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Factors affecting short-term outcomes in robotic-assisted thoracoscopic surgery for lung cancer

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Abstract

Purpose: Robotic-assisted thoracoscopic surgery (RATS) is a new approach to lung cancer surgery. To further develop RATS procedures, we investigated the factors related to short-term postoperative outcomes.

Methods: We analyzed patients who underwent RATS lobectomy for primary lung cancer at our institution from June 2018 to January 2023. The primary outcome was operative time, and the estimated value of surgery-related factors was calculated by linear regression analysis. The secondary outcome was surgical morbidity, and the risk was assessed by logistic regression analysis.

Results: The study cohort comprised 238 patients. Left upper lobectomy had the longest mean operative time, followed by right upper lobectomy. Postoperative complications occurred in 13.0% of cases. Multivariate analysis revealed that upper lobectomy, the number of staples used for interlobular fissures, and the number of cases experienced by the surgeon were significantly associated with a longer operative time. The only significant risk factor for postoperative complications was heavy smoking.

***Conclusions*:** Patients with well-lobulated middle or lower lobe lung cancer who are not heavy smokers are recommended for the introductory period of RATS lobectomy. Improving the procedures for upper lobectomy and dividing incomplete interlobular fissures will lead to the further development of RATS.

Introduction

Robotic-assisted thoracoscopic surgery (RATS) is a widely used new surgical treatment approach for lung cancer and mediastinal tumors [1–3]. Although there are a few reports on the long-term postoperative outcomes of RATS [4–6], reports of short-term outcomes have been increasing in recent years. In terms of surgical morbidity, quality of lymph node dissection, and risk of conversion to thoracotomy, RATS is comparable to conventional approaches, such as thoracotomy and video-assisted thoracic surgery (VATS) [7–10]. However, limited information is available on the operative time.

When RATS was first introduced, most institutions required a longer operative time compared with conventional approaches, which was concerning. However, as the number of cases experienced at each institution increased, the operative time tended to decrease. Nevertheless, there is no report of the operative time of RATS being shorter than that of conventional approaches. Shortening the operative time reduces the extent of the procedure's invasiveness and decreases the burden on medical staff, such as surgeons, anesthesiologists, and nurses. Since a robotic surgical device has the mobility of the wrist in the thoracic cavity and is capable of precise manipulation, the surgeon can operate under a 3D visual field, potentially enabling more efficient surgery compared with conventional equipment [3]. However, robotic surgery is more instrument-dependent than conventional approaches, so the surgeon understands of the compatibility between robotic instrumentation and patient characteristics is crucial for maximizing the capabilities of these robotic systems. To further develop RATS, we examined the relationship between

short-term surgical outcomes, including operative time, and patient characteristics in RATS for primary lung cancer at our institution.

Methods

Study design

This was a single-center retrospective observational study. The protocol was approved by the Clinical Research Area Ethics Committee of Kobe University Graduate School of Medicine (B230051) and conformed to the principles of the Declaration of Helsinki. Informed consent was waived due to the retrospective nature of the study.

Patient population

Patients aged >20 years who had undergone RATS lobectomy and mediastinal lymph node dissection for primary lung cancer at our institution from June 2018 to January 2023 were eligible for study inclusion. The exclusion criteria were incomplete resection, combined resection of neighboring organs, bilobectomy, simultaneous tumor resection of another lobe, and patients whose medical information could not be obtained from medical records.

RATS procedure

RATS lobectomy was performed using a da Vinci Surgical System (Intuitive Surgical, Sunnyvale, California, USA). The da Vinci S Surgical System was used from June 2018 to October 2019. From November 2019, only the Xi Surgical System was used, and since November 2021, both the X and Xi Surgical Systems have been used.

Regarding the surgical indications for RATS lobectomy during the study period, patients with a tumor diameter of ≥70 mm, those requiring angioplasty, or those at risk of pneumonectomy were excluded. These criteria align with the surgical indications for VATS in our institution. However, during the introductory period, we chose early-stage cases with well-lobulated lung for RATS. As we gained experience with 80 RATS lobectomies, we progressively included a higher proportion of challenging cases.

The patient was placed in the lateral recumbent position, and axillary pillows and flexion of the bed were used to secure the intercostal space and prevent interference between the robotic arms and the patient's pelvis. For right upper, middle, lower, and left lower lobectomy, four ports (including the camera port) were placed in the 8th intercostal space. For left upper lobectomy, the four ports were placed in the 7th intercostal space. In patients with a slender build, the dorsal port was often moved to the caudal intercostal space, where the ribs were more craniocaudally inclined. The patient-side surgeon operated the conventional automatic staplers and energy devices using a robotic port without a robotic arm or an access port in the 4th intercostal space for upper lobectomy or the 5th intercostal space for middle and

lower lobectomy. The console surgeon used a robotic arm to operate the robotic automatic staplers and energy devices. A three-dimensional oblique camera was used for most cases. When using the S system, CO_2 insufflation was not performed, but when using the Xi system, CO_2 insufflation was performed for all cases, maintaining a pressure range of 5–8 mmHg.

Study outcomes

The primary outcome was operative time, and the secondary outcome was postoperative morbidity. Other outcomes included surgical mortality, the volume of blood loss, and the rate of conversion to thoracotomy. Surgery-related death was defined as death from any cause within 90 days after surgery or death in hospital after surgery. Postoperative complications were classified into four categories: pulmonary (prolonged air leakage, bronchopleural fistula, pneumonia, interstitial pneumonia, atelectasis, respiratory insufficiency, and asthma), cardiovascular (cardiac infarction, heart failure, cerebral hemorrhage, cerebral stroke, arrhythmia, and pulmonary embolism), infectious (wound infection and empyema), and others. Prolonged air leakage was defined as postoperative air leakage persisting for >7 days or requiring an additional postoperative procedure, such as surgery and adhesion therapy, within 7 days. Pneumonia was defined as the development of infection and the presence of lung consolidation on chest radiography or computed tomography images. In terms of comorbidity, interstitial pneumonia was defined as the presence of characteristic features, such as honeycombing and a reticular pattern, on chest

computed tomography images. If regarded as a postoperative complication, interstitial pneumonia was considered an acute exacerbation. Respiratory insufficiency was defined as requiring reintubation, tracheostomy, or ventilatory assistance >48 h after surgery. Arrhythmia was defined as heartbeat irregularities that developed after surgery and required treatment.

Statistical analysis

Patient characteristics and operative outcomes were expressed as medians and ranges for continuous variables and as frequencies and proportions for categorical variables. For the primary outcome, the objective variable was operative time, and surgery-related factors (age, sex, height, smoking history, tumor size, clinical N stage, tumor location, number of staples used for interlobular fissures, use of antiplatelet therapy, and number of experienced cases) were used as explanatory variables to calculate the expected value of the factors and their 95% confidence interval (CI) by linear regression analysis. For the secondary outcome, logistic regression analysis was used to evaluate the association between surgery-related factors and postoperative complications using odds ratios and 95% CIs. Multivariate analysis was performed using the variables with p-values <0.1 in the univariate analysis. All statistical analyses were conducted using JMP v13 software (SAS Institute Inc., Cary, NC, USA). P-values <0.05 were considered statistically significant.

Results

From June 2018 to January 2023, 366 RATS procedures were performed for lung malignancies and mediastinal tumors. Among them, 238 patients (Table 1) underwent lobectomy for primary lung cancer and were included in our study cohort (Fig. 1). Most patients receiving preoperative antiplatelet therapy was administered a single antiplatelet treatment perioperatively. Of the three da Vinci Surgical Systems used at our institution, the Xi Surgical System was used most frequently, and five surgeons operated as console surgeons during the study period. Right upper lobectomy was most frequently performed.

Table 2 shows the perioperative outcomes. The median operative time was 177 minutes, and the mean operative time was the longest for left upper lobectomy, followed by right upper lobectomy (Fig. 2a). The shortest operative time was observed in the patients with a height ≥145 and <155 cm (Fig. 2b). Operative time was assessed for every 40 cases and tended to be shorter as the number of cases experienced by the surgeon increased, although the console time remained unchanged (Fig. 3). The median intraoperative blood loss volume was 5 ml. There was only one case of conversion to thoracotomy, which was due to pulmonary artery injury during a left upper lobectomy. The median number of staples used for dividing interlobular fissure was 2, and a 60-mm cartridge was frequently used. Regarding the automatic staplers used during surgery, the patient-side surgeon often utilized conventional automatic staplers in our cases. Postoperative complications occurred in 13.0% of the patients, where prolonged air leakage and arrhythmia were common (Supplemental Table 1). No deaths

were observed in the 90 days following surgery, but there was one case of in hospital death due to cerebral infarction.

Univariate analysis revealed that the male sex, a taller stature, heavy smoking (>30 pack-years), clinical N stage positive, upper lobe surgery, the number of staples used for interlobular fissures, and the number of cases experienced by the surgeon was significantly associated with operative time. In the multivariate analysis, upper lobe surgery, the number of staples used for interlobular fissures, and the number of cases experienced by the surgeon remained significant factors (Table 3). Univariate analysis showed that the occurrence of postoperative complications was significantly associated with the male sex, heavy smoking, and the number of staples used for interlobular fissures. However, multivariate analysis revealed that only heavy smoking was significantly associated with the occurrence of postoperative complications (Table 4).

Discussion

In this study, upper lobectomy, the number of staples used for interlobular fissures, and the number of cases experienced by the surgeon influenced the operative time of RATS lobectomy for lung cancer, while heavy smoking negatively impacted postoperative complications.

Due to the structure of the arm used in robotic surgery, it is difficult to operate the robotic forceps in front of the visual field. Therefore, we expected that lower lobectomy would take a longer time

to perform than upper lobectomy. Unexpectedly, left upper lobectomy had the longest mean operative time, followed by right upper lobectomy. Moreover, upper lobectomy was significantly associated with a longer operative time. There are several possible reasons for this. One is that there are more pulmonary arteries to be resected in the upper lobe than in the middle or lower lobes. Additionally, since our RATS are performed under the look-up view from the 8th intercostal space, it may be difficult to secure a visual field for the cranial dissection of the pulmonary arteries. Since intraoperative injury of the pulmonary artery can be fatal [11, 12], we believe that upper lobectomy took longer to perform because of the need for careful dissection of the pulmonary artery in the upper lobe.

In anatomical pulmonary resection, the degree of interlobular fissure is related to operative time because an incomplete fissure requires an additional dividing procedure. Since it is difficult to objectively evaluate the degree of interlobular fissure, the number of staples used for interlobular fissures was adopted as a covariate in the multivariate analysis in this study. This factor was also identified as an independent operative time-related factor, even in RATS.

Robotic surgery enables three-dimensional and magnified vision, and the manipulation of forceps is delicate and has the mobility of the wrist. Additionally, since there is a function to correct tremors in forceps movements, it is possible to operate the forceps in the thoracic cavity as desired, which is not possible in VATS. On the other hand, robotic forceps have no sense of touch [3]. Therefore, more care must be taken when dissecting the structures surrounding blood vessels and the bronchus, grasping

lungs, and using robotic forceps outside the field of view. Moreover, it takes time to get used to the robotic settings before performing the console procedure. It was reported that surgeons completed the learning phase of RATS lobectomy once they had experienced approximately 30 cases [13]. Another report showed an initial reduction in operative time following the experience of approximately 20 cases and a further reduction after >60 cases [14]. At our institution, the operative time is becoming gradually shorter, even though new console surgeons have started performing RATS. Considering the current trend, it is expected that the operative time will become even shorter in the future.

Several reports have shown that RATS is of greater benefit in larger patients [15, 16]. However, there are no reports on RATS for small-sized patients. It is difficult to secure a sufficient distance between the robotic arms when performing RATS on small patients, and interference between the arms is likely. Therefore, we expected that RATS would be difficult to perform in patients with short stature, resulting in a longer operative time. However, we found that differences in patients' height did not affect the operative time. Although there was a tendency toward a longer operative time for patients with a height ≤145 cm, the surgery was completed without any major issues. On the other hand, the operative time was most shortened in patients with a height ≥145 and <155 cm. When RATS is performed in small patients, sufficient space between the ports cannot be secured, and there is not enough space to operate the forceps in the thoracic cavity. Therefore, it is crucial for the console surgeon to avoid interference between the arms by minimizing swings in forceps manipulation. Furthermore, it is difficult to expand the operative

field with the third arm in small patients. However, in our RATS approach, the patient-side surgeon develops the cranial operative field from the 4th intercostal space, and the third arm mainly develops the caudal operative field, enabling comfortable forceps manipulation, even in a narrow chest cavity. We believe that sharing intrathoracic space that can be easily covered by the third arm and that the patient-side surgeon contributed to our favorable surgical results for small-sized patients.

Although operative time was mentioned above, placing too much focus on shortening it poses safety risks. We believe that safety is more important than the operative time. In our patients, there was only one case of conversion to thoracotomy, which was caused by bleeding from an injury to the pulmonary artery. The rate of conversion to thoracotomy from RATS has been reported as 0%–11.5% [2, 6, 10, 12, 17]. Compared with these reports, our conversion rate (0.4%) was low. We gradually increased the proportion of difficult cases for RATS during the introductory period. We believe that this gradual expansion of RATS indications is contributing to low conversion rates. The postoperative complication rate of RATS pulmonary resection has been reported as approximately 9%–30%, with prolonged air leakage and cardiovascular complications being common [2, 6]. Our rate of postoperative complications was 13.0%, which was comparable to previous reports, and prolonged air leakage and arrhythmia were common. Our study also examined factors related to postoperative complications and heavy smoking was identified as a factor influencing postoperative complications. Previous study showed that heavy smoking significantly increases not only pulmonary complications but also cardiovascular and infectious

complications after pulmonary lobectomy by VATS and thoracotomy [18]. Thus, it is not a unique risk factor for postoperative complications after RATS lobectomy. This suggests that we could safely shorten the operative time of RATS lobectomy.

Two surgeons can perform RATS, which is less than the number of surgeons required for VATS or thoracotomy. Furthermore, if the operative time were significantly shortened, the personnel costs for surgical staff, including anesthesiologists, nurses, and clinical engineers, would be reduced. Robotic surgery has a higher setup cost than other approaches [1, 3, 19, 20]. Therefore, the quality of RATS needs to substantially improve while improving time-cost performance.

There are some limitations to our study. First, this is a single-institution study. There are various approaches to port placement, and the approach adopted at each institution differs. Since the results may vary depending on the approach, a multicenter study is necessary to verify our findings. Second, our study cohort comprised a high number of patients who underwent right upper lobectomies and patients with adenocarcinoma. Two years after the introduction of RATS, in an effort to emphasize safety, we stopped performing left upper lobectomy, and right upper lobectomy was frequently performed to standardize the procedure. Therefore, our technique for RATS left upper lobectomy was less mature compared with lobectomy for other lobes. During the same period, RATS for early-stage lung cancer was often performed, and this may be responsible for the higher proportion of adenocarcinoma patients. Third,

only RATS cases were evaluated in this study. Therefore, we would like to compare the outcomes of RATS and VATS in future studies.

In conclusion, we investigated factors related to operative time and postoperative complications in RATS from its introduction at our institution in June 2018 to January 2023. Increasing the number of experiences using RATS for middle and lower lobectomy with sufficient lobulation would lead to the efficient introduction of RATS at institutions where the long operative time of RATS is problematic. The next issue to be addressed for more efficient RATS lobectomy is the further improvement of upper lobectomy and interlobar dissection.

Conflict of interest

Yugo Tanaka received a lecture fee from Johnson & Johnson K.K. and Intuitive Surgical G.K. These lectures are not associated with this study. All other authors have no conflicts of interest to disclose.

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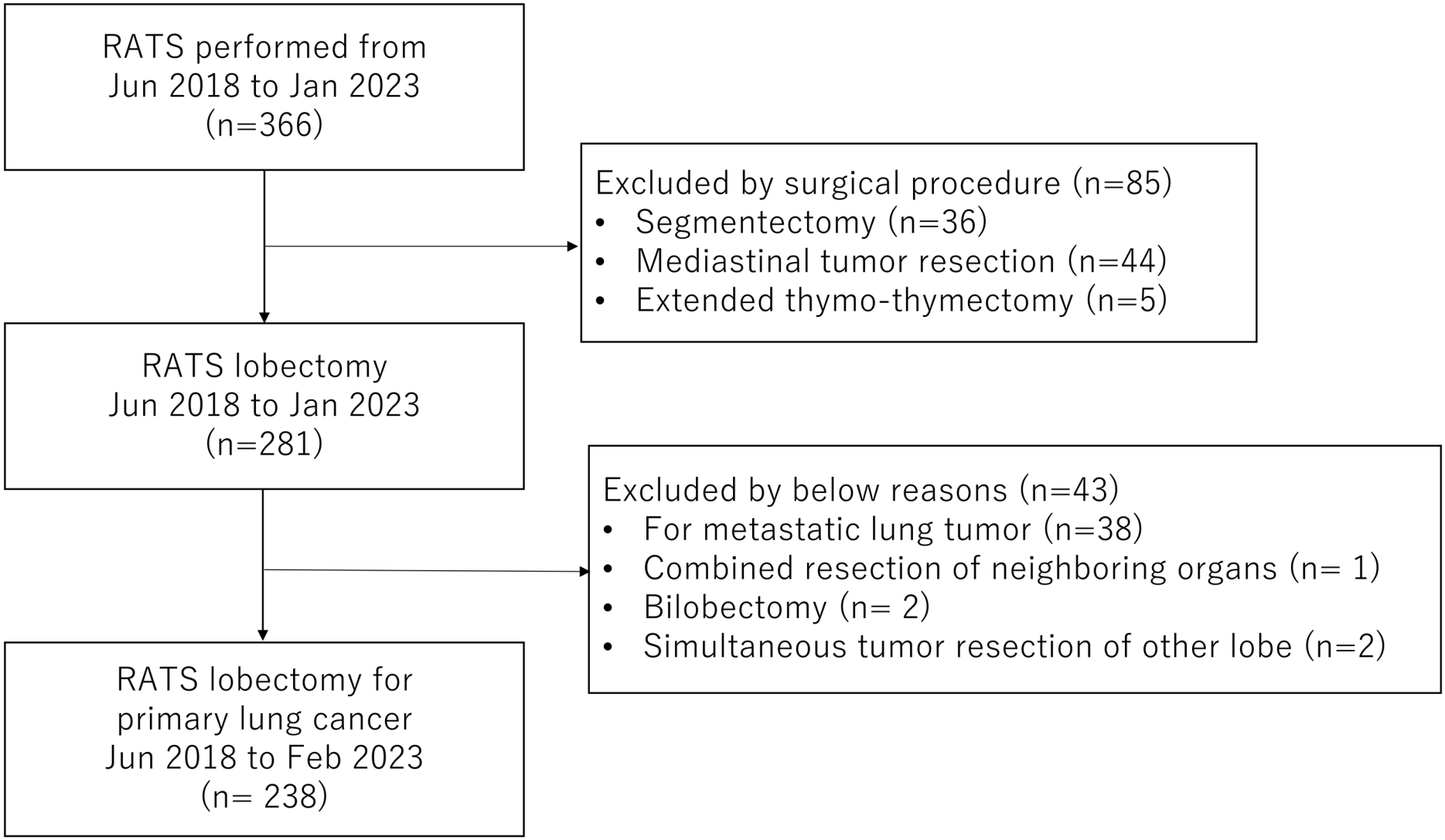
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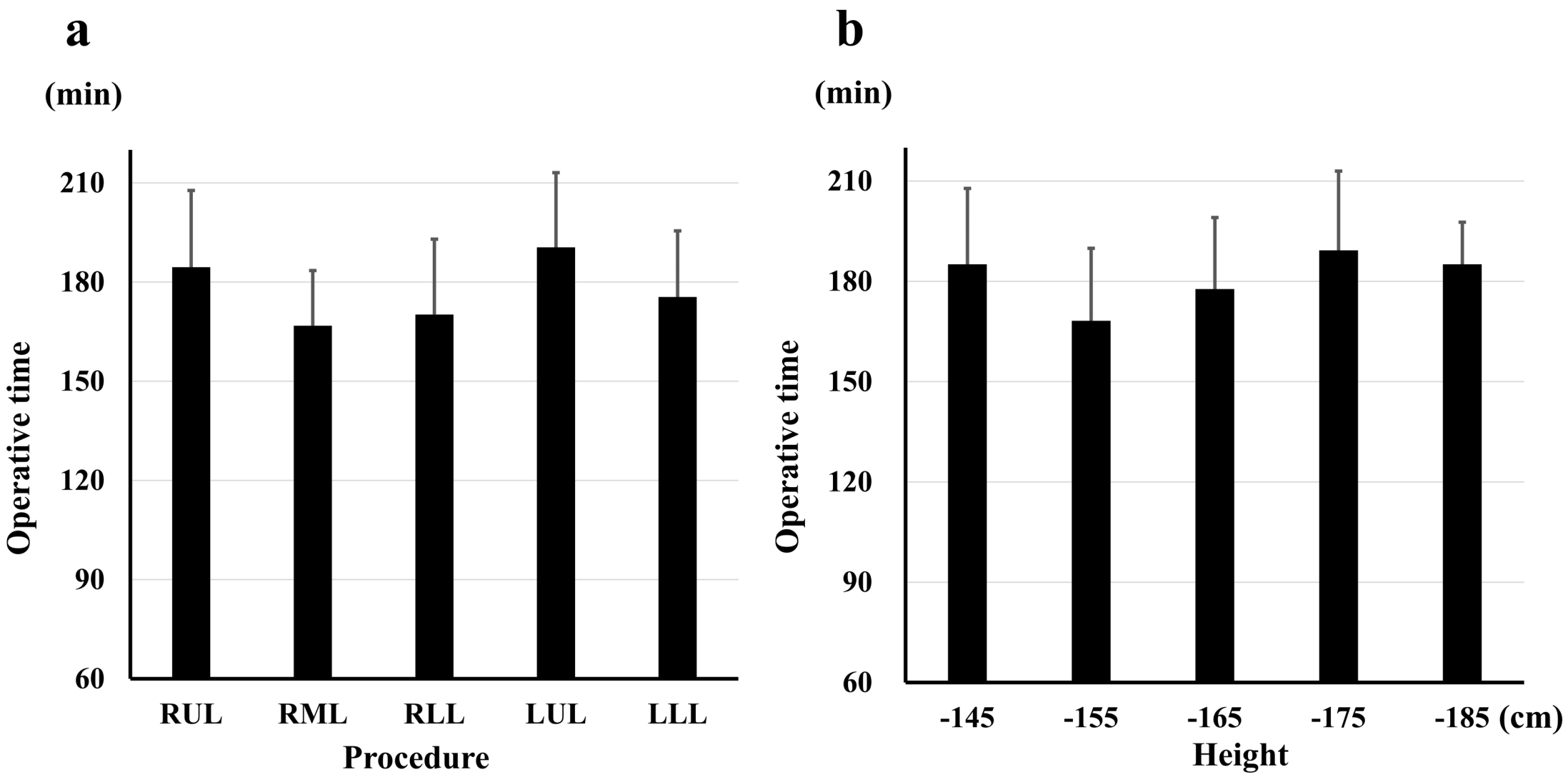
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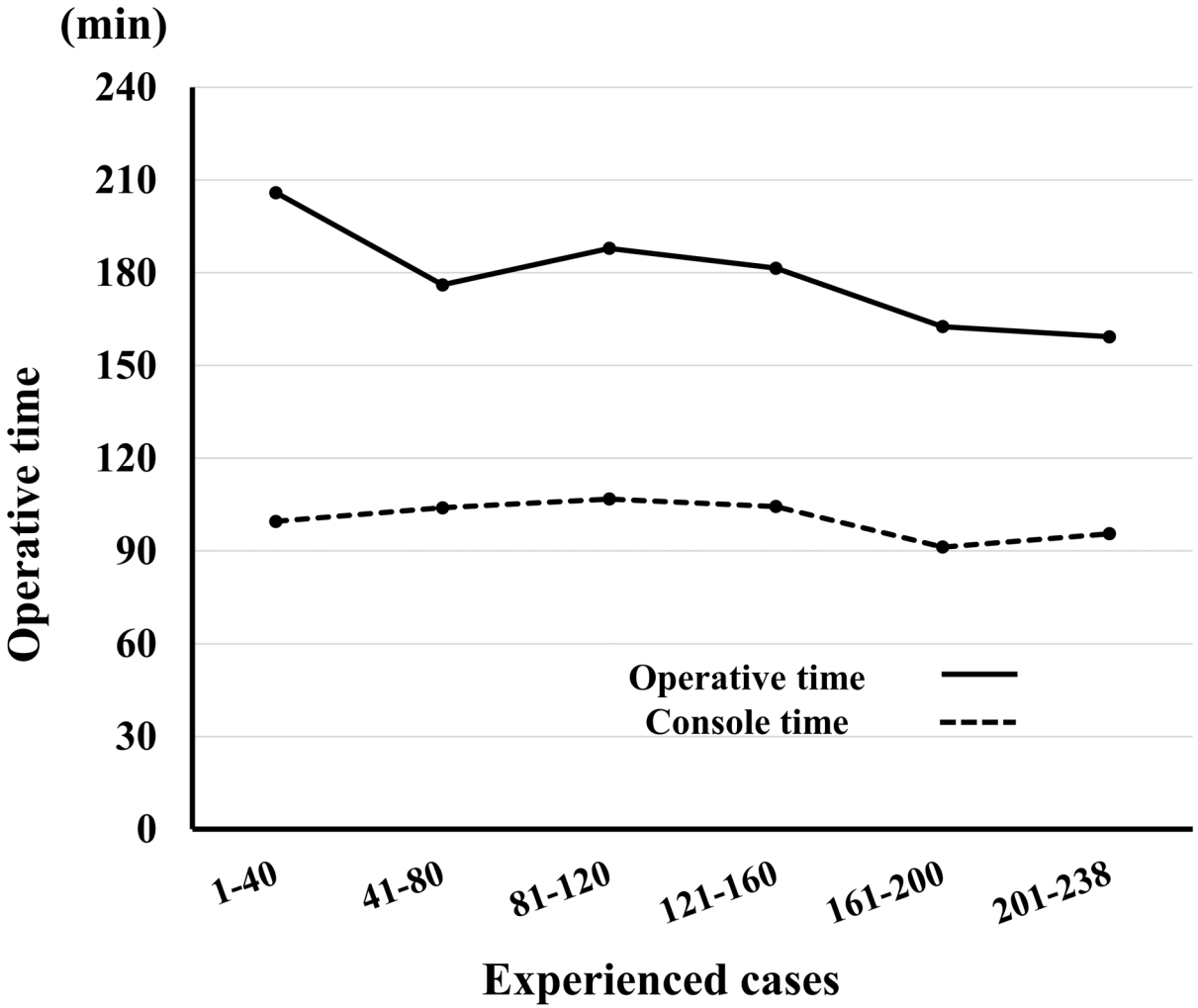
Fig. 1 Flowchart of patient inclusion in this study. *RATS* robotic-assisted thoracoscopic surgery

Fig. 2 a Mean operative time for each lung lobe, **b** Mean operative time per 10 cm patient height. *RUL* right upper lobectomy; *RML* right middle lobectomy; *RLL* right lower lobectomy; *LUL* left upper lobectomy; *LLL* left lower lobectomy

Fig. 3 Mean operative time and console time for every 40 surgical experiences. The number of cases experienced by each of the five console surgeons, and the number of surgeons who performed surgery since the new surgeon was included. Solid line, operative time; dashed line, console time


RATS performed from
Jun 2018 to Jan 2023
(n=366)
Excluded by surgical procedure (n=85)
• Segmentectomy (n=36)
• Mediastinal tumor resection (n=44)
• Extended thymo-thymectomy (n=5)
RATS lobectomy
Jun 2018 to Jan 2023
(n=281)
Excluded by below reasons (n=43)
• For metastatic lung tumor (n=38)
• Combined resection of neighboring organs (n= 1)
• Bilobectomy (n= 2)
• Simultaneous tumor resection of other lobe (n=2)
RATS lobectomy for
primary lung cancer
Jun 2018 to Feb 2023
(n= 238)


a
(min)
210
180
150
120
90
60
Operative time
RUL
RML
RLL
LUL
LLL
Procedure
b
(min)
210
180
150
120
90
60
Operative time
-145
-155
-165
-175
-185 (cm)
Height



Surgeon	Experienced cases
A	110
B	67
C	20
D	28
E	13

Case	Number of console surgeons
1~10	1 (A)
11~76	2 (A,B)
77~112	3 (A,B,C)
113~141	4 (A,B,C,D)
114~200	3 (A,B,D)
201~238	4 (A,B,D,E)

Table 1 Patient characteristics

Factors		All patients (N = 238)
Age	Median (range)	71 (42–91)
Sex	Male/female	128/110
ECOG PS	0/1	229/9
Height (cm)	Median (range)	160 (136.4–183.0)
Weight (kg)	Median (range)	57.3 (31.3–100.7)
BMI	Median (range)	22.2 (13.7–38.4)
Antiplatelet therapy	Yes	38 (16.0%)
Anticoagulation therapy	Yes	8 (3.4%)
Smoking history	Never	110 (46.2%)
	0< PY <30	34 (14.3%)
	PY >30	94 (39.5%)
Clinical T stage	1/2/3	176/60/2
Clinical N stage	0/1/2	225/6/7
Tumor size (mm)	Median (range)	17 (5–43)
Tumor location	RUL	105 (44.1%)
	RML	20 (8.4%)

	RLL	51 (21.4%)
	LUL	23 (9.7%)
	LLL	39 (16.4%)
Histology	AD	207 (87.0%)
	Others	31 (13.0%)

ECOG PS Eastern Cooperative Oncology Group performance status; *BMI* body mass index; *PY* pack-years; *RUL* right upper lobe; *RML* right middle lobe; *RLL* right lower lobe; *LUL* left upper lobe; *LLL* left lower lobe; *AD* adenocarcinoma

Table 2 Intraoperative and postoperative outcomes

Factors		All patients (N = 238)
Operative time (min)	Median (range)	177 (83–340)
Blood loss (ml)	Median (range)	5 (5–1250)
Conversion to thoracotomy	Yes	1 (0.4%)
No. of staples used for interlobular fissures	Median (range)	2 (0–6)
Cartridges used for interlobular fissures	60-mm	136 (57.1%)
	60-mm and 45-mm or less	23 (9.7%)
	45-mm or less	48 (20.2%)
	None	31 (13.0%)
Robotic system	Da Vinci S	43 (18.1%)
	Da Vinci X	9 (3.8%)
	Da Vinci Xi	186 (78.2%)
Staplers used during surgery	Conventional stapler	154 (64.7%)
	Robotic stapler	30 (12.6%)
	Both	54 (22.7%)
Postoperative complications	Total	31 (13.0%)
	Pulmonary	18 (7.5%)

	Cardiovascular	8 (3.4%)
	Infectious	0 (0.0%)
	Others	5 (2.1%)

Table 3 Univariate and multivariate analyses of covariables associated with operation time (min)

Variables	Univariate			Multivariate		
	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Age (>75)	−1.1126	−7.4479 to 5.2226	0.7297			
Sex (male)	7.9297	2.2533 to 13.6062	0.0064	3.5126	−4.7895 to 11.8146	0.4053
Height (per 10 cm)	6.4126	0.0754 to 12.7499	0.0474	0.0981	−8.2216 to 8.4178	0.9815
Pack-year (>30)	7.0791	1.268 to 12.8903	0.0172	4.2242	−2.1177 to 10.5660	0.1907
Tumor size (cm)	0.1738	−0.5795 to 0.9271	0.6499			
Clinical N stage (N1/2)	13.166	0.6265 to 25.7054	0.0397	9.6429	−1.5934 to 20.8792	0.0922
Tumor location (upper lobe)	7.0423	1.3465 to 12.738	0.0156	6.772	1.6686 to 11.8753	0.0095
Tumor location (right side)	−1.3651	−7.9135 to 5.1833	0.6817			

No. of staples used for interlobular fissures	11.1447	7.1845 to 15.1049	<0.001	9.6178	5.8840 to 13.3515	<0.001
Antiplatelet/anticoagulation therapy (yes)	1.0327	−6.2474 to 8.3129	0.7801			
Experienced cases (per 40 cases)	−8.0003	−11.2246 to −4.776	<0.001	−7.6051	−10.58 to −4.630203	<0.001

CI confidence interval

Table 4 Univariate and multivariate analyses of covariables associated with postoperative complications

Variables	Univariate			Multivariate		
	OR	95% CI	p-value	OR	95% CI	p-value
Age (>75)	1.8327	0.8338 to 3.9310	0.1291			
Sex (male)	2.4582	1.1185 to 5.8431	0.0246	1.1329	0.3013 to 4.2413	0.8524
Height (per 10 cm)	1.4718	0.9668 to 2.2812	0.0760	1.0983	0.6030 to 2.0742	0.7632
Pack-year (>30)	2.9730	1.3940 to 6.5893	0.0047	2.7080	1.0535 to 7.4712	0.0384
Tumor size (cm)	1.0150	0.9665 to 1.0630	0.5366			
Clinical N stage (N1/2)	2.0276	0.4356 to 7.0955	0.3040			
Tumor location (upper lobe)	2.0755	0.9586 to 4.7844	0.0643	2.1742	0.9766 to 5.1455	0.0573
Tumor location (right side)	1.0658	0.4683 to 2.6614	0.8843			
No. of staples used for interlobular fissures	1.3268	1.0184 to 1.7285	0.0368	1.2803	0.9691 to 1.6940	0.0817

Antiplatelet/Anticoagulation therapy (yes)	1.4737	0.5825 to 3.4167	0.3846
Experienced cases (per 40 cases)	1.0873	0.5068 to 4.6471	0.4565

CI confidence interval