Original Article

Robot-assisted *vs.* video-assisted thoracoscopic surgery in lung cancer

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Background: The major advantages of robot-assisted surgery are the fine field of view provided by the high-precision three-dimensional (3D) images and the good operability provided by the robotic arms that enables precise movements. A growing number of retrospective studies have compared robotic-assisted thoracoscopic surgery (RATS) with video-assisted thoracoscopic surgery (VATS), but the number of cases is limited and the results are contradictory.

Methods: We studied the medical records of primary lung cancer patients who underwent lobectomy with lymph node dissection between 2017 and 2020. Four hundred and eleven patients fulfilled the inclusion criteria in this study (RATS: 103; VATS: 308). We compared the perioperative factors and postoperative results of the VATS and RATS groups. Further, we adjusted background factors using propensity score matching (PSM) then compared the results of 200 patients (100 patients in each group). In this study, we matched interlobar fissure completeness, which affects operative difficulty and operative time; however, this has been superficially compared in previous studies.

Results: After PSM, a significant difference was observed in the intraoperative blood loss (RATS: 53.3 mL, VATS: 120.3 mL, P=0.04). The rates of surgical complications were comparable between the groups (10.0% *vs.* 13.0%, P=0.66) with similar mean operation times (RATS: 215.0 min, VATS: 210.1 min, P=0.57). The mean postoperative stay in the RATS group was shorter than that in the VATS group (10.0 *vs.* 11.5 days, P=0.04).

Conclusions: Initial experience of RATS had no obvious drawbacks when compared with that of VATS on propensity-matched analysis.

Keywords: Video-assisted thoracoscopic surgery (VATS); robot-assisted thoracoscopic surgery (RATS); lung cancer; lung resection

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Introduction

Robotic-assisted thoracoscopic surgery (RATS) is characterized by its excellent field of view and the maneuverability of its robotic arms, which can move accurately even in a narrow surgical field. Although it is common in laparoscopic surgery, pressure insufflation with carbon dioxide gas (CO_2) also contributes to a better operative field and may reduce blood loss. Moreover, operators can control the camera by themselves in RATS, which enables the development of an ideal field of view. Thus, RATS has the potential to contribute to surgical safety. However, a limited number of high-quality, large-

Video 1 We perform intraluminal ligation of the proximal part of the pulmonary artery branches and seal and cut off the periphery using the daVinci vessel sealing system.

scale randomized trials were reported. Although there are a growing number of retrospective studies comparing RATS and video-assisted thoracoscopic surgery (VATS), the results are conflicting and many reports are limited to including a small number of cases (1-3). Moreover, it is quite difficult to eliminate selection bias in these papers. In this study, we matched interlobar fissure completeness, which increases operative difficulty, operative complications, and operative time; however, this has been superficially compared in previous studies.

Therefore, we evaluated the perioperative outcomes of RATS and VATS lobectomies for lung cancer using a propensity score-matched analysis.

The rapid increase in RATS has led to the development of new and useful devices. However, the surgery employing these devices; daVinci Staplers and vessel sealing system (VSS) have not yet been fully explored. RATS allows the operator to perform the treatment with the superior maneuverability provided by the robotic arms. However, the assistant is blocked by the robotic arms, making it difficult to perform the procedures. To overcome this disadvantage, we developed solo surgery by the operator that is less dependent on an assistant in the operative field.

The pulmonary artery (PA) is usually treated with staplers or hemoclips in RATS lobectomy, and there are few reports of intraluminal ligation of the PA. At our institute, we perform intraluminal ligation of the proximal part of the PA branches and seal and cut off the periphery using the da Vinci VSS (*Video 1*). Moreover, we used the da Vinci stapler for fissure division and bronchial stapling by an operator rather than hand-held staplers, reducing the assistant's stapler use.

In this study, we compared the results of RATS solo lobectomy with VATS lobectomy for lung cancer resection. We present the following article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-21-1696/rc).

Methods

Subjects and study design

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study protocol was approved by the institutional review board of Sapporo Medical University (IRB No. 322-265) and informed consent was waived due to the retrospective nature of the study. This study was a retrospective analysis of patient data from January 2017 to December 2020.

Ultimately, four hundred and eleven patients who underwent pulmonary lobectomy with node dissection were included. Segmentectomy were excluded from the study. Medical records of the patients were reviewed and the precise characteristics were recorded (*Table 1*). The surgeon graded the fissures prospectively at the time of surgery. From our surgical database, we recorded information regarding the lobe fissure completeness using the Craig and Walker classification. We defined incomplete fissure as an interlobar fissure completeness of ≥3 based on the Craig and Walker classification (4).

The indications for RATS and VATS lobectomy were clinical T1–T3, N0–N1, and M0. The preoperative assessments for all patients included chest computed tomography (CT) imaging, bronchoscopy, standard hematology and blood chemistry, cardiological examination, pulmonary function test, and brain magnetic resonance imaging or CT. Positron emission tomography (PET)/CT was taken in almost all patients. Abdominal ultrasound and bone scan were performed in cases in which PET/CT was not performed. Using the propensity score matching (PSM), we compared the perioperative outcomes by two different approaches.

Surgical procedure

VATS approach was performed with one mini-thoracotomy and two ports in all cases. A mini-thoracotomy (35 mm) was placed at the level of the fourth intercostal space (ICS). Then, two ports were placed at the sixth and seventh ICS.

Table 1 Patient demographics (n=411)

Characteristics	RATS (n=103)	VATS (n=308)	P value
Age (years), mean (SD)	68.6 (8.9)	70.6 (8.5)	0.04
Sex (male/female), n	53/50	152/156	0.73
BMI (kg/m^2), mean (SD)	23.3 (3.4)	23.2 (3.5)	0.67
Smoking status, n			0.90
Ever	72	211	
Never	31	97	
%VC, mean (SD)	112.6 (15.9)	108.0 (16.7)	0.02
FEV_1%, mean (SD)	76.4 (11.1)	74.3 (14.8)	0.18
Tumor laterality, n			0.05
Right	62	219	
Left	41	89	
Tumor location, n			0.25
Right upper lobe	34	133	
Right middle lobe	8	20	
Right lower lobe	20	66	
Left upper lobe	23	51	
Left lower lobe	18	38	
Incomplete fissure, n			0.01
−	97	261	
+	6	47	
Clinical stage, n			0.49
IA1	10	39	
IA2	28	83	
IA3	27	66	
IB	13	42	
IIA	3	17	
IIB or more	22	61	
Maximum tumor size (mm), mean (SD)	20.6 (11.8)	24.9 (14.7)	0.01

Incomplete fissure: "−" means absence, and the "+" means presence of the incomplete fissure ≥ grade 3. RATS, robot-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery; SD, standard deviation; BMI, body mass index; %VC, percent vital capacity; %FEV_1, percent forced expired volume in 1 second.

With respect to processing the PA, the proximal part of the PA branch is ligated with a silk thread. Then, the vessel is divided by the VSS. Regarding mediastinal lymph node dissection (MLND), our technique relies on the VSS, which can help control lymphatic leakage (5).

RATS is usually performed using 4-arm robotic techniques, following the method of Cerfolio *et al.* (6). This study was limited to surgery using the daVinci Xi. MLND was conducted by a lobar-specific way. ND2a-2 was performed based on the frozen section diagnosis. Postoperative analgesia was provided using an epidural catheter. All patients were administered postoperative

Table 2 Perioperative outcome and number of dissected lymph nodes (n=411)

Characteristics	RATS (n=103)	VATS (n=308)	P value
Operation time (min), mean (SD)	214.9 (56.1)	206.9 (88.2)	0.28
Bleeding amount (mL), mean (SD)	52.7 (94.7)	124.2 (243.5)	<0.001
Duration of chest tube (days), mean (SD)	1.9 (2.8)	2.6 (4.1)	0.045
Postoperative stay (days), mean (SD)	10.1 (4.1)	12.0 (5.6)	<0.001
Intraoperative complication, n (%)	12 (11.7)	49 (15.9)	0.72
Emergent thoracotomy, n (%)	0	7 (2.3)	0.20
Postoperative complication, n (%)	13 (12.6)	34 (11.0)	0.34
Persistent air leakage, n (%)	3 (2.9)	30 (9.7)	0.03
Number of dissected lymph nodes, mean (SD)			
Total lymph nodes	20.0 (8.6)	19.3 (9.9)	0.53
Mediastinal lymph nodes	12.1 (7.0)	11.8 (7.7)	0.73
Mechanical stapler used	4.3 (1.8)	4.6 (2.1)	0.10

RATS, robot-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery; SD, standard deviation.

nonsteroidal anti-inflammatory drugs (NSAIDs) and ibuprofen at fixed times, adding an opiate in subjects with poor pain control. The epidural catheter was removed when postoperative pain subsided with a visual analogue scale score of 2. The duration of the epidural tube use was used to compare the difference in postoperative pain between the study groups.

A suction pressure of 5 cmH_2O was provided to the chest tube. A persistent air leak (PAL) lasting more than 5 days was defined as a postoperative PAL. The chest tube was removed when there was no air leakage, not serum, and less than 6 cc/kg/day.

Statistical analysis

All patients were matched one-to-one between the RATS and the VATS lobectomy groups. The nearest estimated propensity score was employed to minimalize selection bias among patients. Covariates including age, sex, tumor location, smoking status, fissure completeness, body mass index (BMI), percent vital capacity (%VC), percent forced expired volume in 1 second (%FEV_1), and maximum tumor diameter were selected to estimate the propensity score. We matched propensity scores one-to-one using nearest-neighbor matching methods without replacement using a 0.20 caliper width. After the matching procedure, 100 patients were selected for each group (VATS and RATS) for statistical analysis.

Descriptive statistics are reported as means for continuous variables and tabulated as frequencies and percentages for categorical variables. All statistical analyses were performed using SPSS for Windows (version 22.0; SPSS, Inc., Chicago, IL, USA). Student's *t*-test, χ^2 or Fisher's exact test was performed for analysis. Differences were considered statistically significant at P<0.05.

Results

Patient characteristics in the unmatched cohort

In total, 411 patients fulfilled the inclusion criteria for this study: 103 RATS and 308 VATS lobectomies. Almost two-thirds of patients treated with VATS were on the right side (P=0.05); more patients treated with VATS had incomplete fissures (P=0.01). The average pulmonary function (%VC) was also slightly better in the RATS group than in the VATS group (P=0.02). The maximum tumor size was larger in the VATS group (24.9 *vs.* 20.6 mm, P=0.01). Age, sex, BMI, smoking status, FEV_1, tumor location, and clinical stage were similar (*Table 1*).

Surgery-related outcomes in the unmatched cohort

Table 2 summarizes the surgery-related outcomes. The surgical complication rates were comparable between the groups (intraoperative, postoperative, P=0.721, P=0.339). Emergent thoracotomy was necessary for seven patients in the VATS group but none in the RATS group. Persistent air leakage was more frequent in the VATS group (RATS: 2.9%, VATS: 9.7%, P=0.03). The mean operation times were 214.9 and 206.9 min in the RATS and VATS groups, respectively; P=0.28. The other surgery-related outcomes were as follows: mean intraoperative blood loss (52.7 *vs.* 124.2 mL, P<0.001), mean chest tube duration (1.9 *vs.* 2.6 days, P=0.045), mean postoperative hospital stay (10.1 *vs.* 12.0 days, P<0.001), number of dissected lymph nodes (total: 20.0 *vs.* 19.3, mediastinal: 12.1 *vs.* 11.8, P=0.53 and 0.73, respectively), and the number of mechanical stapler cartridges used (4.3 *vs.* 4.6, P=0.10) in the RATS and the VATS groups, respectively.

Characteristics of the propensity score-matched patients

After PSM, 100 patients were included in each surgical group (n=200). Patient and disease characteristics were well balanced between the groups in the matched cohort (*Table 3*). Most importantly, we confirmed that interlobar fissure completeness was almost similar between the groups.

Surgery-related outcomes of the propensity score-matched patients

Table 4 summarizes the surgery-related outcomes. The rates of postoperative complications were comparable between the groups (RATS: 10.0% *vs.* VATS 13.0%, P=0.66). Emergent thoracotomy was necessary in two cases in the VATS group. There was no emergent thoracotomy in the RATS group. The rates of intraoperative complications were comparable between the groups (RATS: 12.0% *vs.* VATS 7.0%, P=0.24). Persistent air leakage was comparable (RATS: 3.0%, VATS: 8.0%, P=0.21). The mean operation times were 215.0 and 210.1 min in the RATS and VATS groups, respectively (P=0.57). The other surgery-related outcomes were as follows: mean intraoperative blood loss (53.3 *vs.* 120.3 mL, P=0.04), mean chest tube duration (1.9 *vs.* 2.4 days, P=0.31), mean postoperative hospital stay (10.0 *vs.* 11.5 days, P=0.04); the number of dissected lymph nodes (total: 20.0 *vs.* 17.6, mediastinal: 12.0 *vs.* 10.6, P=0.05 and P=0.18, respectively), and the number of mechanical stapler cartridges used during surgery (4.3 *vs.* 4.6, P=0.25).

Additionally, pathological results were analyzed. Regarding resection completeness, no difference was found between the two groups. The upstaging rate of N factor (12% *vs.* 8%, P=0.48) and T factor (28% *vs.* 21%, P=0.32) was compared, and no difference was observed.

Discussion

Thoracoscopic lung resection for lung cancer has shown improved perioperative outcomes and oncological effects similar to open thoracotomy (7-9). RATS is characterized by its high-definition three-dimensional (3D) images and the maneuverability of its robotic arms (9). These features of RATS make the thorough, technically demanding lymph node dissection relatively easy. Although the results are conflicting and many reports are limited to including a small number of cases (2,3). In previous studies using the huge database, RATS was reported to have the advantage of decreased length of stay and decreased conversion rate compared to VATS (10,11). Though propensity matching was performed to reduce the selection bias in these studies, interlobar fissure completeness was not accounted into variables to be matched. We think interlobar fissure completeness affect the operative difficulty and operative time at a non-negligible level.

Therefore, in this study, we tried to reduce the selection bias to use the precise matching that includes the interlobar fissure completeness. In the present study, we observed no demonstrable disadvantages of robotic surgery over the traditional thoracoscopic technique. We observed no difference in surgical complications between the RATS and the VATS groups (intraoperative, postoperative, P=0.24, P=0.66). Emergent thoracotomy was not necessary in the RATS group.

Cerfolio *et al.* reported that emergent thoracotomy conversions were required in 39 of 632 patients (6.1%) with RATS anatomical lung resection (12). Hence, Ueno reported that three of 192 patients required the emergent thoracotomy conversions due to bleeding with RATS anatomical lung resection (2.3%) (13). In this study, most of the PA injured lesions were peripheral parts of the PA. Therefore, there was no bleeding from PA more than 500 mL. This may have resulted in no emergent thoracotomy conversions in the RATS group. In addition, robotic solo lobectomy for lung cancer was found to dramatically reduce intraoperative blood loss compared to VATS surgery (53.3 *vs.* 120.3 mL, P=0.04). We believe that the exceptional surgical view made possible by the high-definition 3D images and the careful dissection around PA by the robotic arms contributed to this phenomenon. Although the reduction of intraoperative blood loss did not affect the

Table 3 Patient demographics after PSM (n=200)

Characteristics	RATS (n=100)	VATS (n=100)	P value
Age (years), mean (SD)	68.9 (8.8)	68.8 (9.2)	0.94
Sex (male/female), n	52/48	51/49	0.99
BMI (kg/m^2), mean (SD)	23.4 (3.5)	23.0 (3.6)	0.47
Smoking status, n			0.88
Ever	70	68	
Never	30	32	
%VC, mean (SD)	112.3 (15.8)	114.6 (16.5)	0.32
FEV_1%, mean (SD)	76.4 (11.1)	76.2 (15.2)	0.92
Tumor laterality, n			0.46
Right	61	67	
Left	39	33	
Primary lobe, n			0.75
Right upper lobe	33	40	
Right middle lobe	8	5	
Right lower lobe	20	22	
Left upper lobe	23	20	
Left lower lobe	16	13	
Incomplete fissure, n			0.99
−	94	93	
+	6	7	
Clinical stage, n			0.45
IA1	15	14	
IA2	31	30	
IA3	28	19	
IB	9	11	
IIA	3	8	
IIB or more	14	18	
Maximum tumor size (mm), mean (SD)	20.5 (11.7)	21.0 (10.9)	0.76
Pathological stage, n			0.21
IA1	10	18	
IA2	32	23	
IA3	17	17	
IB	18	20	
IIA	0	5	
IIB or more	23	24	

Incomplete fissure: "−" means absence, and the "+" means presence of the incomplete fissure ≥ grade 3. PSM, propensity score matching; RATS, robot-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery; SD, standard deviation; BMI, body mass index; %VC, percent vital capacity; %FEV_1, percent forced expired volume in 1 second.

Table 4 Perioperative outcome and number of dissected lymph nodes after PSM (n=200)

Characteristics	RATS (n=100)	VATS (n=100)	P value
Operation time (min), mean (SD)	215.0 (56.3)	210.1 (64.9)	0.57
Bleeding amount (mL), mean (SD)	53.3 (95.5)	120.3 (314.7)	0.04
Blood transfusion, n	0	1	0.99
Duration of chest tube (days), mean (SD)	1.9 (2.8)	2.4 (4.3)	0.31
Duration of epidural tube (days), mean (SD)	1.6 (1.2)	1.7 (1.2)	0.86
Postoperative stay (days), mean (SD)	10.0 (4.2)	11.5 (5.6)	0.04
Intraoperative complication, n (%)	12.0 (12.0)	7.0 (7.0)	0.24
Emergent thoracotomy, n (%)	0	2.0 (2.0)	0.50
Postoperative complication, n (%)	10.0 (10.0)	13.0 (13.0)	0.66
Persistent air leakage, n	3	8	0.21
Cerebral infarction, n	1	0	0.99
Arrhythmia, n	2	2	0.99
Pneumonia, n	1	3	0.62
Laryngeal nerve palsy, n	1	1	0.99
Wound trouble, n	2	0	0.50
Number of dissected lymph nodes, mean (SD)			
Total lymph nodes	20.0 (8.7)	17.6 (8.5)	0.05
Mediastinal lymph nodes	12.0 (7.1)	10.6 (7.4)	0.18
Upstaging of N-factor, n	12	8	0.48
Upstaging of T-factor, n	28	21	0.32
Mechanical stapler used, mean (SD)	4.3 (1.8)	4.6 (2.1)	0.25
Resection completeness, n			0.99
R0	97	97	
R1	2	2	
R2	1	1	

PSM, propensity score matching; RATS, robot-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery; SD, standard deviation.

blood transfusion rate in this study, a clear operative field must have improved the operative quality.

Moreover, in our robotic solo lobectomy, there was no increase in operative time compared to VATS surgery. Swanson *et al.* showed no differences in surgical complication rates from a multi-hospital database with 295 propensity score-matched cases during VATS and RATS lobectomies (14). Regarding the intraoperative complication, we experienced two vessel injuries resulting from daVinci forceps interference. With the magnified vision, the surgeon must pay attention to the fact that the surgical field view becomes quite narrow. We compared the differences between the VATS and RATS groups in terms of patients' baseline characteristics (*Table 1*). As this study includes our initial cases for robotic surgery, we preferred simpler cases for the first 20 cases for RATS lobectomy. We avoided the patients with interlobar fissure incompleteness and clinical node positivity.

Thereafter, we put no bias in patient selection for RATS lobectomy. Moreover, we matched interlobar fissure incompleteness with PSM (*Table 3*). However, the type of surgery (VATS or RATS) was decided at the discretion of the surgeon, this could affect the outcome of each surgery. Therefore, the inherent selection bias cannot be ruled out.

When the stapler was used, the assistant experienced considerable difficulty when blocked by the robotic arms. To overcome this disadvantage, we developed solo surgery by the operator that is less dependent on assistants in the operative field. In part, this factor might have resulted in the reduction of blood loss in the RATS group.

In thoracoscopic surgery, the ligation of blood vessels is controlled by the tactile sensation directly transmitted to the operator's hand; However, in RATS, these sensations are not transmitted. Therefore, there is the inherent risk of accidentally damaging blood vessels or threads. However, an experienced operator in thoracoscopic surgery can safely perform surgery by inferring the force applied from the video information.

Nonetheless, it is desirable to have a tactile sensation to enhance the safety and quality of the surgery, which is being gradually developed (15,16). One of the advantages of RATS is its maneuverability, allowing surgeons to perform extensive lymph node resections (17). The number of lymph nodes dissected in this study suggests that it is similar between the RATS and VATS groups. Previous studies have shown the equivalence of two minimally invasive approaches (18). Whereas, some reported the higher upstaging rate in RATS (19). Further randomized prospective studies would be needed (6).

We observed a shorter postoperative stay in the RATS group. Although it may seem long, it is shorter compared to the 15.5 days reported by the Japan Hospital Information Organization database [2020] (20). The difference in postoperative stay could be attributable to the reduction in pain, we are unable to judge the superiority of RATS in this aspect in this study. we did not observe any difference in the duration of epidural tube use. Although many studies reported that RATS showed a more favorable pain control profile compared with thoracotomy, there were no significant difference between RATS and VATS (21,22).

This study has some limitations. First, this study was a single-center retrospective study reviewing medical records. Propensity matching reduced but did not eliminate selection bias, and prospective randomized studies are required. Second, the robot data in this series contains initial experiences that may skew the results, then inherent selection bias cannot be eliminated. However, because of previous experiences of open and thoracoscopic pulmonary resection, as well as the relatively steep learning curve (23), we believe the difference in experience between the two approaches would be minimized although not eliminated. Third, postoperative pain and long-term survival were not analyzed in this study

Conclusions

The initial experience of RATS lobectomy had no obvious drawbacks compared to VATS technique by propensity score-matched analysis. Moreover, we ascertained that robotic solo lobectomy for lung cancer was safe and effective.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-21-1696/rc

Data Sharing Statement: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-21-1696/dss

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-21-1696/coif). 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 study protocol was approved by the institutional review board of Sapporo Medical University (IRB No. 322-265) and informed consent was waived due to the retrospective nature of the study.

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