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Multi-center experience in an optimized right upper lobectomy surgical procedure in China

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Abstract

Background: This multi-center study was aimed at retrospectively evaluating the feasibility, safety, clinical outcomes, and surgical learning curve of an optimized procedure for right upper lobectomy (RUL), which is challenging because of the anatomical structures and features of this lobe.

Methods: This study included 45 RUL cases of robot-assisted thoracoscopy (RATS) in a pilot cohort and 187 RUL cases of video-assisted thoracoscopy (VATS) in three cohorts. A total of 121 and 111 patients underwent traditional and optimized RUL, respectively. The optimized surgical procedure was performed to consecutively transect the superior arterial trunk and bronchus, and finally disconnect the pulmonary vein and posterior ascending artery with interlobar fissures. Clinical and radiological data were reviewed retrospectively.

Results: Optimized RUL can be performed successfully by RATS or VATS. The optimized procedure yielded better clinical outcomes than the traditional procedure, including shorter operation times, less blood loss, fewer complications, shorter hospital times, lower costs, and a lower likelihood of postoperative intermedius bronchial kinking. Additionally, for calcified interlobar lymph nodes, the optimized VATS group was less likely to be converted to thoracotomy than the traditional group. The skills required to perform optimized VATS RUL can be gained by surgeons after 12 to 15 cases. The two RUL procedures in the pilot cohort showed similar disease-free survival.

Conclusions: The optimized RUL was safe, economical, and feasible, with a short learning curve and satisfactory disease-free survival.

KEYWORDS

lung cancer, right upper lobectomy, surgical technology

Long-Yong Mei, Wen-Zhou Liu, and Yu-Chi Xiu contributed equally.

INTRODUCTION

Minimally invasive lobectomy including video or robot-assisted thoracoscopic (VATS or RATS) is a standard treatment for lung cancer (LC). Older patients with early stage

LC who undergo lobectomy have better overall survival than those who undergo stereotactic radiotherapy.[1] Intriguingly, minimally invasive lobectomy in the early period of 2002 to 2008 did not yield a better overall survival than thoracotomy (hazard ratio [HR], 0.97; 95% confidence interval [CI], 0.87–1.09; $p = 0.62$).[2] However, with improvements in procedures and skills, in 2009 to 2013, minimally invasive lobectomy gradually yielded significantly better overall survival (HR, 0.84; 95% CI, 0.75–0.93; $p < 0.001$) than thoracotomy.[2]

LC often affects the right upper lobe,[3] and therefore right upper lobectomy (RUL) accounts for 28.3%[4] to 37.3%[5] of all lobectomies. However, RUL is risky because of the anatomical structures and features of the lobe, particularly in cases of calcified interlobar lymph nodes, which are associated with higher composite mortality and morbidity, intraoperative transfusion rates and postoperative lengths of stay than the other four lobectomies.[6] In this multi-center study, the feasibility, safety, clinical outcomes, and learning curve for optimized RUL were retrospectively analyzed.

PATIENTS AND METHODS

Patients

Demographic and clinical information was retrieved for RUL cases including those in the pilot cohort receiving RATS at Daping Hospital (January 2017 to December 2018) and three VATS cohorts (January 2015 to October 2021) at Daping Hospital (cohort A), the Second Affiliated Hospital of Guangxi Medical University (cohort B), and General Hospital of Northern Theater Command (cohort C). In each cohort, the operations were performed by one single surgical team lead by a skilled physician with at least 10 years of experience in RUL.

This retrospective study was approved by the ethics committees of the abovementioned institutions with waivers of informed consent and was conducted in accordance with the Declaration of Helsinki and the Ethical Guidelines for Medical and Health Research Involving Human Subjects.

The inclusion criteria were as follows: radiologically suspected primary LC in the right upper lobe, and resectable lesions without definite distant metastasis or any surgical contraindications in adult patients.

The exclusion criteria were as follows: (i) sub-lobectomy recommended as an alternative; (ii) pleural dissemination, local invasion, or other unresectable situations intraoperatively identified; (iii) prior neoadjuvant chemo- and/or radiotherapy; and (iv) history of operation or trauma of the right thoracic cavity.

Position and incisions

For RATS, our optimized "3-4-6-8" four-port procedure was performed with a Da Vinci Si Robot Surgical System (Intuitive Surgical) according to a previously published method[7] as follows: the assistant port was located at the fourth intercostal space ~4 cm outward from the midclavicular line; the 1-cm camera port was inserted at the sixth intercostal space in the posterior axillary line; and the 0.5-cm da Vinci ports for instrument arms were placed at the third intercostal space in the anterior axillary line, and the eighth or ninth intercostal space in the posterior axillary line. The patient cart entered from the back of the patient's head and shoulders at 75° with respect to the longitudinal line. The assistant was located at the ventral side of the patient and was used to install the endoscope and instruments for linkage.

In VATS, the patients underwent the operation in the left lateral position after successful general anesthesia with mechanical ventilation via a double lumen endotracheal catheter. The camera port was located at the 7th intercostal space in the middle axillary line, whereas the utility incision was located at the 4th intercostal space in the anterior axillary line for VATS at all three institutions. The patient position and port sites were consistent for either traditional or optimized procedures.

Traditional surgical procedures

The pleural cavity and the lesion were explored via RATS or VATS. The procedures performed in all three institutions included the steps (Figure 1) as follows: (i) the inferior pulmonary ligament was divided, and the posterior mediastinal pleura were dissected. The pulmonary parenchyma at the intersection of the oblique and horizontal fissures was divided by sharp or blunt dissection to expose the interlobar artery trunk. (ii) Thereafter, a posterior "tunnel" above the interlobar artery trunk was established under the posterior oblique fissure and divided through stapling or cauterization. (iii) After dissection of the anterior mediastinal pleura, an anterior "tunnel" under the horizontal fissure was established from the interval between the upper-middle pulmonary veins to the branch of the middle pulmonary artery, and divided with a stapler. (iv) The ascending A2 artery, superior pulmonary vein, and superior arterial trunk were carefully separated sequentially and divided with an endovascular stapler. (v) The right upper lobe bronchus was transected and stapled (Ethicon Endo-Surgery LLC, PSE45A, ECR45G). Finally, systematic dissection or sampling of the hilar and mediastinal lymph nodes was performed.

Optimized surgical procedure

The optimized surgical procedures for RATS or VATS RUL were similar. The procedure is shown as in Figure 2: (i) the covering pleura were disconnected to expose the superior arterial trunk, and the 10th lymph node was removed. (ii) Thereafter, the superior arterial trunk was transected

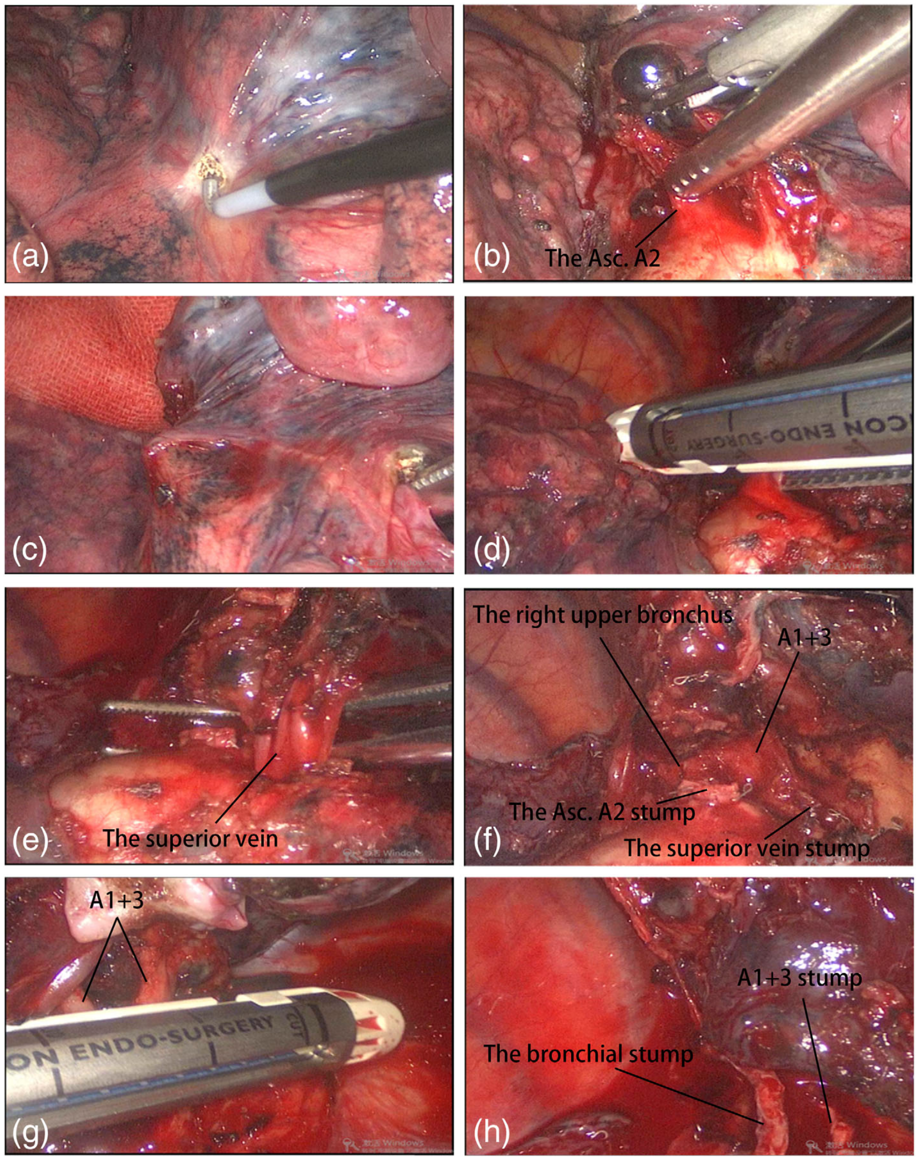

FIGURE 1 The main steps of traditional VATS RUL. (a) Division of the intersection of oblique and horizontal fissures. (b) Dissection of the 11th lymph nodes and oblique fissure by electrocautery. (c) Establishment of the "tunnel" above the interlobar artery trunk for division with an endovascular stapler. (d) Transection of the ascending A2 artery with an endovascular stapler. (e) Dissection of the right superior vein. (f), (g) Dissection and transection of the superior arterial trunk. (h) Transection of the bronchus. VATS, video-assisted thoracoscopy; RUL, right upper lobectomy

with a stapler. (iii) The inferior pulmonary ligament and posterior mediastinal pleura were disconnected, and the 11th and 7th lymph nodes were removed. (iv) Thereafter, the upper lobe was pulled forward to expose, isolate, and transect the upper lobe bronchus with a stapler. The 10th lymph node beneath the transected bronchus was removed. (v) From anterior to posterior, the stapling device was used to transect the superior pulmonary vein and the ascending A2 artery along with fissures (cohorts A and B), or the isolation and transection of A2 artery was prioritized (cohort C) on the basis of the following: (i) in the case of a recognizable vascular sheath or boundary, the ascending A2 artery was completely and safely disconnected by a staple cartridge; and (ii) if the ascending A2 artery was unrecognizable because of the thick parenchyma, the interlobar fissure was separated forward in small steps, with gentle traction to the upper lobe and preparation for the next clipping by the staple cartridge. An ECR45W or ECR45B staple cartridge was used to disconnect the pulmonary parenchyma, whereas an ECR45D or ECR45G staple cartridge was used for vessels along with the pulmonary parenchyma. Finally, systematic dissection or sampling of hilar and mediastinal lymph nodes was performed.

Evaluation of bronchial kinking

The available chest computed tomography (CT) data 3 to 6 months after surgery were reviewed carefully by the attending surgeon to evaluate intermediate bronchial kinking, which was radiologically defined as a protrusion arising from the posterior wall of the intermedius bronchus. A straight posterior wall of the intermediate bronchus was considered to have no intermediate bronchial kinking.

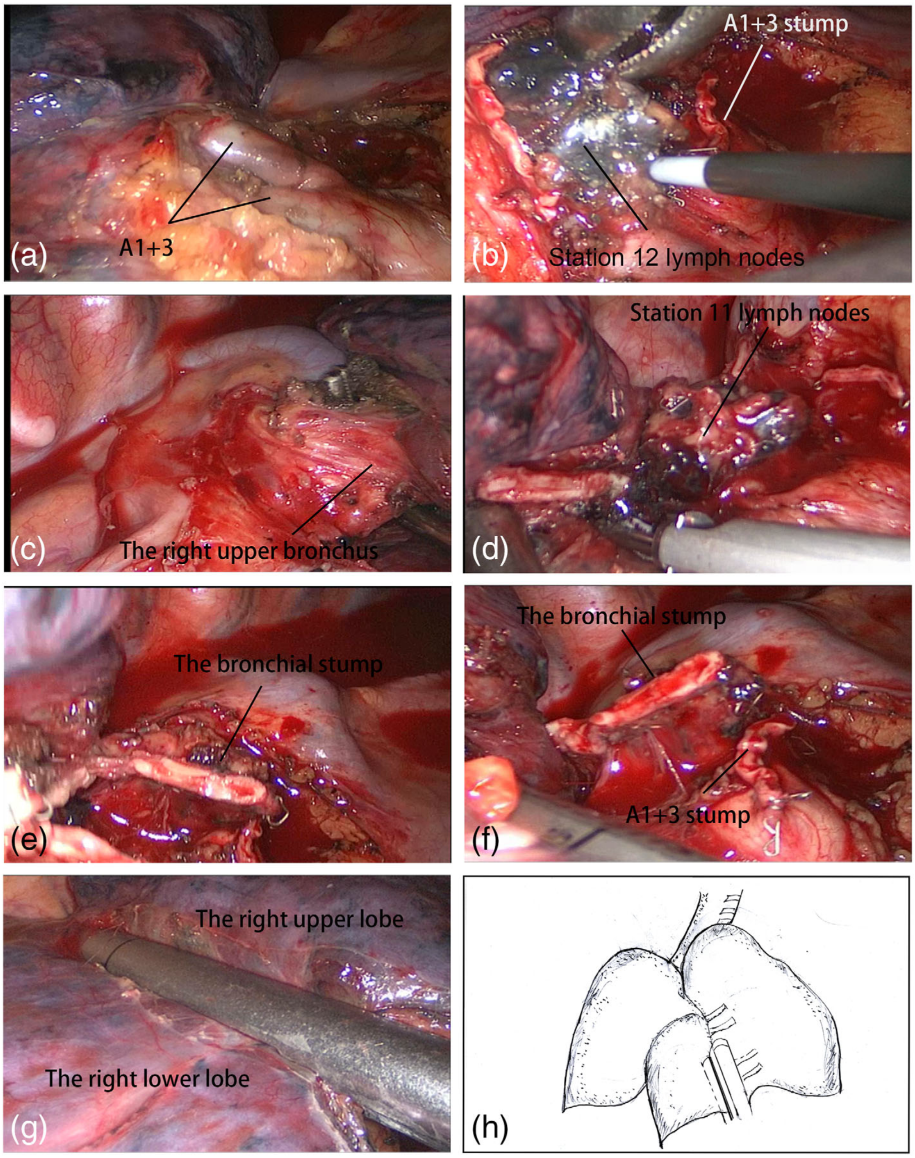

FIGURE 2 The main steps of optimized VATS RUL. (a) Dissection of the superior arterial trunk. (b) Dissection of the 12th lymph nodes. (c), (d) Dissection and transection of the bronchus. (e)–(g) Transection of fissures with the superior vein and the ascending A2 artery simultaneously. (h) Schematic diagram of optimized VATS RUL. VATS, video-assisted thoracoscopy; RUL, right upper lobectomy

Survival analyses

Disease-free survival (in months) was defined as the survival time from operation to locoregional recurrence or metastasis, and confirmed radiographically or pathologically. The long-term follow-up through outpatient visits and by telephone, involving chest CT and imaging examination of other organs if necessary, and survival analysis in the pilot cohort were performed until March 2022. Survival analysis could not be conducted in the other cohorts because of the relatively short postoperative period.

Evaluation of the learning curve for the procedure

The cumulative summation (CUSUM) method was used to precisely investigate the learning curve for performing the procedure. The deviation was determined by calculation of the sequential difference between the average value and the individual data. The patients in the optimized group in each cohort were sequentially numbered according to surgery date, and the CUSUM value was calculated according to operation time as follows:

$$\mathrm{CUSUM} = \sum_{i=1}^{n} (\mathrm{X}i - \mu),$$

where Xi represents each case's operation time, and μ equals the average operation time.

Statistical analysis

Statistical analysis was performed in SPSS statistical software (SPSS version 26). Continuous data, described as mean ± standard deviation (SD), were compared with Student's *t*-test

TABLE 1 Basic characteristics of patients enrolled in the two groups

Characteristic	Pilot			A			B			C		
	Traditional, $n = 16$	**Optimized, $n = 29$**	***p***	**Traditional, $n = 37$**	**Optimized, $n = 35$**	***p***	**Traditional, $n = 44$**	**Optimized, $n = 20$**	***p***	**Traditional, $n = 24$**	**Optimized, $n = 27$**	***p***
Sex			0.660			**0.002**			0.227			0.488
Male	10	20		19	9		29	10		13	12	
Female	6	9		18	29		15	10		11	15	
Age (yr)	59.9 ± 9.2	59.3 ± 7.4	0.818	54.1 ± 9.5	58.2 ± 10.7	0.086	61.1 ± 9.8	60.8 ± 11.5	0.909	61.4 ± 6.8	60.4 ± 8.6	0.658
Smoking history			0.175			**0.001**			0.802			0.524
Yes	6	17		16	3		14	7		11	10	
No	10	12		21	32		30	13		13	17	
FEV1 (L)	2.38 ± 0.72	2.41 ± 0.66	0.899	2.29 ± 0.65	2.11 ± 0.58	0.202	1.99 ± 0.19	2.15 ± 0.19	**0.004**	2.36 ± 0.54	2.42 ± 0.68	0.734
Tumor size (cm)	2.48 ± 1.44	2.32 ± 0.99	0.654	2.20 ± 0.95	1.70 ± 0.81	**0.020**	2.47 ± 1.14	3.35 ± 2.11	**0.034**	2.06 ± 0.92	2.66 ± 1.23	0.060
pTNM stage			0.779			0.609[a]			0.802			>0.999[a]
Stage 0 and I	14	23		36	33		30	13		20	23	
Stage II and III	2	6		1	2		14	7		4	4	

Note: The significance of bold in all Tables was the *p* value less than 0.05.

Abbreviations: FEV1, forced expiratory volume in 1 second; pTNM, pathological tumor, nodes, and metastasis.

[a]Fisher's exact test.

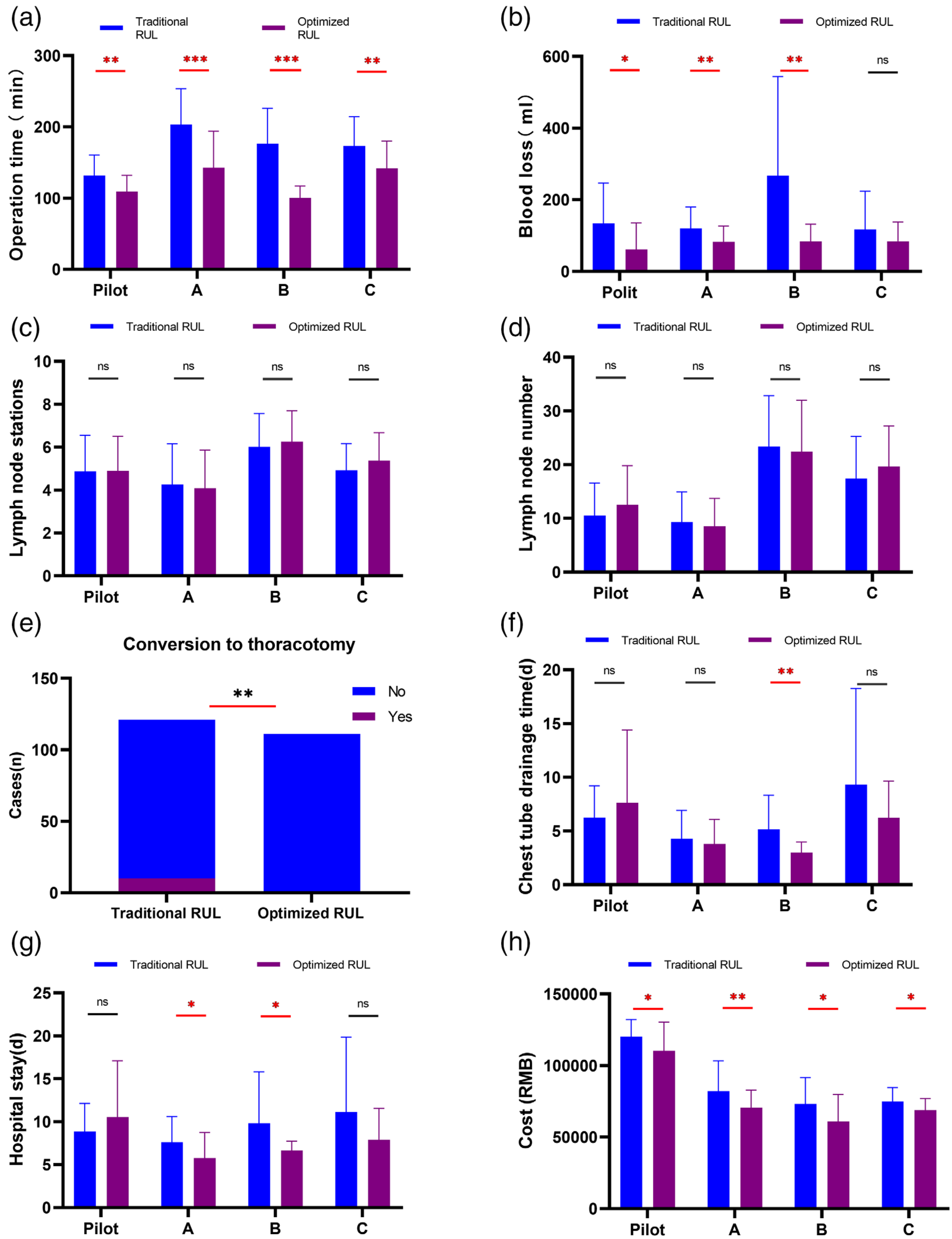

FIGURE 3 Perioperative outcomes between the traditional and optimized groups in the four cohorts. (a)–(e) Intraoperative variables including operation time, blood loss, resected lymph node number, lymph node stations, and the incidence of conversion to thoracotomy. (f)–(h) Postoperative outcomes including chest tube drainage time, hospital stay, and cost of hospitalization. $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$

or one-way analysis of variance with the Least Significance Difference (LSD) method for multiple comparisons. Categorical data, described as ratios, were compared with Pearson's χ^2 or Fisher's exact test. Disease-free survival was estimated with the Kaplan–Meier method, and p-values were calculated with the log-rank test. Cox proportional hazards regression analysis was used to examine the effects of factors on disease-free survival. The statistical significance was set at $p < 0.05$.

TABLE 2 Postoperative complications or outcomes.

Complications	Pilot			A			B			C		
	Traditional, $n = 16$	**Optimized, $n = 29$**	p	**Traditional, $n = 37$**	**Optimized, $n = 35$**	p	**Traditional, $n = 44$**	**Optimized, $n = 20$**	p	**Traditional, $n = 24$**	**Optimized, $n = 27$**	p
PAL	3	1	0.121[a]	3	5	0.473[a]	4	0	0.300[a]	2	2	>0.999[a]
DVT	–	–	–	1	1	>0.999[a]	–	–	–	–	–	–
Pneumothorax	1	0	0.356[a]	2	1	>0.999[a]	1	0	>0.99[a]	–	–	–
Aerodermectasia	–	–	–	–	–	–	–	–	–	3	2	0.656[a]
Hemorrhage	–	–	–	0	1	0.486[c]	–	–	–	–	–	–
Chylothorax	1	2	>0.999[a]	–	–	–	–	–	–	1	1	>0.999[a]
Atelectasis	–	–	–	–	–	–	1	0	>0.999[a]	–	–	–
Pneumonia	–	–	–	–	–	–	8	1	0.309	–	–	–
Bronchial kinking	5/9[b]	11/19[b]	>0.999[a]	10/29[c]	9/23[c]	0.730	9	0	**0.047**[a]	5	0	**0.018**
Total	10	14	0.360	16	17	0.650	23	1	**<0.001**	11	5	**0.036**

Note: The significance of bold in all Tables was the p value less than 0.05.
Abbreviations: DVT, deep venous thrombosis; PAL, prolonged air leak.
[a]Fisher's exact test.
[b]A total of 28 patients in the pilot group had chest computed tomography (CT) data during the postoperative follow-up.
[c]A total of 52 patients in cohort A had chest CT data during the postoperative follow-up.

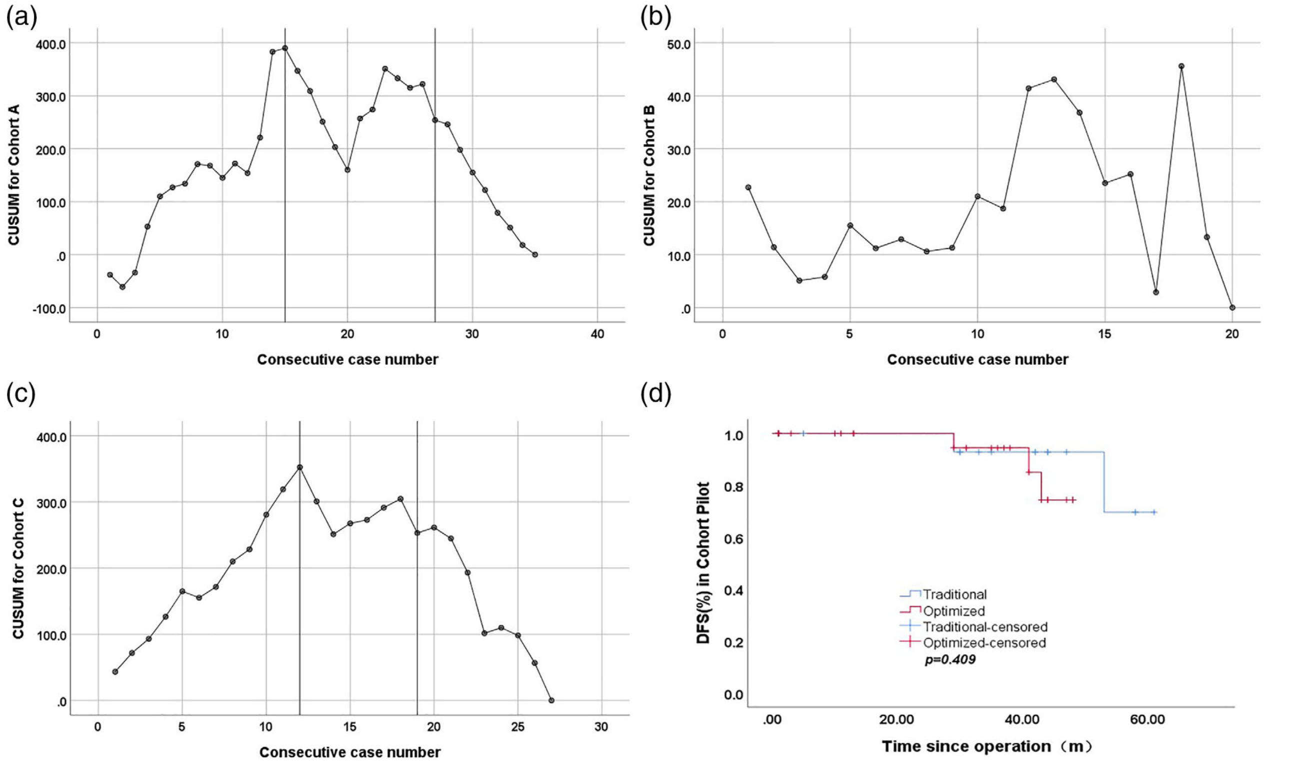

FIGURE 4 The learning curve for performing optimized right upper lobectomy in cohorts (a)–(c), and the Kaplan–Meier curve for disease free survival with optimized RUL versus traditional RUL by RATS in cohort pilot. RUL, right upper lobectomy; RATS, robot-assisted thoracoscopy

RESULTS

Optimized RUL can be performed successfully by RATS or VATS. The pilot cohort included 16 and 29 patients who underwent traditional and optimized RUL by RATS, respectively. The other VATS cohorts included 105 and 82 patients who underwent traditional and optimized RUL, respectively. Finally, a total of 232 patients were included in the study, as shown in Table 1, with 121 cases in the traditional group and 111 cases in the optimized group.

Clinical outcomes

The demographic and clinical characteristics are shown in Table 1. The cases in the traditional group were more likely to be men or smokers in cohort A, or to have poorer forced expiratory volume in 1 second (FEV1) in cohort B. Additionally, the traditional group and the optimized group in cohort A and cohort B had larger tumor sizes, respectively.

Intraoperative variables

As shown in Figure 3(a),(b), the operation time in the optimized group was significantly shorter than that in the traditional group in one RATS and all three VATS cohorts. Furthermore, significantly less blood loss was observed in the optimized group than the traditional group (61.4 ± 73.67 vs. 134.4 ± 112.6; 82.0 ± 44.6 vs. 120.0 ± 59.7, $p = 0.003$; 267.3 ± 276.6 vs. 83.5 ± 48.5, $p = 0.005$), as illustrated in the pilot, A and B cohorts. However, no statistical difference was found regarding the stations and number of resected lymph nodes between groups, as illustrated in all cohorts (Figure 3(c),(d)).

No conversion to thoracotomy was performed in the pilot cohort. Eleven cases were converted to thoracotomy in the other cohorts; 10 cases in the traditional group and one case in the optimized group (10/105 vs. 1/82, $p = 0.037$). Of the 10 patients, two had incomplete interlobar fissures leading to difficulties in exposing the interlobar artery in VATS; four had calcified lymph nodes involving the ascending A2 artery or superior arterial trunk; two had bleeding during the isolation of the recurrent A2 artery or the superior arterial trunk; one had extensive pleural adhesion; and one had a tumor located in the vicinity of the hilum. In the optimized group, one case was converted to thoracotomy because of bleeding during the separation of the superior arterial trunk.

Postoperative outcomes

Perioperative death was defined as death during the surgical procedure or within 30 days after surgery, whereas postoperative complications were defined as complications occurring within 30 days after surgery.

TABLE 3 Characteristics and perioperative outcomes in the different periods in the optimized group in cohorts A and C

Cohort	Factor	Total	Period 1	Period 2	Period 3	*p*
A	*n*	35	15	12	8	–
	FEV1	2.11 ± 0.58	2.01 ± 0.58	2.25 ± 0.65	2.10 ± 0.49	0.580
	Tumor size (cm)	1.1 ± 0.81	1.72 ± 0.73	1.50 ± 0.76	1.99 ± 1.04	0.434
	LN stations	4.09 ± 1.77	3.20 ± 1.61	4.58 ± 1.51	5.00 ± 1.85	0.028[a]
	Total of lymph nodes	8.51 ± 5.19	6.40 ± 4.79	10.75 ± 5.96	9.13 ± 3.27	0.087
	Operation time (min)	143.0 ± 51.1	169.0 ± 51.7	131.7 ± 52.4	111.3 ± 13.6	0.018[a]
	Blood loss (ml)	82.0 ± 44.6	116.7 ± 45.0	55.8 ± 22.3	56.3 ± 17.7	<0.001[a]
	Time of drainage (d)	3.80 ± 2.27	5.00 ± 2.73	3.42 ± 1.38	2.13 ± 0.83	0.008[a]
	Day of hospital stay (d)	5.77 ± 2.98	7.80 ± 2.83	5.50 ± 1.45	2.38 ± 1.30	<0.001[a]
	Overall complications	7(20%)	4(26.7%)	3(25%)	0(0%)	0.319[b]
C	*n*	27	12	7	8	–
	FEV1	2.42 ± 0.68	2.58 ± 0.77	1.95 ± 0.42	2.57 ± 0.59	0.110
	Tumor size (cm)	2.66 ± 1.23	3.15 ± 1.62	2.17 ± 0.76	2.33 ± 0.49	0.173
	LN stations	5.37 ± 1.31	5.67 ± 1.23	5.71 ± 1.11	4.63 ± 1.41	0.157
	Total of lymph nodes	19.67 ± 7.52	22.67 ± 8.49	16.14 ± 4.49	18.25 ± 7.03	0.156
	Operation time (min)	141.6 ± 38.4	171.0 ± 16.2	127.4 ± 34.6	110.0 ± 34.9	<0.001[a]
	Blood loss (mL)	84.1 ± 53.8	125.0 ± 54.4	51.4 ± 23.4	51.3 ± 21.7	<0.001[a]
	Time of drainage (d)	6.63 ± 3.41	6.58 ± 1.88	5.14 ± 1.86	8.00 ± 5.50	0.279
	Day of hospital stay (d)	7.89 ± 3.66	7.83 ± 2.17	6.29 ± 1.98	9.38 ± 5.83	0.274
	Overall complications	4 (14.8%)	2 (28.6%)	2 (25%)	0 (0%)	0.130[b]

Abbreviations: FEV1, forced expiratory volume in 1 second; LN, lymph nodes.
[a]The LSD method was used for pairwise comparison.
[b]Fisher's exact test.

No perioperative deaths occurred in all four cohorts. The incidence of postoperative complications was 17.8% (8/45) in the RATS group and 21.4% (40/187) in the VATS group. The optimized group had fewer complications, as illustrated in cohorts B and C (Table 2).

The major complication was air leakage. However, the incidence of prolonged air leakage (> for 5 days) and the chest tube drainage time were similar in the two groups, except in cohort B, which showed a shorter chest drainage time in the optimized group than the traditional group (Figure 3(f)). The other complications included deep vein thrombosis, pneumothorax, aerodermectasia, atelectasis, pneumonia, chylothorax, and postoperative bleeding (Table 2). In cohort A, one patient in the optimized group underwent a second operation because of postoperative hemorrhage from the bronchial artery; however, there was no significant difference in the occurrence of this complication between groups (1/35 vs. 0/37).

Furthermore, the hospital stay in the optimized group (Figure 3(g)) was shorter than that in the traditional group in cohorts A and B (5.77 ± 2.98 d vs. 7.62 ± 2.99 d, $p = 0.011$; 9.82 ± 6.00 d vs. 6.65 ± 1.09 d, $p = 0.012$), and the hospital costs (~80% for the stapler and staple cartridge) were also markedly lower in the optimized group, as illustrated in all four cohorts (Figure 3(h)).

As shown in Table 2, the incidence of postoperative intermedius bronchial kinking, as confirmed by available follow-up chest CT scans, was lower in the optimized group than the traditional group in cohorts B and C (9/44 vs. 0/20, $p = 0.047$; 5/24 vs. 0/27, $p = 0.036$), despite no statistical difference in the pilot and A cohorts.

Learning curve for the procedure in the optimized group

As shown in Figure 4, the learning curve of cohort A was divided into three periods: period 1 (cases 1–15), period 2 (cases 16–27), and period 3 (cases 28–35). Similarly, the learning curve of cohort C was divided into three periods: period 1 (cases 1–12), period 2 (cases 13–19), and period 3 (cases 20–27). The operation time appeared to decrease significantly after the initial 12 to 15 cases. However, the learning curve of cohort B did not reach a stable plateau, owing to a fluctuation in the learning curve caused by the 18th patient, despite a tendency of the curve to decrease after the initial 15 cases.

As shown in Table 3, no statistical difference was observed in FEV1 and tumor size among the periods in either cohort A or C. The operation time was significantly shorter, and the intraoperative blood loss was significantly less in periods 2 and 3 than in period 1 in both cohorts. In cohort A, one case was converted to thoracotomy in period 1, owing to intraoperative bleeding of the superior arterial trunk, the stations of removed lymph nodes in periods

2 and 3 were significantly higher than those in period 1 ($p = 0.036$ and $p = 0.017$), and the postoperative chest tube drainage time and hospital stay were statistically shorter than those in period 1. However, no difference was observed between period 2 and period 3 regarding operation time, intraoperative blood loss, lymph node number, lymph node stations, and chest tube drainage time. In cohort C, no statistical differences in lymph node number, lymph node stations, chest tube drainage time and postoperative hospital stay were observed between period 2 and period 3 (Table 3). Postoperative complications among the three periods showed no significant differences in either cohort A or C. Therefore, the platform stage with stable skills could be achieved by surgeons after the initial 12 to 15 cases.

Disease-free survival

In the pilot cohort, the median follow-up times for traditional and optimized cases were 42 months and 31 months, respectively. As shown in Figure 4(d), disease-free survival did not statistically significantly differ ($p = 0.409$), and similar 3-year disease-free survival rates were observed (94.4% vs. 92.9%), between groups. The multivariable Cox regression model demonstrated that pathological tumor, nodes, and metastasis (pTNM) stage (HR, 7.26, 95% CI, 0.911–57.748, $p = 0.061$), rather than surgical procedure (HR, 3.608, 95% CI, 0.334–38.991, $p = 0.291$), was the only risk factor in disease-free survival. However, the overall survival warrants further long-term evaluation.

DISCUSSION

First, we acknowledge the differences in demographic and clinical features among several cohorts, because this was not a randomized clinical trial. However, the size difference (∼0.5 cm) was statistically significant, but has no surgical implications regarding operative risks or difficulties. Moreover, in cohort A, the higher proportion of smokers in the traditional group did not cause worse FEV1 than that in the optimized group, probably because of the patients' younger ages. Therefore, we believe that the results remain promising.

The proportion of incomplete interlobar fissures has been reported to vary from 18.5% to 85.0%.[8,9] Li et al.[10] have evaluated the degree of pulmonary fissure completeness during thoracoscopic lobotomy, reporting 67.3% incomplete right oblique fissure and 77.5% horizontal fissure, therefore potentially leading to RUL difficulties.[10] RATS or VATS RUL is believed to pose challenges in exposing the interlobar arterial trunk in cases of chronic inflammation and a thickened vascular sheath. In addition, the wide base of the upper pulmonary vein may cause difficulties in transection with an endovascular stapler or even disastrous injury to the underlying pulmonary artery. Therefore, traditional RUL, which requires division of the oblique and horizontal fissures, and isolation of the upper pulmonary vein, is challenging for thoracic surgeons.

Liu et al.[11] have described the concept of "single-direction" VATS lobectomy, which is sequentially performed in a single direction; that is, the superficial structures initially exposed are dissected or transected. In VATS RUL, the sequential procedure of division involves the pulmonary vein, superior arterial trunk, ascending A2 artery, bronchus, and fissures and therefore, is not affected by incomplete fissures. However, this procedure requires excellent skills and anatomical knowledge to clearly and accurately identify the hilum and its adjacent structures.

The other two recently introduced novel methods involve simultaneous manipulation of the right superior pulmonary vein along with the superior arterial trunk to decrease the number of surgical steps and use of endovascular staplers.[12,13] Lin et al.[12] have reported their experience in first dividing oblique fissures to expose, isolate, and transect the upper bronchus; then dividing horizontal fissures; and finally performing simultaneous transection of the right superior veins with arteries. Furthermore, Zhai et al.[13] have described a similar method in which the ascending A2 artery is disconnected as the first priority (Asc. A2-B-Fissure-AV). However, similarly to the traditional method, the above two methods initially require the division of oblique fissures and subsequent transection of the bronchus before the superior arterial trunk risks tearing the superior arterial trunk beneath the bronchus.

The traditional procedure was performed in the past. However, the initial optimized procedures were extemporaneously designed and tested in several unexpectedly difficult cases with scarcely developed interlobar fissure or calcified interlobar lymph nodes. To avoid conversion to open thoracotomy, these procedures seem to provide an optimal alternative in the minimally invasive approach. With the accumulation of experience, surgeons are currently more willing to use the optimized procedures for RUL. This method has the following advantages: (i) avoidance of division of the pulmonary parenchyma in incomplete fissures, and a better surgical field with less bleeding; (ii) avoidance of injury to the superior arterial trunk during isolation of the bronchus; (iii) adequate distance between the superior pulmonary vein and ascending A2 artery, therefore, enabling transection from anterior to posterior; (iv) avoidance of isolation of calcified and scarred interlobar lymph nodes; and (v) less risk of torsion of the middle lobe, owing to minor manipulation of the fissure and hilum.

Although RATS generally differs from VATS in setting and approach, the basic procedures and principles of RUL are similar. Importantly, optimized procedures by using RATS yielded better outcomes in the optimized group in terms of operation time, blood loss, and hospitalization time and cost. Thereafter, we performed VATS procedures, and the better clinical outcomes of the optimized procedures were also validated in the other centers.

The optimized RUL technology, compared with the traditional method, enabled shorter operation times, fewer complications, less blood loss, shorter hospitalization times, and lower costs, while yielding similar disease-free survival. Surgeons' skills in performing this optimized procedure became stable after learning from the initial 12 to 15 cases. In this study, we did not combine the cohorts for analysis, owing to the heterogeneity of clinical outcomes, such as the operation speed of each surgeon and local medical costs. Furthermore, this was a non-randomized retrospective observational study with inherent limitations. Multi-center and randomized cohort studies are needed to further evaluate safety and outcomes.

CONCLUSIONS

Here, an optimized surgical procedure for RATS or VATS RUL was introduced, involving transection of fissures with the superior pulmonary vein and the ascending A2 artery simultaneously with interlobar fissures. This procedure achieved better clinical outcomes than the traditional method, including shorter operation times, fewer complications, less blood loss, shorter hospitalization times, and lower costs, while yielding similar disease-free survival. The procedure was safe, reliable, and economical, in accordance with the idea of enhanced recovery after surgery.

AUTHOR CONTRIBUTIONS

All authors had full access to the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. *Conceptualization*: Bo Deng and Long-Yong Mei. *Methodology*: Bo Deng, Long-Yong Mei, Shi-Guang Xu, and Lei Xian. *Formal analysis*: Long-Yong Mei, Wen-Zhou Liu, and Yu-Chi Xiu. *Resources*: Qun-You Tan, Shi-Guang Xu, Lei Xian, Bo Deng, Yong-Geng Feng, and Shao-Lin Tao. *Writing—original draft*: Long-Yong Mei and Bo Deng. *Writing—review and editing*; Shi-Guang Xu and Lei Xian. *Visualization*: Long-Yong Mei, Wen-Zhou Liu and Yu-Chi Xiu. *Supervision*: Qun-You Tan and Bo Deng. *Funding acquisition*: Lei Xian and Shao-Lin Tao. All authors read and approved the final manuscript.

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CONFLICTS OF INTEREST

The authors made no disclosures.

ETHICS STATEMENT

This study protocol was approved by the Ethics Committee of Daping Hospital of Army Medical University no. 226 (2021), the Second Affiliated Hospital of Guangxi Medical University no. KY-0331 (2021) and General Hospital of Northern Theater Command no. Y001 (2022), with waivers of informed consent.

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