Preoperative 3D-CT bronchography and angiography facilitates single-direction uniportal thoracoscopic anatomic lobectomy

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Background: Competency in video-assisted thoracoscopic surgery (VATS) lobectomy is estimated to be reached after 50 cases. Preoperative identification of individualized pulmonary vascular drainage is essential for the safe and fluent performance of single-direction uniportal VATS (UVATS) anatomic lobectomy. Digital anatomy models established by three-dimensional computed tomography bronchography and angiography (3D-CTBA) is therefore utilized to accumulate variations of the right upper lobe (RUL) veins, as right upper lobectomy is considered to be the most complicated and challenging procedure. This study aims to investigate the perioperative outcomes and learning curve of single-direction UVATS RUL lobectomy assisted with 3D-CTBA.

Methods: The patients who underwent single-direction intercostal UVATS anatomic RUL lobectomy after 3D-CTBA simulation by the same surgeon at Xuzhou Central Hospital between January 2017 and April 2019 were retrospectively reviewed (3D-CTBA group), and consisted of 99 males and 54 females, with a mean age of 61.6 years, with the variations of the RUL vein being assessed preoperatively. They were further divided into group A (30 cases), B (30 cases), C (30 cases), and D (63 cases), in accordance with the order of surgery. Meanwhile, the first 35 cases of single-direction UVATS RUL lobectomy by another experienced surgeon (after the learning curve of this procedure) who did not use 3D-CTBA was enrolled as a control group. The operation time, intraoperative blood loss, stations and numbers of harvested lymph nodes, the incidence of conversion to multiport VATS or thoracotomy, thoracic tube retention for drainage, complications defined under the Clavien-Dindo system, pain score, and postoperative hospital stay were analyzed. The previous surgical experience of the two surgeons was also evaluated.

Results: A significant difference was evident among the 5 groups in terms of age, smoking history, the proportion of neoadjuvant chemotherapy, and T staging of the tumors ($P<0.05$, respectively). As for the 3D-CTBA group, a total of 29 cases (19.0%) of anomalous RUL posterior segmental pulmonary vein (PV) (V^2) drainage were recorded, while the other 124 patients indicated the central type (V2a. Cent.). Of the uncommon RUL V^2, they could be further classified into 4 types [V2a. Post. (5/153, 3.3%), VX2a. Ant. (17/153, 11.1%), VXX2a. Ant. (3/153, 2.0%), and nonspecific complicated (4/153, 2.6%)]. Single-direction UVATS lobectomy was performed in every patient successfully. No perioperative mortality, major bleeding, conversion to thoracotomy, the addition of incisions, or 30-day unplanned readmission was recorded. One patient in group B reported an injury of a bronchial artery. All cases had an R0 resection. The operation time of group A (109.8±25.4 min) was significantly longer than that of group B (79.7±11.1 min), C (77.0±12.1 min), D (69.3±16.0 min), and the control (86.1±17.9 min, $P<0.001$ respectively). Moreover, the operation time of the patients in group B, C, and D was slightly shorter than the control, although without significance ($P>0.05$, respectively). Furthermore, the duration of chest tube drainage in group A (3.7±2.2 days) was noticeably longer than that in group B (3.0±0.9 days), C (2.7±1.6 days), D (2.6±0.8 days), and the control (2.7±1.6 days, P=0.004 among the groups). Similarly, postoperative hospital stay in group A (3.9±2.3 days) was noticeably longer than that in group B (3.0±1.0 days), C (2.8±1.8 days), D (2.6±0.8 days), and the control (2.8±1.8 days, P=0.002 among the groups). The 5 groups indicated comparable stations and numbers of the harvested lymph nodes, intraoperative blood loss, postoperative total chest drainage volume, incidence of complications, and pain scale on the 14^{th} day after surgery (P>0.05, respectively).

Conclusions: Preoperative 3D-CTBA digital anatomy facilitates the safe and fluent performance of single-direction UVATS anatomic right upper lobectomy, with a learning curve of 30 cases. High-quality trials for better evidence are called for to verify these findings.

Keywords: Uniportal video-assisted thoracoscopic surgery (UVATS); single-direction; digital anatomy; three-dimensional computed tomography bronchography and angiography (3D-CTBA)

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Introduction

A surgical approach should be safe, efficient, and easily learned by surgeons. It is estimated that competency in performing video-assisted thoracoscopic surgery (VATS) lobectomy could be achieved after 50 cases (1). The learning curve of uniportal VATS (UVATS) right upper lobe (RUL) lobectomy is steep, as it is considered to be the most complicated and challenging procedure due to the variation rate of the vessels. The accurate identification of RUL venous variations is helpful to anatomic resection. Previous lung anatomy is normally studied using chest X-rays and contrast-enhanced computed tomography (CT) images. Three-dimensional (3D) digital anatomy models could be used in postgraduate teaching and surgical planning (2). Several reports have described the variation and frequency of pulmonary artery (PA) and vein branches by 3D-CT bronchography and angiography (3D-CTBA) (3). The optimal anatomic approach depends on the variations of pulmonary vessels, which could be revealed using 3D-CTBA, leading to faster operation with diminished intraoperative blood loss, as compared with those without 3D-CT simulation (4). Anatomic digital models are also useful in training for inexperienced surgeons.

It is reported that variant types are more common on the right side (32.8%) than the left (2.6%), without variations in the left lower lobes (5). Briefly speaking, pulmonary vein (PV) branches are defined as (I) an anterior vein (V. Ant.) which originates from V1b and descends down the anterior side of the RUL bronchus, finally draining into the superior PV, and (II) central vein (V. Cent.) which originates from the V2a and descends through the center of the upper lobe, between B2 and B3, finally draining into the superior PV (5). In this study, we analyzed the drainage variations of RUL veins and investigated the learning curve of single-direction UVATS RUL lobectomy assisted with 3D-CTBA.

Methods

The patients who underwent anatomic resection of RUL by the same surgeon (Dr. Zhang) following preoperative 3D-CTBA simulation at Thoracic Department of Xuzhou Central Hospital between January 2017 and April 2019 were retrospectively reviewed.

The inclusion criteria were as follows: (I) the tumor was localized without distal metastasis confirmed by whole-body contrast-enhanced CT, brain magnetic resonance imaging, and bone emission CT; (II) patients were tumor stages I–III according to the 8^{th} AJCC/UICC tumor-node-metastasis (TNM) staging system for lung cancer (6); and (III) the American Society of Anesthesiologists score and indicators of cardio-pulmonary function such as left-ventricular ejaculation fraction, forced expiratory volume in one second, and maximal voluntary ventilation were appropriate for general anesthesia and lobectomy. Cases where the tumor or involved lymph node caused RUL atelectasis or compression of hilum structures were excluded. Segmentectomies, sleeve resections, and pneumonectomies were regularly performed by open procedure because the surgeons involved in this study lacked the experience of complex UVATS procedures. Furthermore, patients

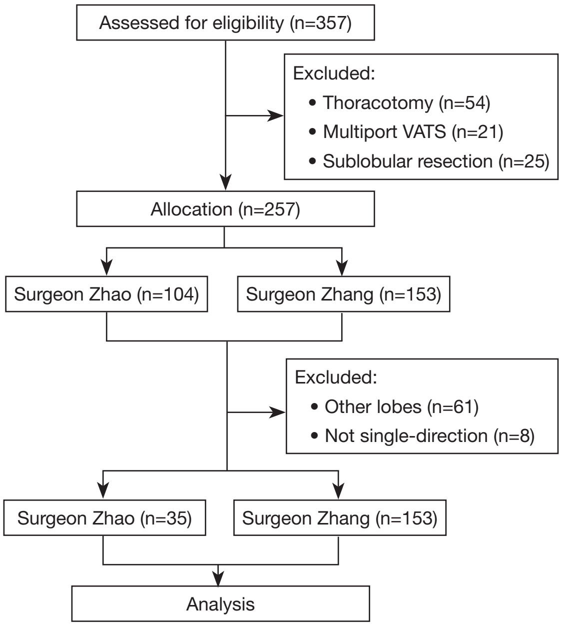

Figure 1 Flow chart of this retrospective study. VATS, video-assisted thoracoscopic surgery.

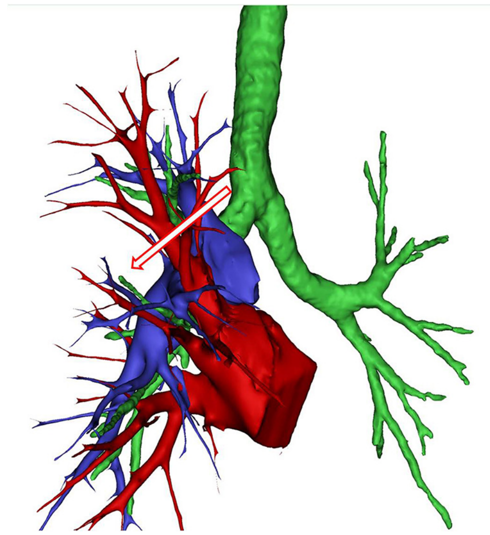

Figure 2 Preoperative single-direction resection simulation using 3D-CTBA digital anatomy. 3D-CTBA, three-dimensional computed tomography bronchography and angiography.

with previous thoracic operations or other cancer history, extended resections, and segmentectomy or wedge resection, were also excluded. The flow chart of this study is illustrated in *Figure 1*.

In addition, RUL lobectomies without 3D-CTBA performed by another surgeon (Dr. Tian Zhao) were enrolled as a control group. Surgeon Zhao had finished the learning curve of single-direction UVATS lobectomy in a high-volume center (Shanghai Pulmonary Hospital, Shanghai, China) after a year. The earlier surgical experience of the two surgeons was also evaluated to identify any difference in terms of the learning curve.

This study was approved by the Ethics Committee of Xuzhou Central Hospital (ethical approval number: XZXY-LJ-20160115-014). Informed consent was obtained from each involved patient. The data in this research were treated anonymously to maintain patient privacy.

Enhanced recovery protocol

Fast-track procedures for thoracic surgery were administered individually. Pulmonary rehabilitation was conducted regularly for 5–10 days. The clear fluid of maltodextrin solution was administered orally 6 h (400 mL) and 2 h (200 mL) before surgery. Additionally, multimodal analgesia using patient-controlled analgesia in combination with ultrasound-guided serratus anterior plane block was applied to improve pain relief after surgery. Early mobilization out of bed and direct oral feeding were started 6 h after the surgery. Moreover, prophylactic enoxaparin was started 48 h after the surgery for selected patients with Caprini score for risk assessment of venous thromboembolism ≥5.

Preoperative surgical simulation

As for the surgeon in the 3D-CTBA group, contrast-enhanced thin-slice CT sections (1.0 mm thickness) were collected, and then the 3D-CTBA of anatomic variations in RUL was recorded by the free software, OsiriX. The PAs, veins, and bronchi were reconstructed and marked out with different colors, and preoperative simulation of anatomical lobectomy was performed individually based on the digital models (*Figure 2*) to diminish unplanned injury of abnormal vessels. Briefly, we recorded and classified RUL vein drainage into common and uncommon types.

Procedures of thoracoscopic lobectomy

All surgeons used a similar operative technique. Each patient was placed at a left-side lateral decubitus position. General anesthesia with double-lumen intubation and one-

Table 1 Baseline characteristics of the patients before therapy

Characteristics	Control group (n=35)	3D-CTBA group (n=153)				P value
		A (n=30)	B (n=30)	C (n=30)	D (n=63)	
Age, years	65.2±8.3	59.9±11.0	64.0±7.1	63.4±9.4	60.3±9.1	0.042
Female/male, n	12/23	16/14	10/20	12/18	16/47	0.122
Body mass index, kg/m^2	23.8±2.5	24.2±2.8	24.2±3.6	23.9±2.2	24.0±3.2	0.986
Smoking history (never/previous), n	7/28	10/20	15/15	19/11	18/45	0.002
Neoadjuvant chemotherapy, n	2	0	6	1	10	0.019
Clinical T1–2/T3, n	21/14	5/25	21/9	9/21	20/43	<0.001

Continuous data was shown as mean ± SD, and the categorical data were shown as number (%). SD, standard deviation; 3D-CTBA, three-dimensional computed tomography bronchography and angiography.

lung ventilation was administered. The surgical incision was made without rib spreading, and soft tissue retractors were used. Single-direction UVATS was performed according to the preoperative resection simulation of pulmonary vessels, with an incision of 3.5–4.5 cm as required by the expected size of the lobe in the 3rd–5th intercostal space along the anterior axillary line. Pulmonary vessels, bronchi, and incomplete fissures were divided sequentially with endoscopic staplers. Furthermore, the suction-assisted electrocautery sharp dissection technique was applied during the procedure (7). The RUL resection sequence was as follows: anterior apical branch of the PA, right upper bronchus, posterior ascending branch of the PA, PV and fissure, and the removal of the specimen using a surgical glove. The mediastinal lymph nodes were harvested after that. A 26 French chest tube was inserted for postoperative drainage. Finally, ultrasound-guided serratus anterior block was performed at the level of the 3rd–5th ribs, using 0.2% bupivacaine at a dosage of 0.3 mL per kilogram of body weight for postoperative pain relief (8).

The operation time, intraoperative blood loss, stations and numbers of harvested lymph nodes, the incidence of conversion to multiport VATS or thoracotomy, thoracic tube retention for drainage, complications defined under the Clavien-Dindo system, pain score, and postoperative hospital stay were analyzed. The patients in this cohort were followed up regularly using smartphone online, and unplanned readmission such as late-onset chylothorax or fistula was recorded.

Statistics

Continuous data were presented as means ± standard deviations (SDs). Statistical analysis was performed using Statistical Package for the Social Sciences software version 23.0 for Windows (SPSS Inc., Chicago, IL, USA). Student's *t*-test or Wilcoxon test was used to compare quantitative continuous data. Chi-square or Fisher's exact test was used when required for dichotomous or categorical variables. A P value of less than 0.05 was considered statistically significant.

Results

Baseline demographics of the patients and the surgeons

For the 3D-CTBA group, the data of 153 patients who underwent UVATS RUL lobectomy was collected, including 99 man and 54 women, with a mean age of 61.6 years. They were further divided into group A (30 cases), B (30 cases), C (30 cases), and D (63 cases), in accordance with the order of surgery. Meanwhile, the first 35 cases of single-direction UVATS right upper lobectomy by the experienced surgeon Zhao who did not use 3D-CTBA were enrolled as a control group (*Table 1*).

The significant difference was indicated among the 5 groups in terms of age, smoking history, neoadjuvant chemotherapy, and T staging of the tumors (P<0.05, respectively). As shown in *Table 2*, the previous experience of thoracotomy, multiport VATS, and UVATS anatomic, as well as the surgical volume, in the 5 years before this study of surgeon Zhao was better than surgeon Zhang. Furthermore, Zhao had finished the learning curve of single-direction UVATS lobectomy in a high-volume center (Shanghai Pulmonary Hospital, Shanghai, China). Meanwhile, during the study period, UVATS lobectomy

Table 2 General information of the two surgeons

Features	Surgeon Zhao (control group)	Surgeon Zhang (3D-CTBA group)
Previous experience as an independent surgeon, years	15	11
Training in high-volume center*, months		
Single-direction UVATS	6	NA
Single-direction multiport VATS	6	3
Surgery volume 5 years before the study		
Thoracotomy, n/year	10–20	10–20
Multiport VATS, n/year	40–60	10–30
UVATS, n/year	50–70	30–60
Other VATS lobectomy during the study period	69	0

*, Shanghai Pulmonary Hospital, Shanghai, China. NA, not available; 3D-CTBA, three-dimensional computed tomography bronchography and angiography; UVATS, uniportal video-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery.

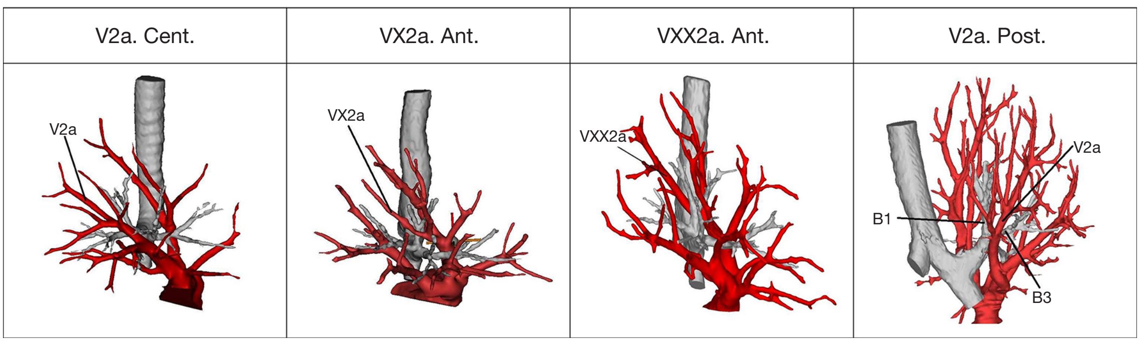

Figure 3 Patterns of branches from the right upper pulmonary veins of the patients in the 3D-CTBA group. 3D-CTBA, three-dimensional computed tomography bronchography and angiography.

other than RUL was performed by surgeon Zhao, while surgeon Zhang performed the RUL surgery for competency training.

Variations of the RUL veins

The digital models of the 153 patients in 3D-CTBA group revealed that there were 29 cases (19.0%) showing anomalous posterior segmental PV of RUL (V2) drainage, while the other 124 patients (81.0%) indicated the central type (V2a. Cent.). Of the uncommon RUL V2, they could be further classified into 4 types [V2a. Post. (5/153, 3.3%), VX2a. Ant. (17/153, 11.1%), VXX2a. Ant. (3/153, 2.0%), and nonspecific complicated (4/153, 2.6%)], as depicted in *Figure 3*.

Operative features

The patients in this cohort underwent single-direction UVATS RUL lobectomy with lymph node sampling or dissection successfully. No perioperative mortality, conversion to thoracotomy, the addition of incisions, major bleeding, lung infarction, or 30-day unplanned readmission was observed in this cohort, except for one case in group B reporting an injury of the bronchial artery which was controlled quickly.

As shown in *Table 3*, the operation time of group A (109.8±25.4 min) was significantly longer than that of group B (79.7±11.1 min), C (77.0±12.1 min), D (69.3±16.0 min), and the control (86.1±17.9 min, P<0.001 respectively). Moreover, the operation time of the patients in group B, C, and D was slightly shorter than the control, without

Table 3 Perioperative parameters of the patients

Variables	Control group (n=35)	3D-CTBA group (n=153)				P value
		A (n=30)	B (n=30)	C (n=30)	D (n=63)	
Lymph node harvested						
Dissection/sampling, n	25/10	29/1	25/5	26/4	53/10	0.092
Stations	4.4±1.4	3.9±1.5	4.3±1.3	4.9±1.3	4.3±1.3	0.059
Numbers	7.7±2.8	7.3±2.6	7.5±3.6	8.1±2.2	7.9±3.1	0.797
Operation time, min	86.1±17.9*	109.8±25.4	79.7±11.1*	77.0±12.1*	69.3±16.0*,#	<0.001
Blood loss, mL	85.3±28.2	78.7±28.1	82.7±28.4	74.8±14.6	76.1±14.7	0.237
Chest tube drainage						
Duration, days	2.7±1.6*	3.7±2.2	3.0±0.9*	2.7±1.6*	2.6±0.8*	0.004
Total volume, mL	334.3±165.3	406.7±159.6	333.3±171.4	341.7±160.3	384.9±166.5	0.224
Postoperative complications, n	5	3	6	3	12	0.673
Chylothorax, n	0	1	2	1	3	
Atelectasis, n	0	0	1	0	2	
Air leak >7 days, n	1	0	0	1	1	
Bronchopleural fistula, n	1	0	0	0	0	
Arrhythmia, n	3	2	3	1	6	
Postoperative hospital stay, days	2.8±1.8*	3.9±2.3	3.0±1.0*	2.8±1.8*	2.6±0.8*	0.002
Pain VAS on 14th POD	2.9±0.8	2.8±0.7	2.9±0.7	2.5±0.8	2.8±0.7	0.164

Continuous data was shown as mean ± SD, and the categorical data were shown as number (%). *, P<0.01, as compared with group A; #, P<0.05, as compared with group B. SD, standard deviation; 3D-CTBA, three-dimensional computed tomography bronchography and angiography; VAS, visual analog scale; POD, postoperative day.

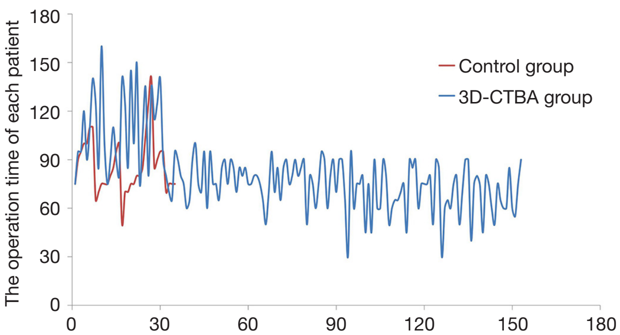

Figure 4 The operation time during the learning curve of single-direction UVATS right upper lobectomy. UVATS, uniportal video-assisted thoracoscopic surgery; 3D-CTBA, three-dimensional computed tomography bronchography and angiography.

significance (P>0.05, respectively).

The total incidence rate of complications in the 3D-CTBA group was 15.7% (n=24), without bronchopleural fistula, empyema, or right middle pulmonary torsion, while the complication rate in the control group was 14.3% (n=5), which were controlled efficiently. All cases had an R0 complete cancer resection on histology.

Furthermore, the duration of chest tube drainage in group A (3.7±2.2 days) was noticeably longer than that in group B (3.0±0.9 days), C (2.7±1.6 days), D (2.6±0.8 days), and the control (2.7±1.6 days, P=0.004 among the groups). Similarly, postoperative hospital stay in group A (3.9±2.3 days) was noticeably longer than that in group B (3.0±1.0 days), C (2.8±1.8 days), D (2.6±0.8 days), and the control (2.8±1.8 days, P=0.002 among the groups). The 5 groups indicated comparable stations and numbers of the harvested

Table 4 The reports regarding variations of pulmonary veins and arteries

First author	No. of cases	PVs variations, n (%)	PAs variations, n (%)
Shiina N (3)	189	15 (8.0) in RUL, 29 (15.3) in RML, 18 (9.5) in RLL, 5 (2.6) in LUL	NA
Hagiwara M (4)	124	5 (4.0)	15 (12.1)
Tekbas G (18)	783	18 (2.3) in right, and 8 (1.0) in left side	NA
Fourdrain A (21)	100	25 (25.0) in right, and 11 (11.0) in left side	NA
Yamada S (22)	86	5 (5.8)	NA
Amore D (23)	346	25 (7.2) in total	NA
Akiba T (24)	121 of left, 126 of right lobes	2 (1.7) in left, and 18 (14.3) in right side	NA
Altinkaynak D (25)	550	311 (56.5) in total	NA
Shimizu K (5)	338 of RUL	65 (19.0) in RUL	NA
Nagashima T (26)	263 of RUL	23 (8.7) in RUL	NA
Nagashima T (27)	270 of RML and RLL	NA	About 25.2% in RLL
Okumura Y (28)	1,116 of RML and RLL	67 (6.0) in right side, with 20 (1.8) in RML, 46 (4.1) in RLL, and 1 (0.1) in common	

PVs, pulmonary veins; PAs, pulmonary arteries, RUL, right upper lobe; RML, right middle lobe; RLL, right lower lobe; LUL, left upper lobe; NA, not available.

lymph nodes, intraoperative blood loss, postoperative total chest drainage volume, incidence of complications, and pain scale on the 14th day after surgery (P>0.05, respectively).

The operation time during the learning curve of single-direction UVATS lobectomy with and without preoperative simulation is shown in *Figure 4*. The cases in 3D-CTBA group showed a tendency of decreased operation time, as compared with the control. Although the surgeon in the control group had finished the learning curve of single-direction UVATS lobectomy in a high-volume center before this study, the operation time of each RUL lobectomy remained unstable. It can theoretically be ascribed to a lack of a preoperative resection plan, as the surgeon should always be cautious when manipulating vessels to diminish major bleeding, which may hamper the fluency of the UVATS procedure. Based on these findings, preoperative 3D-CTBA facilitates single-direction UVATS lobectomy with a learning curve of 30 cases.

The postoperative course of the patients in this cohort was largely uneventful, and they were discharged after the removal of chest tubes. During the follow-up, they reported satisfactory quality of life and tolerable postoperative pain.

Discussion

VATS is the preferred procedure as compared with open surgery (9). Meanwhile, the predictive factors for vascular injuries and conversion during VATS partly depend on the surgeons' experience (10). With continued experience and optimized technique, VATS lobectomy can be performed in most of the clinical stage II and IIIA non-small cell lung cancer (NSCLC) cases without compromising the oncologic efficacy including disease-free survival and overall survival of locally advanced NSCLC patients as compared with thoracotomy (11). However, a learning curve defining attainment and maintenance of proficiency in VATS lobectomy is yet to be elucidated. Most high-volume centers have demonstrated proficiency after 50 cases, while maintenance of proficiency is not ensured (12). A consensus report from the UVATS Interest Group of the European Society of Thoracic Surgeons shows that, 50 cases are required to overcome the learning curve for training in UVATS lobectomy (13), and 40 cases should be performed annually to maintain uniportal operative skills, although a detailed guideline is lacking because of the heterogeneity of different surgeons. Moreover, intensive training of young surgeons at high-volume centers may improve VATS proficiency in a short period, and provide a time-efficient modality for thoracic surgical training (14). Our preliminary study shows that the competency of single-direction UVATS RUL lobectomy assisted with 3D-CTBA could be reached after 30 cases of practice. Accordingly, there are several issues that need to be further elucidated.

First, competency in UVATS lobectomy can be acquired safely with adequate training in selected cases, although it will be achieved faster in surgeons with the earlier competency in multiport VATS lobectomy (1). However, previous surgical training has a minimal impact on intraoperative and postoperative outcomes, except conversion rate (15). Similarly, one review shows that surgeons with limited experience in open lobectomy can achieve good outcomes in VATS lobectomy comparable with their experienced seniors (16). It is noteworthy that the outcomes for lung cancer surgery are currently measured by perioperative morbidity and mortality, but the oncologic efficacy is reflected by long-term survival. Therefore, lung cancer surgery performance metrics should assess the safety of surgery and long-term survival (17).

Second, intraoperative misunderstandings of pulmonary venous anatomy can lead to serious complications such as major bleeding and delayed lung infarction or even necrosis. Furthermore, PVs play a key role as the triggering focus of the electrical activity in atrial fibrillation (18,19). However, CT scanning is still the mainstay of conventional preoperative imaging. A study evaluated the ability of different imaging techniques, such as CT scanning, maximal intensity projection imaging, 3D reconstruction, and 3D printing, to define the anatomy of hilar structures before anatomic lung resection. 3D printing in the planning of thoracic surgery may suggest a benefit over normal CT images and digital reconstruction (20). The 3D-CTBA models for precise simulation allow us to fully comprehend the vascular anatomy within a few minutes before UVATS, which is essential to avoid injury and congestion of residual lungs. As for this cohort, 29 cases (19.0%) of anomalous RUL posterior segmental PV (V^2) have been revealed by 3D-CTBA. Available reports about the variations in the PV for VATS are somewhat limited, as shown in *Table 4*. Anomalous drainage of right V^2 occurs in 7.5% of cases (5). The V^2 might drain into V^6 (29), and inferior PV (30). Fourdrain *et al*. reported a right-sided pulmonary venous variation of 36% in 100 patients, and the most frequent variation is three separate PVs (16%) (21). Yamada *et al*. recorded 5.8% patients (5/86) with anomalous PV and one of the variations was right-sided V^2 draining directly into the left atrium (22).

Third, there is a learning curve of the UVATS procedure to overcome before becoming proficient, which includes operative time, blood loss, number of dissected mediastinal lymph nodes and nodal stations, thoracotomy conversion rate, surgery-related complications, duration of chest drainage, postoperative hospital stay, disease-free survival, and long-term survival. However, VATS lobectomy has a vaguely defined learning curve for competency and proficiency. Li *et al*. reported that 100–200 cases are required to achieve efficiency, while consistency requires even more cases (31). Both UVATS lobectomy and sleeve resections for locally advanced lung tumors have a steep learning curve after proper training (32,33). Accurate 3D-CTBA anatomy models for resection simulation might also facilitate UVATS approach for bronchial, bronchovesicular, tracheal, and carinal reconstruction. The presented study indicates that the learning curve of single-direction UVATS lobectomy using 3D-CTBA for selected patients without complex manipulation is 30 cases. As compared with another experienced surgeon who did not use 3D-CTBA in this cohort, the less experienced surgeon had a tendency of shorter operation time when performing single-direction UVATS assisted with preoperative resection simulation using 3D-CTBA digital anatomic models.

Moreover, the single-direction procedure could shorten operation time to the utmost and, therefore, diminish the stress injury to the patients during surgery and anesthesia. Single-direction thoracoscopic lobectomy is characterized by incisions convenient for the placement of instruments, and the lobectomy proceeded progressively from superficial to deep structures of the thorax. It overcomes the difficulty in manipulation of incomplete pulmonary fissures and potentially extends the indications of UVATS lobectomy (34). Simplified synchronous disconnection of PAs and PVs is an effective therapeutic procedure for RUL carcinoma (35). It has been reported that non-grasping *en bloc* mediastinal lymph node dissection is a superior approach to remove lymph nodes, which could lead to better survival as compared with traditional grasping lymph node dissection (36).

On the other hand, it is of vital importance to reduce the risk of tumor dissemination during surgery, and a multicenter, randomized clinical trial indicates that ligating effluent veins first during pulmonary resection may reduce the dissemination of the tumor cells, and improve survival outcomes in NSCLC patients (37).

Furthermore, one of the major concerns of the learning curve is whether lymph node sampling or dissection is necessary and can be achieved sufficiently using UVATS. The number of sampled lymph nodes, one of the surrogates for quality and accurate staging, is actually influenced by many factors. The number of sampled lymph nodes has an effect on survival of NSCLC patients (sampling <10 lymph nodes versus ≥10), but the influence is dependent on staging, moreover, the optimal number of harvested lymph nodes remains unclear (38). A meta-analysis suggests that mediastinal lymph node sampling can get similar outcomes as lymphadenectomy in stage I NSCLC regarding 1-year survival, but a radical dissection of the lymph nodes is superior to sampling for 3- and 5-year survival (39). Also, for patients with tumors larger than 3 cm or N1 disease, mediastinal lymph node dissection is recommended (40). However, no consensus exists regarding the minimal or optimal number of lymph nodes to resect at curative lung cancer surgery. Research using a large database revealed that ≥16 examined lymph nodes may lead to improved survival and reduced disparities in care (41).

Similarly, another study using large databases shows that a greater number of examined lymph nodes are associated with more-accurate node staging and better long-term survival of resected NSCLC, and at least 16 lymph nodes are recommended for evaluating the quality of lymph node examination and prognostic stratification (42). As for our study, the harvested number of lymph nodes is not enough according to the number of dissected stations, and there are many reasons for this drawback. The lymph nodes were sampled or dissected according to the T staging. Also, the number of lymph nodes in the sampled or dissected soft tissues in small size might be omitted as normal fat tissue in our hospital.

This cohort study has many limitations, including but not limited to its retrospective nature and small sample size. The 3D-CTBA models which originated from CT images when the pulmonary lobes were inflated may deviate from real findings. The availability of large datasets and new deep-learning algorithms has ushered in a new era of artificial intelligence (AI) in medicine and radiology (43). AI is considered to be helpful in efficiency improvement of imaging interpretation (44). Radiographic assessment of disease most commonly relies on visual evaluations, while AI provides a qualitative interpretation of cancer imaging (45). Based on these reports, a large-scale 3D-CTBA digital anatomy database for patients undergoing accurate lobectomy is necessary for big data analysis in the era of precision medicine and AI.

Conclusions

Preoperative 3D-CTBA facilitates the safe and fluent performance of single-direction UVATS anatomic right upper lobectomy, with a learning curve of 30 cases. Well-designed, high-quality studies for better evidence are called for to verify these findings.

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Footnote

Conflicts of Interest: 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. Written informed consent was obtained from the patients involved in this study for publication of any accompanying images. This study was approved by the Ethics Committee of Xuzhou Central Hospital (Ethical approval number: XZXY-LJ-20160115-014). The data in this research were treated anonymously to maintain patient privacy.

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