Clinical Research

Early Outcomes of Robotic Versus Video-Assisted Thoracoscopic Anatomical Resection for Lung Cancer

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Background: We compared the safety and effectiveness of robotic anatomical resection and video-assisted thoracoscopic surgery (VATS).
Methods: A retrospective analysis was conducted of the records of 4,283 patients, in whom an attempt was made to perform minimally invasive anatomical resection for lung cancer at Seoul National University Hospital from January 2011 to July 2020. Of these patients, 138 underwent robotic surgery and 4,145 underwent VATS. Perioperative outcomes were compared after propensity score matching including age, sex, height, weight, pulmonary function, smoking status, performance status, comorbidities, type of resection, combined bronchoplasty/angioplasty, tumor size, clinical T/N category, histology, and neoadjuvant treatment.
Results: In total, 137 well-balanced pairs were obtained. There were no cases of 30-day mortality in the entire cohort. Conversion to thoracotomy was required more frequently in the VATS group (VATS 6.6% vs. robotic 0.7%, p=0.008). The complete resection rate (VATS 97.8% vs. robotic 98.5%, p=1.000) and postoperative complication rate (VATS 17.5% vs. robotic 19.0%, p=0.874) were not significantly different between the 2 groups. The robotic group showed a slightly shorter hospital stay (VATS 5.8±3.9 days vs. robotic 5.0±3.6 days, p=0.052). N2 nodal upstaging (cN0/pN2) was more common in the robotic group than the VATS group, but without statistical significance (VATS 4% vs. robotic 12%, p=0.077).
Conclusion: Robotic anatomical resection in lung cancer showed comparable early outcomes when compared to VATS. In particular, robotic resection presented a lower conversion-to-thoracotomy rate. Furthermore, a robotic approach might improve lymph node harvesting in the N2 station.

Keywords: Robotic surgical procedures, Lung neoplasms, Minimally invasive surgery

Introduction

Minimally invasive surgery has become a standard technique for lung cancer worldwide. Video-assisted thoracoscopic surgery (VATS) has been established as the gold standard for early-stage lung cancer based on its superiority to open thoracotomy in terms of low postoperative morbidity and comparable long-term survival [1,2]. Meanwhile, robot-assisted thoracoscopic surgery (RATS) has recently gained popularity due to its improved vision and the advantages offered by robotic instruments. Technical advances in robotic systems have provided a less invasive method with oncologic completeness for the surgical treatment of lung cancer.

Previous studies showed comparable short-term and long-term outcomes in RATS for lung cancer compared to VATS and thoracotomy [3-6]. Most of all, adequate lymph node yields have been confirmed [7,8]. Furthermore, RATS has been shown to be feasible and safe even in cases of locally advanced lung cancer and in technically demanding procedures such as sleeve resection or angioplasty, where RATS can achieve oncologic integrity [9-11].

Hence, we evaluated the safety and effectiveness of robotic anatomical resection in comparison to VATS at a high-volume center.

Methods

Ethical statement

The study was approved by the Institutional Review Board of Seoul National University Hospital. The requirement for individual consent was waived (approval no., H-2010-114-1165).

Patients

We conducted a retrospective study of patients who underwent curative anatomical resection via VATS or RATS for lung cancer between January 2011 and July 2020. We excluded patients who underwent (1) intentional thoracotomy, (2) non-curative surgery (i.e., biopsy only), and (3) non-anatomical resection. A total of 4,283 patients were enrolled in this study, including 4,145 who underwent VATS and 138 who underwent RATS (Fig. 1).

There were no differences in the preoperative and postoperative treatment protocol between the approaches. Data on patients' baseline characteristics, pathologic results, and short-term outcomes were collected. The postoperative complications were described according to the Clavien–Dindo classification. The clinical and pathologic stages were evaluated according to the seventh edition of the TNM classification for lung cancer.

Operative techniques

VATS has been adopted for lung cancer since 2005, and currently over 80% of patients with lung cancer undergo curative resection via VATS at our institution. We implemented RATS for lung cancer in 2011 using the da Vinci system (Intuitive, Sunnyvale, CA, USA). After our early experience, RATS has been performed based on conventional port placement following previous research [12,13]. However, this technique has some drawbacks associated with the need for an assistant surgeon and a small working space in the Asian population. Moreover, since the da Vinci Xi system was released, robotic staplers can be fully utilized in thoracic surgery. Therefore, we have modified robotic port placement for lung cancer, with an anterolateral approach [14]. We believe that the current port placement maximizes the advantages of robotic surgery, which are as follows: (1) full use of the 4 robotic arms, (2) solo surgery without the need of an assistant's help, (3) sufficient distance between the robotic arms in patients with small chests, and (4) sufficient intrathoracic space for a robotic stapler. The first utility incision was made in the fifth intercostal space along the anterior axillary line, measuring 3 cm. In patients requiring tissue diagnosis before anatomic lung resection, wedge resection was usually performed by an uniportal technique through this utility incision. The second port was made 7.5 cm below the first port and was usually located in the seventh intercostal space along the anterior axillary line. The third port was the camera port, which was made in the ninth intercostal space along the midaxillary line. The fourth port was made in the 11th intercostal space, along the posterior axillary line, anterior to the scapular tip since a posterior location can increase the conflict between the grasper and the vertebral body during subcarinal lymph node dissection [14].

Statistical analysis

All statistical analyses were performed using IBM SPSS ver. 22.0 (IBM Corp., Armonk, NY, USA). The Student t-test and Wilcoxon rank-sum test were used to compare continuous variables. Propensity score matching was used
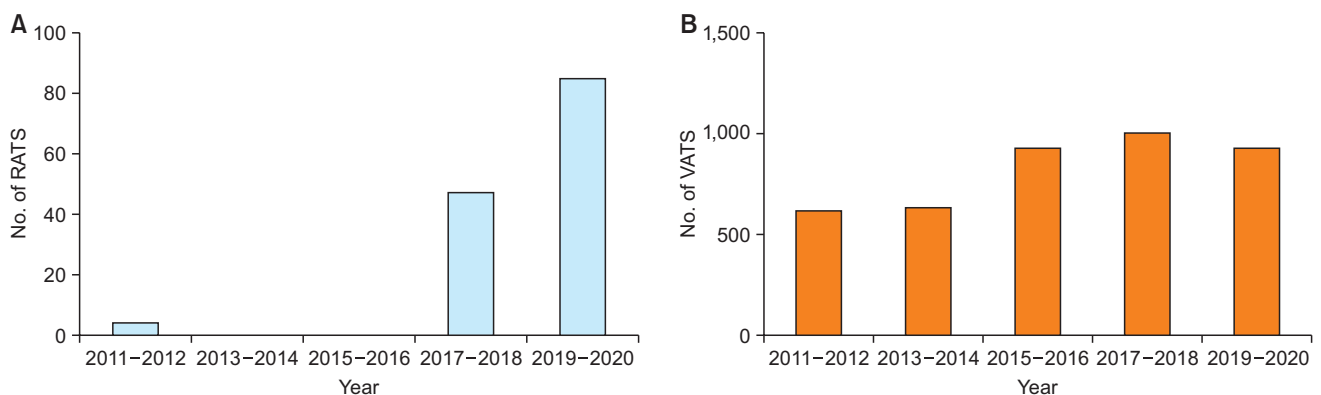

Fig. 1. Number of operations per year: (A) robot-assisted thoracoscopic surgery (RATS) and (B) video-assisted thoracoscopic surgery (VATS).

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to adjust for between-group differences in baseline characteristics and disease severity. The propensity scores were based on logistic regression modeling, which included the following variables: age, sex, height, weight, pulmonary function, smoking status, performance status, comorbidities, type of resection, combined bronchoplasty/angioplasty, tumor size, clinical T/N category, histology and neoadjuvant treatment. We matched the propensity scores 1-to-1 using the nearest-neighbor method without replacement, with a 0.2 caliper width. After the matching procedure, 137 patients from each group were selected for analysis. All statistical analyses were performed using 2-sided tests, and statistical significance was set at $p < 0.05$.

Results

The baseline characteristics of the study population before and after matching are shown in Table 1. The distribution of age, sex, height, weight, pulmonary function, smoking status, performance status, comorbidities, type of resection, combined bronchoplasty/angioplasty, tumor size,

clinical T/N category, histology, and neoadjuvant treatment were comparable between the 2 groups after propensity score matching. In the matched cohort, the between-group difference in terms of whether bronchoplasty/angioplasty was performed decreased (VATS 5.1% versus RATS 6.6%). Most patients enrolled in this study were in clinical stage T1 (VATS 70.8% versus RATS 62.0%) and N0 (VATS 94.2% versus RATS 89.8%). The neoadjuvant treatment rate was 0.7% and 1.5% in VATS and RATS, respectively. Most of the patients in the study underwent mediastinal lymph node dissection, and fewer than 3% of patients underwent mediastinal lymph node sampling.

Operative outcomes

Table 2 demonstrates the operative outcomes. In the matched cohort, there were no cases of 30-day mortality in the entire cohort. Conversion to thoracotomy was significantly lower in the RATS group than in the VATS group (VATS 6.6% versus RATS 0.7%, p=0.008). Nine cases (6.6%) in the matched VATS group required conversion to thora-

Table 1. Preoperative characteristics of the study population

Characteristic	Unmatched patients			Propensity score-matched patients		
	VATS (N=4,145)	RATS (N=138)	SMD	VATS (N=137)	RATS (N=137)	SMD
Age (yr)	63.4±9.8	63.9±9.6	-0.02	63.4±10.7	63.9±9.7	0.06
Sex (male)	2,129 (51.4)	72 (52.2)	0.02	64 (46.7)	71 (51.8)	0.10
Height (cm)	161.5±8.4	162.1±9.0	0.07	161.6±8.2	162.2±9.1	0.06
Weight (kg)	62.1±14.6	63.1±10.9	0.09	62.9±11.2	63.0±10.9	0.01
Never-smoker	2,255 (54.4)	71 (51.4)	0.06	77 (56.2)	71 (51.88)	0.09
FVC (%)	102.9±19.8	103.3±14.6	-0.04	103.9±14.0	103.3±14.6	-0.04
FEV_1 (%)	105.5±18.5	106.7±19.3	0.00	106.8±18.1	106.8±19.3	0.00
Size on CT scan (cm)	2.6±1.4	2.7±1.5	0.04	2.5±1.4	2.6±1.5	0.12
Comorbidities						
Diabetes mellitus	685 (13.5)	17 (12.3)	-0.13	18 (13.1)	17 (12.4)	-0.02
Renal insufficiency	126 (3.0)	8 (5.8)	0.12	4 (2.9)	7 (5.1)	0.09
Pulmonary disease	513 (12.4)	12 (8.7)	-0.13	7 (5.1)	12 (8.8)	0.13
Cardiovascular disease	1,597 (38.5)	46 (33.3)	-0.11	44 (48.9)	46 (51.1)	0.03
Cancer history	745 (18.0)	26 (18.8)	0.02	27 (19.7)	26 (19.0)	-0.02
Neoadjuvant treatment	27 (0.7)	2 (1.4)	0.07	1 (0.7)	2 (1.5)	0.06
Clinical T1 (vs. >T2)	2,619 (63.2)	85 (61.6)	0.03	97 (70.8)	85 (62.0)	0.18
Clinical N0 (vs. >N1)	3,804 (91.8)	123 (89.1)	0.08	129 (94.2)	123 (89.8)	0.14
Extent of resection						
Segmentectomy	501 (12.1)	20 (14.5)	0.04	26 (19.0)	20 (14.6)	-0.10
Lobectomy	3,619 (87.3)	117 (84.7)	-0.07	111 (80.2)	116 (85.2)	0.10
Pneumonectomy	25 (0.6)	1 (0.7)	0.01	0	1 (0.7)	0.09
Bronchoplasty or angioplasty	74 (1.8)	9 (6.5)	0.19	7 (5.1)	9 (6.6)	0.06
Mediastinal LN dissection	4,018 (96.9)	134 (97.1)	0.00	132 (96.4)	133 (97.1)	-0.04
Adenocarcinoma	3,433 (82.8)	109 (79.6)	0.10	109 (79.6)	109 (79.6)	0.03

Values are presented as mean±standard deviation or number (%), unless otherwise stated.
VATS, video-assisted thoracoscopic surgery; RATS, robot-assisted thoracoscopic surgery; SMD, standardized mean difference; FVC, forced vital capacity; FEV_1, forced expiratory volume in one second; CT, computed tomography; LN, lymph node.

Table 2. Perioperative data of the study population

Variable	Unmatched patients			Propensity score-matched patients		
	VATS (N=4,145)	RATS (N=138)	p-value	VATS (N=137)	RATS (N=137)	p-value
Thoracotomy conversion	314 (7.6)	1 (0.7)	0.001	9 (6.6)	1 (0.7)	0.008
Hospital stay (day)	5.9±6.0	5.0±3.6	0.087	5.8±3.9	5.0±3.6	0.052
Complication rate	785 (18.9)	26 (18.8)	0.829	24 (17.5)	26 (19.0)	0.874
≥Grade III	227 (5.5)	7 (5.1)	1.000	6 (4.4)	7 (5.1)	1.000
30-day mortality	4 (0.1)	0	1.000	0	0	-
Complete resection	4,125 (99.5)	136 (98.6)	0.157	134 (97.8)	135 (98.5)	1.000
No. of resected lymph nodes	24.3±10.3	24.1±8.8	0.825	23.0±9.4	24.0±8.8	0.0370
Nodal upstaging	475 (11.5)	24 (17.4)	0.033	13 (9.5)	24 (17.5)	0.052
cN0/pN1	212 (5.1)	12 (8.7)	0.6186	9 (6.6)	12 (8.8)	0.664
cN0/pN2	260 (6.3)	12 (8.7)	0.915	4 (2.9)	12 (8.8)	0.077

Values are presented as mean±standard deviation or number (%), unless otherwise stated.
VATS, video-assisted thoracoscopic surgery; RATS, robot-assisted thoracoscopic surgery.

Table 3. Cause of conversion to thoracotomy

Variable	Propensity score-matched patients	
	VATS (N=9)	RATS (N=1)
Technical difficulty	8	0
Anthracotic lymph node	3	0
Extensive adhesion	2	0
Angioplasty	2	0
Bronchoplasty	1	0
Uncontrolled bleeding	1	1

VATS, video-assisted thoracoscopic surgery; RATS, robot-assisted thoracoscopic surgery.

cotomy because of technical difficulty including anthracofibrotic lymph nodes, extensive adhesion, bronchoplasty/angioplasty, and uncontrolled bleeding (Table 3). One patient in the matched RATS group (0.7%) required conversion to thoracotomy due to uncontrolled bleeding. The postoperative complication rate (VATS 17.5% versus RATS 19.0%, p=0.874) was not significantly different between the 2 groups. The length of hospital stay tended to be slightly shorter in the RATS group than in the VATS group (VATS 5.8±3.9 days versus RATS 5.0±3.6 days, p=0.052). The complete resection rate (VATS 97.8% versus RATS 98.5%, p=1.000) and number of resected lymph nodes (VATS 23.0±9.4 versus RATS 24.0±8.8, p=0.370) were similar between the 2 groups. In the unmatched cohort, nodal upstaging in the RATS group was significantly higher than in the VATS group (VATS 11.5% versus RATS 17.4%, p=0.033). However, the difference lost significance in the matched cohort (VATS 9.5% versus RATS 17.5%, p=0.052). N1 nodal upstaging (cN0/pN1) was similar between the 2 groups (VATS 6.6% versus RATS 8.8%, p=0.664). N2 nodal upstaging (cN0/pN2) tended to be more common in the

RATS group than in the VATS group, but without statistical significance (VATS 4% versus RATS 12%, p=0.077) in the matched cohort.

Discussion

We compared the early clinical outcomes of VATS and RATS for anatomical lung cancer surgery. Our propensity-matched analysis revealed that RATS was safe and had satisfactory short-term oncologic outcomes, in terms of postoperative complications and complete resection with sufficient lymph node yield. In addition, RATS was associated with a lower conversion rate than that of VATS despite technically demanding procedures, which were more commonly performed in RATS.

The previous literature consistently showed a lower conversion rate for RATS than for VATS [15,16]. Furthermore, the maximal utilization of robotic techniques makes it possible to perform sleeve resection with decreased bleeding loss, early tube removal, shorter operative time, and similar survival compared to VATS and thoracotomy [17-19]. In experienced hands, intraoperative bleeding can be managed without conversion to thoracotomy [20]. In particular, anthracofibrotic lymph nodes are a significant predictor of intraoperative conversion to thoracotomy, as shown in our study [21]. In tuberculosis-endemic regions, hilar anthracofibrosis results in massive bleeding or injury to the bronchus while surgeons dissect the adjacent pulmonary vessels and bronchus. However, robotic techniques allow meticulous dissection between the pulmonary artery and bronchus at the level of the distal part, which makes the dissection safe.

The number of dissected lymph nodes and nodal upstag-

ing are essential components of surgical resection for lung cancer. As part of oncologic clearance, nodal upstaging and the number of harvested lymph nodes are surrogates for the quality of lung cancer surgery. Our study showed that the number of resected lymph nodes was similar between RATS and VATS; however, nodal upstaging tended to be more common in the RATS group than in the VATS group. Previous studies have revealed that RATS achieved a higher lymph node yield and upstaging rate than those of VATS [3,22], which might be associated with meticulous hilar and mediastinal dissection and the excellent surgical view offered by the robotic technique. Similarly, locally advanced cancers are potential candidates for the robotic technique [17-19].

VATS has been established as a standard minimally invasive approach for lung cancer. However, there have been discrepancies in the utilization of VATS according to region and hospital volume [23-25]. VATS or RATS is strongly recommended when there is no compromise of oncologic principles [26]. At experienced centers, minimally invasive surgery was found to improve early outcomes including reduced pain, decreased length of hospital stay, rapid functional recovery, and low complications with comparable oncologic outcomes in treating lung cancer. However, VATS anatomical resection had a significant learning curve [27, 28]. Meanwhile, RATS may flatten the learning curve of the surgical technique to gain the necessary proficiency without previous experience of minimally invasive surgery [29,30]. Consequently, the utilization of RATS for lung cancer has increased faster than that of VATS in the United States [23].

Some limitations of the present study should be noted. First, there might have been selection bias due to the retrospective nature of this study, which was conducted at a single institution, and the lack of randomization. Nonetheless, we conducted propensity score matching to minimize selection bias. Moreover, long-term clinical outcomes were not evaluated, warranting further research.

In conclusion, robotic anatomical resection for lung cancer resulted in comparable early outcomes compared with those of VATS. In particular, robotic resection resulted in a lower rate of conversion to thoracotomy. Furthermore, a robotic approach might improve lymph node harvesting in the N2 station.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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