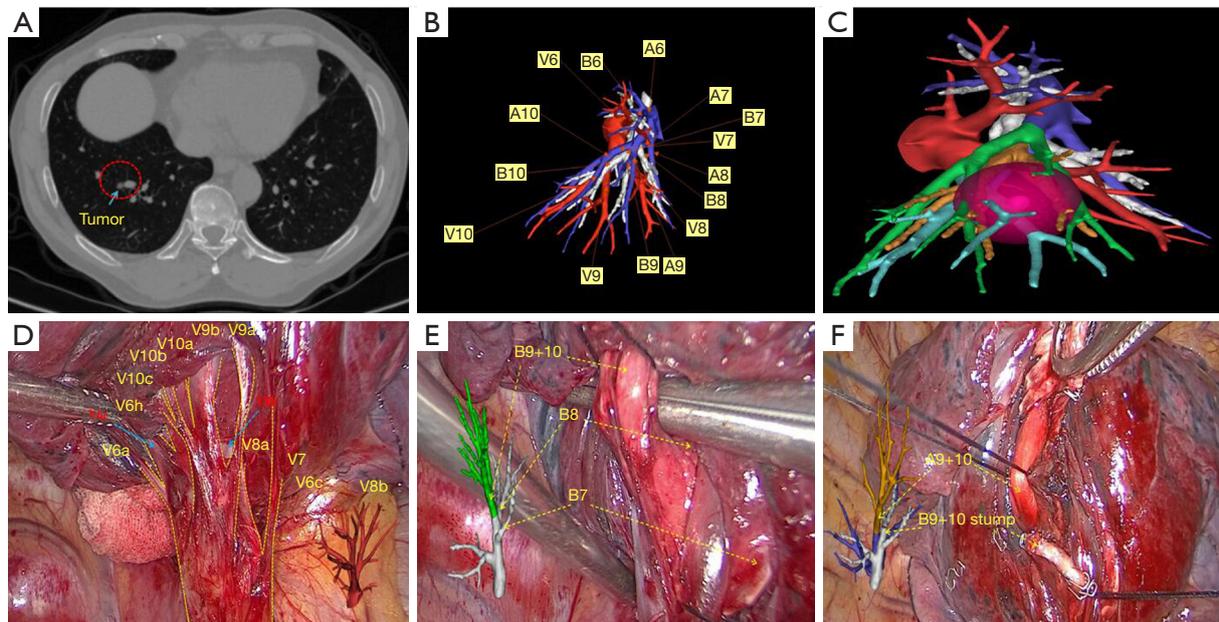
### VATS APL procedure

General anesthesia, double lumen endotracheal tube placement, and single lung ventilation were used. The patient was placed in the contralateral decubitus position. The surgeon stood at the dorsal side of the patient, with the assistant standing at the ventral side of the patient. Surgery was performed with the lung collapsed on the operating side. VATS APL was performed in all patients via a three-port approach. The thoracoscope port was placed along the midaxillary line of the 8<sup>th</sup> intercostal space and was approximately 1.5 cm in length. The main utility incision was made in the 4<sup>th</sup> or 5<sup>th</sup> intercostal space along the anterior axillary line and was approximately 3 cm in length. The

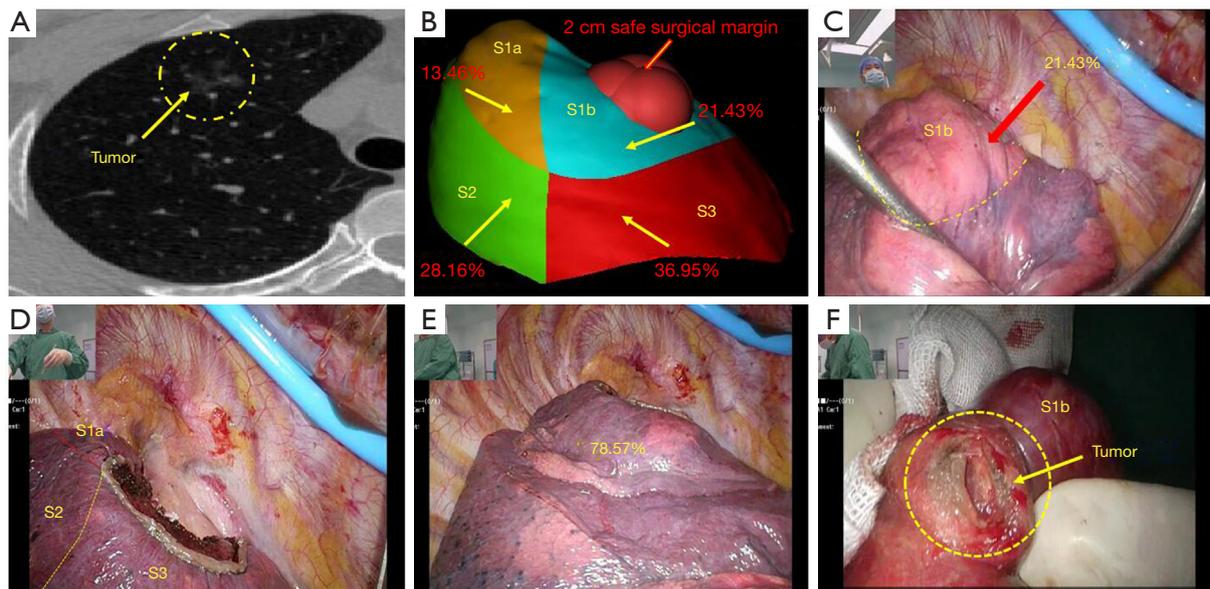
assistant incision was made in the 5<sup>th</sup> intercostal space along the posterior axillary line and was approximately 1.5 cm in length. The incisions were protected with a silicone rubber wound protector.

Thoracoscopic APL for basal segment or subsegment is technically challenging because of the variation and deep location of vessels and bronchi in the parenchyma (13). We have already described the detailed procedures of right S9+10 segmentectomy in previous reports (14). According to the 3D image, we determined the bronchus and vessels of the target segment, which must be dissected during the operation. We then divided the target segmental bronchus and vessels such as for right S9+10 segmentectomy (*Figure 2*). The last step was to manage the intersegmental plane and divide the lung parenchyma. The inflation-deflation method was performed to identify the intersegmental plane, and the contour of the target segment was displayed. Next, a 3D stapler was used for skin closure. Using 3D reconstruction, we could make accurate plans preoperatively, remove the least amount of lung tissue, and retain more lung tissue on the premise of ensuring the safe margin. For example, in procedures such as RS1b subsegmentectomy (*Figure 3*), we only lost 21.43% of the right upper lung function, but achieved the same operation effect as a right upper lobectomy, and retained 78.57% of the right upper lung function.

Upon completion of APL, the lung tissue of the target



**Figure 2** 3D interactive quantitative surgical planning VATS right S9+10 segmentectomy. (A) An 8-mm mixed GGO nodule at the basal segments of the right lower lobe; (B) anatomy of the right basal segment; (C) 2 cm safe resection margin; (D) management of the inferior pulmonary vein; (E) management of the bronchus; and (F) management of the artery. 3D, three-dimensional; VATS, video-assisted thoracoscopic surgery; GGO, ground-glass opacity; V, vein; A, artery; B, bronchus.



**Figure 3** Planning resection region and target lung segment by 3D simulation to evaluate the value of APL. (A) A 13-mm pure GGO nodule at the right upper lobe; (B) 2 cm safe surgical margin was within RS1b; (C-F) APL with RS1b was performed based on the 3D simulation and only 21.43% of the right upper lung function was lost. 3D, three-dimensional; APL, anatomical partial lobectomy; GGO, ground-glass opacity; S1, apical segment; S2, posterior segment; S3, anterior segment.

**Table 1** Baseline characteristics of the patients before surgery

Characteristics	N
Age, years	
Range	33–79
Median	53.7
Male/female	59/97
Active smokers	38
BMI, kg/m <sup>2</sup>	
Range	20.1–25.8
Median	22.3
Image characteristics	
Size, mm	
Range	8–20
Median	13.9
Pure GGO	51
GGO with <50% solid part	105

BMI, body mass index; GGO, ground-glass opacity.

segment was removed in a protective bag through the main utility incision and sent for intraoperative frozen section procedure. If this procedure confirmed a minimally invasive adenocarcinoma (MIA) or AIS, systemic hilar and mediastinal lymph node sampling was performed. If the frozen section procedure confirmed an invasive adenocarcinoma (IA), systemic hilar and mediastinal lymph node dissection was performed. Finally, an 8-Fr thoracic catheter connected to the negative pressure drainage bottle was placed in the observation port. Early mobilization out of bed was started at 12 hours postoperatively. The chest tube was removed if there was no air leak, well-inflated lung on chest X-ray, and less than 150 mL of drainage during the past 24 hours. At 3 months postoperatively, all patients underwent chest CT examination.

### Statistical analysis

All data were expressed as mean ± standard deviation (SD). The statistical software package of social science software version 23.0 for windows (SPSS, Chicago, IL, USA) was used for statistical analysis. The Student's *t*-test or Wilcoxon test were used to compare quantitative continuous data. *P* values less than 0.05 were considered statistically significant.

## Results

The data of 156 patients who underwent 3D interactive quantitative planned VATS APL were collected. The study group included 59 (37.8%) men and 97 (62.2%) women aged between 33 and 79 (median, 53.7) years. Among these patients, 38 were active smokers. In all patients, the body mass index (BMI) ranged from 20.1 to 25.8 (median, 22.3) kg/m<sup>2</sup> and the lesion diameter was between 8 and 20 (median, 13.9) mm, with 51 (32.7%) lesions having pure GGO. The consolidation ratio of 105 (67.3%) lesions was <50%. The patients' characteristics are listed in *Table 1*. 3D reconstruction was successful in all patients, facilitating determination of the operation plan according to the simulation results; adequate resection margin distance was determined for all patients. Eighty-eight patients underwent single segmentectomy or subsegmentectomy, while 68 patients underwent combined segmentectomy or subsegmentectomy. VATS APL was performed in every patient successfully, and there were no conversions to thoracotomy or lobectomy. The types of APL procedures are shown in *Table 2*.

Pathological examination showed that the surgical margins of all patients were sufficient to achieve radical resection. The median surgical margin distance was 2.2 (range, 2.0–2.8) cm. All patients had an R0 complete cancer resection on histology. The histological subtypes of the segmental lesions included 69 cases of MIA, 61 cases of adenocarcinoma, one case of squamous cell carcinoma, 16 cases of AIS, and nine cases of atypical adenomatous hyperplasia (AAH). Among those with AIS or MIA, systemic hilar and mediastinal lymph node sampling was performed in 85 patients. Systemic hilar and mediastinal lymph node dissection were performed in 62 patients among those with adenocarcinoma or squamous cell carcinoma. No patients were identified with postoperative lymph node involvement. The pathological examination characteristics of the patients are shown in *Table 3*.

The median operation time was 119 (range, 57–245) min and median intraoperative blood loss was 37 (range, 15–247) mL. The median duration of chest tube insertion was 2.3 (range, 1–23) days, and the median length of postoperative hospital stay was 3.7 (range, 3–25) days. The postoperative morbidity rate was 7.1% (11/156 patients, including five with prolonged air leakage (3–7 days), one with postoperative atelectasis owing to productive cough in chronic bronchitis, one with pneumonia, and four with hemoptysis (3–7 days). All patients who experienced

**Table 2** Types of VATS APL procedures

Type of APL procedure	N
Left upper lobe	
LS1 + LS2	9
LS1 + LS2a	2
LS1 + LS2a + LS2b	3
LS1 + LS2c	1
LS3	3
LS3b + LS3c	6
LS1 + LS2 + LS3	7
LS4 + LS5	10
LS5	3
LS4 + LS5 + LS3a	3
Left lower lobe	
LS6	11
LS6b + LS8a	3
LS6b + LS8a + LS9a	1
LS6c + LS10a	1
LS8	3
LS8 + LS9	2
LS9	3
LS10	3
LS9 + LS10	3
Right upper lobe	
RS1	9
RS1 + RS3b	3
RS1b + RS3b	2
RS1 + RS2	2
RS2	12
RS2a + RS1a	2
RS2b + RS3a	6
RS3	10
RS1b	3
Right lower lobe	
RS6	12
RS6b + RS8a	3
RS6 + RS10	1

**Table 2** (continued)**Table 2** (continued)

Type of APL procedure	N
RS7 + RS8	2
RS8	2
RS9	2
RS10	3
RS9 + RS10	5

VATS, video-assisted thoracoscopic surgery; APL, anatomical partial lobectomy; L, left; S1, apical segment; S2, posterior segment; S3, anterior segment; LS4, superior lingular segment; LS5, inferior lingular segment; S6, superior segment; S8, anterior basal segment; S9, lateral basal segment; S10, posterior basal segment; R, right; S7, medial basal segment.

postoperative complications were treated and discharged with no obvious symptoms. There were no cases of perioperative death. During the median postoperative follow-up period of 11 (range, 2–26) months, no tumor recurrence or postoperative death was observed. The operative results of the patients are shown in *Table 3*.

The operation time during the learning curve of 3D, interactive quantitative planned VATS anatomic segmentectomy is shown in *Figure 4*. The learning curve showed a tendency towards decreased operation time compared with in the first 30 cases ( $P < 0.01$ ), and the operation time was stable. Based on these findings, 3D interactive quantitative planned VATS APL was determined to have a learning curve of 30 cases.

## Discussion

VATS APL is becoming more widely used in clinical practice, and is a skill that thoracic surgeon must master. Compared with lobectomy, APL can preserve more lung function and is suitable for benign diseases and malignant tumors. Regarding malignant tumors, segmental resection is mainly suitable for patients with early lung cancer. Several studies have demonstrated a similar treatment effect between VATS lobectomy and segmentectomy for early lung cancer involving small lesions (3,4). These advantages have garnered increased attention among both thoracic surgeons and patients. However, VATS APL is a significantly more complex procedure than lobectomy. The main reason that this technique is more challenging and demanding is the anatomic complexity. 3D interactive quantitative surgical planning has demonstrated reliability

**Table 3** Surgical results

Variables	N
Operation time, minutes	
Range	57–245
Median	119
Bleeding, mL	
Range	15–247
Median	37
Chest tube duration, days	
Range	1–23
Median	2.3
Postoperative hospital stay, days	
Range	3–25
Median	3.7
Conversion to thoracotomy	0
Complication	
Atelectasis	1
Air leakage, >3 days	5
Hemoptysis, >3 days	4
Pneumonia	1
Pathology	
AAH	9
AIS	16
MIA	69
IA	
Well-differentiated	37
Moderately-differentiated	23
Poorly-differentiated	1
Squamous cell carcinoma	1

AAH, atypical adenomatous hyperplasia; AIS, adenocarcinoma in situ; MIA, minimally invasive adenocarcinoma; IA, invasive adenocarcinoma.

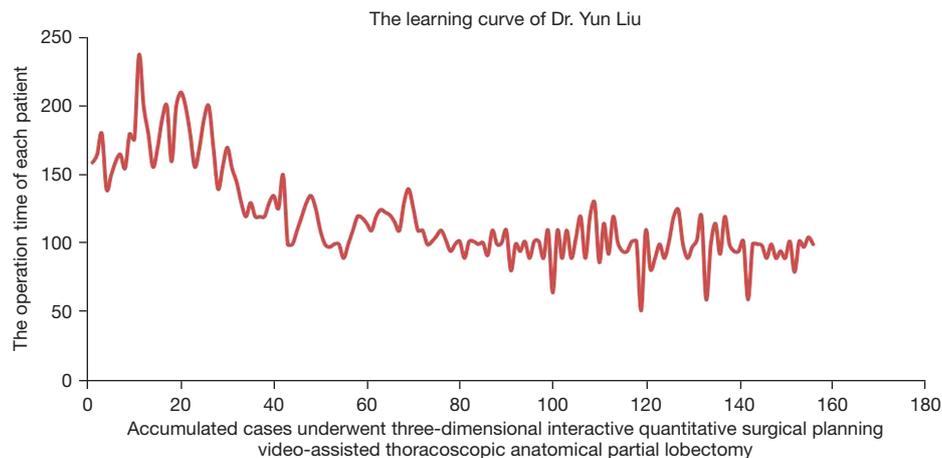
in pulmonary surgical planning; therefore, it is believed that 3D reconstruction could identify segmental structures, reveal anatomic variations, and help locate the pulmonary nodule. Preoperative simulation on 3D images is beneficial to resect target segments accurately while reducing surgical difficulty (9,10,15).

During thoracoscopic APL, in which direct palpation

of the pulmonary nodule is not always possible, effective identification of the tiny pulmonary nodule is crucial. 3D reconstruction is convenient for locating the pulmonary nodule and target segment, particularly those located in the deep parenchyma or on the border of adjacent segments. Identification of surgical margins and the APL approach is important, particularly in cases of malignancy, and the surgical margins should be >2 cm. Preoperative APL simulation using 3D images enables the surgeon to identify safe surgical margins and perform corresponding segmentectomies, including single subsegmentectomy, single segmentectomy, combined segmentectomy, or combined subsegmentectomy. Anatomic variations of segmental bronchi and vessels are complicated, but 3D reconstruction can clearly reveal the segmental anatomic structure and the variations of bronchi and vessels (16), which can improve both the accuracy and safety of the operation. In fact, to design margin or intersegmental line before operation by using 3D reconstruction is a critical step in APL. The presented study indicates that the less experienced surgeon had a tendency of shorter operation time when performing APL assisted with preoperative resection simulation using 3D reconstruction. Based on the 3D interactive quantitative surgical planning, APL can be performed successfully. It also reduces the difficulty of operation and can be applied in most medical centers. Some experienced surgeons prefer to operate by referring to CT images and actual conditions during the operation. However, for complex pulmonary surgery, this is not the primary trend.

The feasibility of segmentectomy for patients with GGO was discussed by Iwata *et al.* (17). We consider segmentectomy as a preferred option for such cases before the final results of two ongoing randomized clinical studies (18,19). During our practice, we also performed APL to ensure there is enough surgical margin. The type of APL procedures was consistent with the preoperative planning in all cases. Although five patients developed prolonged air leakage, the median chest tube duration was only 2.3 days. Postoperative morbidity was low (11/156; 7.1%) and postoperative hospital stay was only 3.7 days. There were no perioperative deaths. The extent of lymph node dissection varied in this study, and no patients were identified with lymph node involvement postoperatively. During the median postoperative follow-up period of 11 months, no tumor recurrence or postoperative death was observed, and the results were satisfactory.

The learning curve of VATS APL has not yet been



**Figure 4** The learning curve of 3D interactive quantitative planned VATS APL. 3D, three-dimensional; VATS, video-assisted thoracoscopic surgery; APL, anatomical partial lobectomy.

elucidated; this study described the learning curve of VATS APL for the first time. Hamada *et al.* (20) reported on the learning curve for thoracoscopic anatomic segmentectomy, and their data suggested that the inflection point for the learning curve was achieved after 84 cases at their institution, whereas the leading surgeon needed only 32 cases to achieve this level of competence. In the current study, we found that the 3D interactive quantitative planned VATS APL could be mastered after 30 cases. Kato *et al.* (11) reported the use of 3D CT images for surgical simulation during anatomic thoracoscopic pulmonary segmentectomy and the effectiveness of this technique. These data should be used by training programs and credentials committees for establishing standards to ascertain good outcomes in thoracic surgery. The results showed the merits of 3D reconstruction in VATS APL, and that 3D interactive quantitative surgical planning may enable accurate identification of GGO lesions and illustrate the variation pattern of the segmental bronchi and vessels (13,21,22). A 3D digital anatomy database for patients undergoing accurate VATS APL is necessary for larger data analysis in the era of precision medicine and artificial intelligence.

APL is a surgical skill that every thoracic surgeon urgently needs to master, 3D interactive quantitative surgical planning reduced the difficulties related to APL. We believe that even an inexperienced surgeon using 3D reconstruction can perform thoracoscopic APL, with a learning curve of 30 cases and with acceptable safety and complications. We suggest that young thoracic surgeons should master 3D reconstruction technology, and complete

3D reconstruction before surgery, which is conducive to doctors to master surgical technology and improve their ability to read CT images.

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### Footnote

*Reporting Checklist:* The authors have completed the STROBE reporting checklist. Available at <https://dx.doi.org/10.21037/jtd-21-1578>

*Data Sharing Statement:* Available at <https://dx.doi.org/10.21037/jtd-21-1578>

*Conflicts of Interest:* All authors have completed the ICMJE uniform disclosure form (available at <https://dx.doi.org/10.21037/jtd-21-1578>). 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. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The protocol of this study was approved by

the institutional review board of Yichang Central People's Hospital (No. HEC-KYJJ-2018-601-01). Informed consent was obtained from the patients before surgery.

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