Early outcomes of robotic versus thoracoscopic segmentectomy for early-stage lung cancer: A multi-institutional propensity score-matched analysis

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Yajie Zhang, MD, PhD,[a] Chun Chen, MD, PhD,[b] Jian Hu, MD, PhD,[c] Yu Han, MD,[a] Maosheng Huang, MD,[d] Jie Xiang, MD,[a] and Hecheng Li, MD, PhD[a]

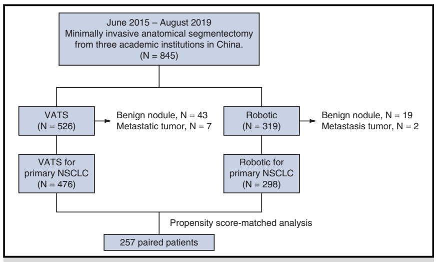
ABSTRACT

Objectives: Anatomical segmentectomy via robotic thoracic surgery and video-assisted thoracic surgery (VATS) are minimally invasive surgical approaches for treatment of early-stage non–small cell lung cancer (NSCLC). However, few research studies have compared early outcomes.

Methods: A retrospective analysis was made of 774 patients, 298 who received robotic and 476 who received VATS, who underwent minimally invasive segmentectomy for early-stage NSCLC at 3 academic institutions between June 2015 and August 2019. Perioperative outcomes were compared after propensity score-matching on the basis of age, gender, body mass index, percent forced expiratory volume in 1 second, smoking status, American Society of Anesthesiologists score, type of segmentectomy, tumor size, and institution.

Results: There were 257 patients in each group after propensity score-matching. The baseline characteristics and type of segmentectomy were comparable. Three conversions to thoracotomy occurred in the VATS group, and 1 in the robotic group ($P = .624$). There was no significant difference in operative time (147.91 ± 52.42 vs 149.23 ± 49.66 minutes; $P = .773$), blood loss (50 mL [interquartile range (IQR), 50-100 mL] vs 100 mL [IQR, 30-100 mL]; $P = .177$), rates of overall complications (17.9 vs 14.8%; $P = .340$), and length of stay (4 days [IQR, 3-5 days] vs 4 days [IQR, 3-5 days]; $P = .417$) between the robotic and VATS groups, respectively. Robotic segmentectomy was more costly ($12,019.30 ± 1678.30 vs $7834.80 ± 1291.20; $P < .001$) because of the amortization and consumables of the robotic system. There were a greater number of N1 lymph nodes and N1 stations in the robotic group.

Conclusions: Segmentectomy with robotic and VATS are safe and feasible for early-stage NSCLC treatment. A robotic approach might lead to a better N1 lymph node dissection. (J Thorac Cardiovasc Surg 2020;160:1363-72)



Flow of the patients through the study.

CENTRAL MESSAGE

Robotic segmentectomy resulted in comparable short-term outcomes compared with VATS segmentectomy for early NSCLC. A potential benefit of robotics might relate to an improved N1 lymph node retrieval.

PERSPECTIVE

Few research studies have compared perioperative outcomes of robotic and VATS segmentectomy for early-stage NSCLC. In our multi-institutional study, using a propensity score-matched analysis, we showed that robotic portal segmentectomy resulted in comparable short-term outcomes and oncologic safety compared with VATS. A potential benefit of robotics might relate to an improved N1 lymph node retrieval.

See Commentaries on pages 1373 and 1374.

Lung cancer remains the leading cause of cancer incidence and mortality worldwide, with non-small cell lung cancer (NSCLC) accounting for 85% of all lung cancers.[1,2] With the implementation of lung cancer screening protocols using low-dose computed tomography for high-risk patients, an increasing number of small early-stage NSCLC

From the [a]Department of Thoracic Surgery, Ruijin Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai, China; [b]Department of Thoracic Surgery, Fujian Medical University Union Hospital, Fuzhou, China; [c]Department of Thoracic Surgery, The First Affiliated Hospital, School of Medicine, Zhejiang University, Hangzhou, China; and [d]Department of Epidemiology, the University of Texas M.D. Anderson Cancer Center, Houston, Tex.
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Drs Zhang, Chen, Hu, and Han contributed equally to this work.
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Address for reprints: Hecheng Li, MD, PhD, Department of Thoracic Surgery, Ruijin Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai 200025, China (E-mail: lihecheng2000@hotmail.com).
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Abbreviations and Acronyms

%FEV1	= percent forced expiratory volume in 1 second
IQR	= interquartile range
NSCLC	= non–small cell lung cancer
PSM	= propensity score matched
VATS	= video-assisted thoracic surgery

Scanning this QR code will take you to the article title page to access supplementary information.

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(≤2 cm) have been identified.[3] For these lesions, particularly those that present as ground-glass opacities, anatomical segmentectomy could be considered as an effective alternative to lobectomy, provided that adequate margins and accurate lymph node staging are obtained.[4,5] In addition, anatomical segmentectomy has been implemented to offer better pulmonary function preservation than lobectomy for patients with impaired lung function and enhance the possibility of further resections in the case of a second primary lung cancer.[6,7]

Over the recent years, video-assisted thoracic surgery (VATS) has been gradually extended from full lobar resections to technically challenging procedures, such as segmentectomy,[8] with benefits of reduced postoperative pain,[9] fewer complications,[10] and shorter hospital stay.[10] However, hilar dissection in anatomical segmentectomies can be technically more complex than lobectomy because of the extended and more distal isolation of segmental vessels and bronchi, which requires a thorough familiarity of segmental anatomy and delicate maneuvers. Moreover, some segments can be difficult to be removed because of the deep location of vessels and bronchi into the parenchyma.[11] These difficulties are compounded by the inherent drawbacks of VATS systems including counter-intuitive hand movements to manipulate the instruments, an instrument fulcrum effect, and 2-dimensional visualization. A considerable learning curve has to be overcome before a surgeon is proficient in using this technique.[12,13]

Recently, robotic thoracic surgery has been introduced to provide advantages over traditional VATS, including 3-dimensional field of view, improved greater dexterity, no fulcrum effect, filtration of physiological tremor, and greater comfort for surgeons.[14] However, robotic thoracic surgery has also some drawbacks compared with VATS, such as a lack of tactile feedback and being more costly. Although there has been an increasing adoption of robotic surgery for anatomical segmentectomies,[15-17] the literature published in this area is still sparse. More importantly, there is little evidence to confirm whether robotic systems can provide perioperative and oncologic outcomes comparable with VATS segmentectomy. The aim of this multi-institutional study was to compare the short-term outcomes, oncologic safety, and cost–benefit analysis of anatomical segmentectomy for early-stage NSCLC of robotic and VATS approaches using a propensity score matched (PSM) analysis.

METHODS

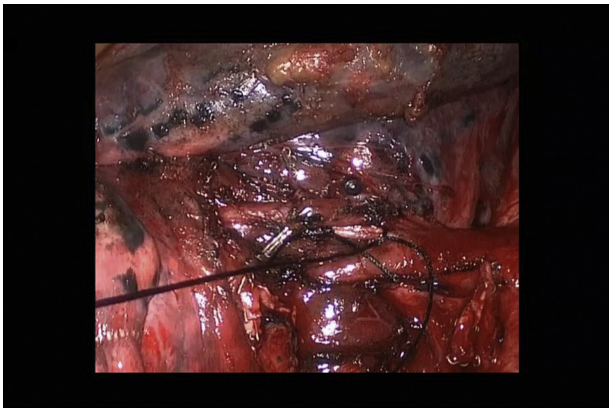
Patients

We performed a retrospective study of patients who underwent minimally invasive anatomical segmentectomy including robotic and VATS for early-stage NSCLC at 3 academic medical centers between June 2015 and August 2019. Data were prospectively collected and retrospectively analyzed using an investigational review board-approved system (KY201996), which includes approved between-institution sharing protocols and appropriate deidentification of patients for privacy protection. Because of its retrospective nature, informed patient consent was not required. The indications for anatomical segmentectomy for early-stage lung cancer in our series include: (1) preoperatively biopsied lung tumor nodules or nonbiopsied nodules highly suspected to be disease ≤2 cm, (2) nodule ≥50% ground-glass appearance on computed tomography or radiologic surveillance confirmation of a long doubling time (≥400 days), and (3) no lymph node metastasis. Segmentectomies can be classified into typical and atypical on the basis of the difficulty of the procedure.[18,19] Typical segmentectomies include segmentectomy of the left upper lobe (trisegmentectomy or lingulectomy), superior segment (S^6), and basilar segments; whereas atypical segmentectomies include segmentectomies of individual segments of the upper, middle, and lower lobes (except S^6) or combined segmentectomies (ie, bisegmentectomy or segmentectomy combined with subsegmentectomy). Hook–wire localization and 3-dimensional images of computed tomography angiography and bronchography (Xudong, Shenzhen, China) were selectively used in some difficult and/or atypical segmentectomies. All of the patients chose the surgical approach according to their own preference.

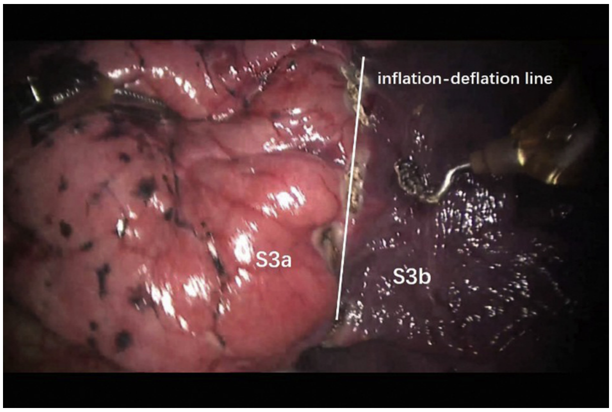
There was no difference in the preoperative preparation and postoperative treatment protocol in the robotic and VATS segmentectomy procedures. The basic demographic characteristics, pathological results, and short-term outcomes data were collected. Percent forced expiratory volume in 1 second (%FEV1) was divided into 3 categories: ≥80%, 50% to 80%, and <50%, on the basis of the Global Initiative for Chronic Obstructive Disease classification of airflow limitation severity in chronic obstructive pulmonary disease.[20] The postoperative complications were described according to the Clavien–Dindo classification.[21] The clinical and pathological stages were evaluated according to the eighth edition of the TNM classification for lung cancer.[22] The total overall cost for each patient was calculated as the sum of the direct cost and the indirect cost by the 3 academic institutions' financial divisions. Direct cost was defined as the cost of any items used in the care of the patient, including all operating room disposable supplies, staplers, laboratory tests, imaging studies, and medications. The indirect costs are the sum of all additional costs for the hospital that is comprised of overhead cost and amortization of capital equipment, including of the purchase and maintenance of minimally invasive platforms.

Techniques

VATS segmentectomy was performed using videoscopic guidance (Karl Storz, Tuttlingen, Germany) via 1 to 3 incisions without rib spreading



VIDEO 1. VATS left $S^{1+2}+S^3c$ segmentectomy. Video available at: https://www.jtcvs.org/article/S0022-5223(20)30226-9/fulltext.



VIDEO 2. Robotic portal right S^2b+S^3a segmentectomy. Video available at: https://www.jtcvs.org/article/S0022-5223(20)30226-9/fulltext.

(Video 1). Robotic portal segmentectomy (Model S; Intuitive Surgical, Inc, Sunnyvale, Calif) using a 4-arm technique was performed as we previously described (Video 2).[23] In both techniques, segmentectomies were performed by dissecting the fissure and removing the nodes around the segmental artery and bronchus. Arteries and veins were clipped with Hem-o-Lok (Teleflex, Morrisville, NC) or stapled with a vascular stapler. Bronchus was subsequently isolated and stapled. The imaginary intersegmental plane was stapled after ventilating and deflating the remnant lung. Mediastinal and hilar nodes were always dissected. During the procedure, frozen section analysis was performed on enlarged resected nodes (>1 cm), and parenchymal and bronchial margins. Positive margins or lymph node invasion would dictate conversion to a lobectomy.

Statistical Analysis

To minimize the bias caused by the nonrandomized selection of patients, PSM analysis was performed to control the baseline characteristics between the 2 different groups using R Project Software (version 2.14.1; http://www.r-project.org). Each patient's propensity score was calculated from a multivariable logistic regression model with covariates, including age, gender, body mass index, %FEV1, smoking status, American Society of Anesthesiologists score, type of segmentectomy, tumor size, and institution. Patients treated with robotic segmentectomy were matched 1:1 with no replacement to patients treated with VATS segmentectomy using the nearest-neighbor method with a caliper with of 0.01.

The statistical analysis was performed using SPSS version 20.0 (IBM Corp, Armonk, NY). The Student *t* test or Wilcoxon rank sum test was applied to compare the continuous variables between the groups, and the χ^2 test or Fisher exact test was applied for comparing the categorical data.

RESULTS

Patient Characteristics

Between June 2015 and August 2019, a total of 774 patients who fulfilled the selection criteria underwent minimally invasive anatomical segmentectomy for early-stage NSCLC completed using robotic (n = 298) or VATS (n = 476; Figure 1). Patient demographic and clinical characteristics before and after PSM are summarized in Table 1. Before propensity score matching, the robotic and VATS cohorts were comparable with respect to age, gender, body mass index, %FEV1, and type of segmentectomy, however, differed in American Society of Anesthesiologists score, smoking history, and tumor size. After propensity score matching, 257 paired patients were matched. As expected, this resulted in similar distributions of propensity scores (Figure 2) and baseline characteristics (Table 1).

Type of Segmentectomy

Table 2 shows the type of segmentectomy of robotic and VATS. After propensity score matching, the type of segmentectomy was well distributed between the 2 groups. The robotic group included 110 typical (42.8%) and 147 atypical (57.2%) segmentectomies, whereas the VATS group consisted of 106 (41.2%) typical and 151 atypical (58.8%) segmentectomies (P = .721). Of all typical segmentectomies, the S^6 of both lungs was the most common segmental resection performed followed by the trisegmentectomy ($S^{1+2}+S^3$) of the left lung in both groups. As for atypical segmentectomies, the most frequent segmental resections were the apical segmentectomy (S^1) of the right lung and the apical posterior segmentectomy (S^{1+2}) of the left lung. In both groups, the atypical segmentectomy included bisegmentectomy or segmentectomy combined with subsegmentectomy, such as right S^2+S^1a, S^2+S^3a, S^2b+S^3a, and S^9+S^8b, left $S^{1+2}(a+b)$, and $S^{1+2}+S^3c$.

Perioperative Outcomes

Table 3 shows the perioperative outcomes of the 2 groups. After propensity score matching, one conversion to thoracotomy occurred in the robotic group because of the pulmonary artery injury, whereas in the VATS group, 2 were converted to thoracotomy because of the pulmonary artery injury, and the other was due to severe chest adhesion. There was no in-hospital or 30-day mortality in either group. No significant difference was

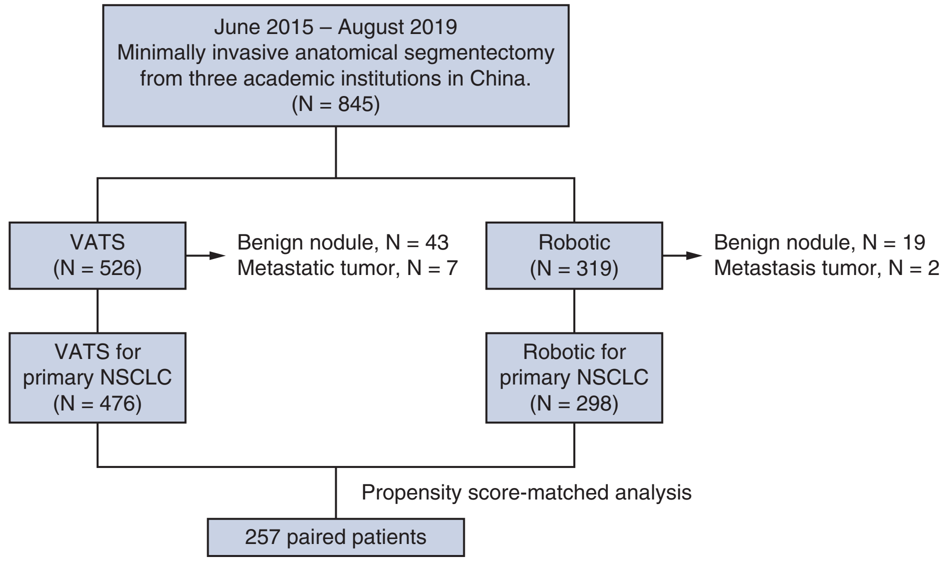


FIGURE 1. Flow of the patients through the study. *VATS*, Video-assisted thoracic surgery; *NSCLC*, non–small cell lung cancer.

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observed in the operative time (147.91 ± 52.42 minutes vs 149.23 ± 49.66 minutes; *P* = .773), intraoperative blood loss (50 mL [interquartile range (IQR), 50-100 mL] vs 100 mL [IQR, 30-100 mL]; *P* = .177), and the overall complication rate (17.9 vs 14.8%; *P* = .340) for robotic and VATS. There were no significant differences in the

TABLE 1. Patient characteristics

	Before propensity score matching			After propensity score matching		
Characteristic*	Robotic (n = 298)	VATS (n = 476)	*P* value	Robotic (n = 257)	VATS (n = 257)	*P* value
Age, y	53.15 ± 10.78	54.57 ± 11.66	.089	53.53 ± 10.96	52.21 ± 11.89	.184
Gender			.938			.641
Male	106 (35.6)	168 (35.3)		84 (32.7)	89 (34.6)	
Female	192 (64.4)	308 (64.7)		173 (67.3)	168 (65.4)	
BMI	23.16 ± 2.63	22.84 ± 3.37	.160	23.13 ± 2.71	23.02 ± 3.88	.689
%FEV1			.078			.838
≥0.8	272 (91.3)	411 (86.3)		231 (89.9)	231 (89.9)	
0.5-0.8	24 (8.1)	63 (13.2)		24 (9.3)	25 (9.7)	
<0.5	2 (0.7)	2 (0.4)		2 (0.8)	1 (0.4)	
ASA score			.046			.622
1	126 (42.3)	163 (34.2)		94 (36.6)	101 (39.3)	
2	158 (53.0)	278 (58.4)		149 (58.0)	146 (56.8)	
3	14 (4.7)	35 (7.4)		14 (5.4)	10 (3.9)	
Tobacco use			.023			.302
Current smokers	40 (13.4)	36 (7.6)		24 (9.3)	26 (10.1)	
Abstained for at least 1 y	10 (3.4)	22 (4.6)		8 (3.1)	15 (5.8)	
Never	248 (83.2)	418 (87.8)		225 (87.5)	216 (84.0)	
Hook-wire localization	93 (31.2)	123 (25.8)	.105	73 (28.4)	80 (31.1)	.500
3D-CTAB	75 (25.2)	144 (30.3)	.126	66 (25.7)	72 (28.0)	.550
Type of segmentectomy			.757			.721
Typical	115 (38.6)	189 (39.7)		110 (42.8)	106 (41.2)	
Atypical	183 (61.4)	287 (60.3)		147 (57.2)	151 (58.8)	
Tumor size, cm	0.88 ± 0.40	0.99 ± 0.55	.001	0.90 ± 0.40	0.90 ± 0.40	.572

VATS, Video-assisted thoracic surgery; *BMI*, body mass index; *%FEV1*, percent forced expiratory volume in 1 second; *ASA*, American Society of Anesthesiologists; *CTAB*, computed tomography angiography and bronchography. *Categoric data are expressed as n (%) and continuous data as mean ± standard deviation.

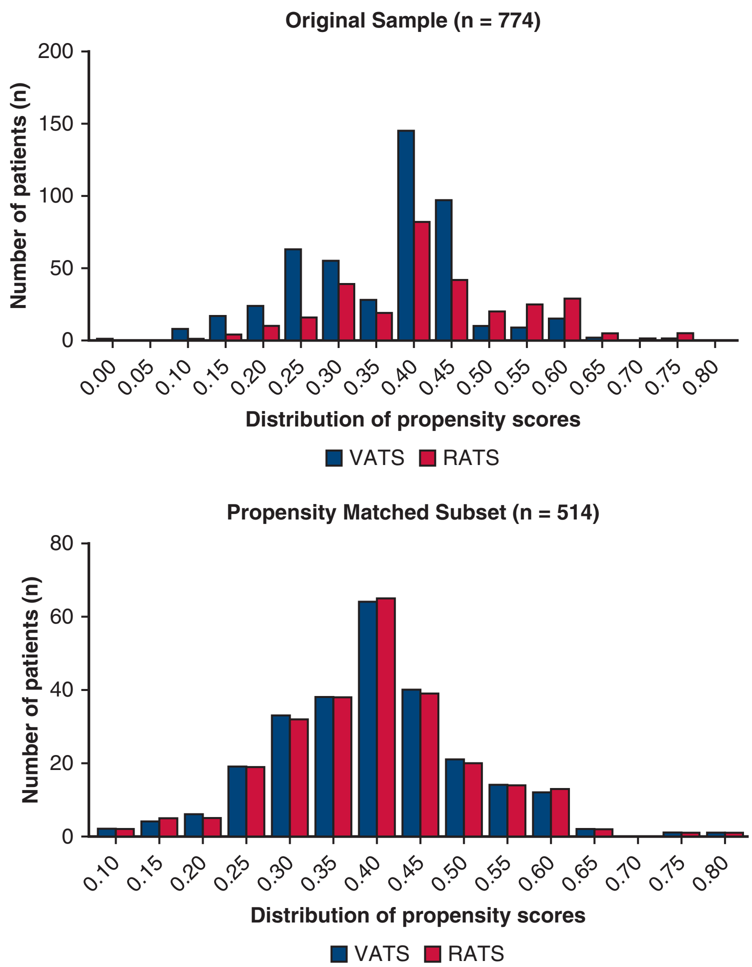

FIGURE 2. Distribution of propensity scores before and after matching. *VATS*, Video-assisted thoracic surgery; *RATS*, robot-assisted thoracic surgery.

mean duration of drainage (3 days [IQR, 2-4 days] vs 3 days [IQR, 2-4 days]; $P = .121$), length of stay (4 days [IQR, 3-5 days] vs 4 days [IQR, 3-5 days]; $P = .417$), and 30-day readmission rate (2.3% vs 1.6%; $P = .523$) in comparisons of robotic and VATS groups.

Pathologic Outcomes

Table 4 shows the pathologic outcomes of the 2 groups. After propensity score matching, the R0 resection was achieved in all patients, except for 1 patient in the VATS group. Adenocarcinoma was the most common pathological type in both groups (99.6% vs 99.2%; $P = .606$). The distributions of T and N stage were similar between the 2 groups. One clinical T1bN0 (cT1bN0) adenocarcinoma in the VATS group and 2 cT1bN0 in the robotic group were upstaged to pathological T1cN0 (pT1cN0) because of the tumor size in the pathological specimens. Two cT1bN0 adenocarcinoma in the robotic group were upstaged to pT1bN2 because of microscopic N2 nodal metastasis. As for lymph node dissections, although there was no significant difference in the number (4 [IQR, 3-7] vs 4 [IQR, 2-7]; $P = .511$) or the stations (3 [IQR, 2.5-4] vs 3 [IQR, 2-4]; $P = .131$) of N2 lymph nodes removed from the 2 groups, the number (4 [IQR, 2-6] vs 3 [IQR, 2-4]; $P < .01$) and the stations (3 [IQR, 2-3] vs 2 [IQR, 1-3]; $P < .01$) of N1 lymph nodes dissected in the robotic group were greater than that in the VATS group.

Cost Analysis

The cost comparison according to surgical approach is presented in Table 5. The propensity- adjusted results revealed a higher mean total cost ($12,019.30 ± 1678.30 vs $7834.80 ± 1291.20; $P < .01$) and mean indirect cost ($4300.20 ± 23.00 vs 338.30 ± 19.80; $P < .01$) in the robotic group compared with the VATS group. However, there was no difference in the mean direct cost ($7719.00 ± 1668.50 vs $7496.40 ± 1285.60; $P = .072$) in the 2 groups.

TABLE 2. Type and location of resected segments

Type of segmentectomy*	Before propensity score matching			After propensity score matching		
	Robotic (n = 298)	VATS (n = 476)	*P* value	Robotic (n = 257)	VATS (n = 257)	*P* value
Variable			.126			.353
Typical	115 (38.6)	189 (39.7)		110 (42.8)	106 (41.2)	
Right lung						
S^6	24 (8.1)	42 (8.8)		24 (9.3)	27 (10.5)	
$S^{7+8+9+10}$	1 (0.3)	2 (0.4)		1 (0.4)	1 (0.4)	
Left lung						
$S^{1+2}+S^3$	32 (10.7)	54 (11.3)		31 (12.1)	31 (12.1)	
S^4+S^5	21 (7.0)	38 (8.0)		19 (7.4)	19 (7.4)	
S^6	35 (11.7)	47 (9.9)		33 (12.8)	25 (9.7)	
S^{8+9+10}	2 (0.7)	6 (1.3)		2 (0.8)	3 (1.2)	
Atypical	183 (61.4)	287 (60.3)		147 (57.2)	151 (58.8)	
Right lung						
S^1	43 (14.4)	60 (12.6)		35 (13.6)	34 (13.2)	
S^1+S^2	6 (2.0)	13 (0.6)		6 (2.3)	8 (3.1)	
S^1+S^2a	–	3 (0.6)		–	2 (0.8)	
S^1+S^3	–	5 (1.1)		–	4 (1.6)	
S^1a	2 (0.7)	–		2 (0.8)	–	
S^1b+S^3b	–	1 (0.2)		–	–	
S^2	24 (8.1)	41 (8.6)		19 (7.4)	15 (5.8)	
S^2+S^1a	4 (1.3)	2 (0.4)		2 (0.8)	–	
S^2+S^3a	2 (0.7)	1 (0.2)		1 (0.4)	1 (0.4)	
S^2+S^3	–	1 (0.2)		–	1 (0.4)	
S^2b+S^3a	5 (1.7)	4 (0.8)		5 (1.9)	3 (1.2)	
S^3	12 (0.4)	19 (4.0)		12 (4.7)	13 (5.1)	
S^3+S^1b	1 (0.3)	1 (0.2)		1 (0.4)	–	
S^4	1 (0.3)	–		–	–	
S^4+S^6	1 (0.3)	–		1 (0.4)	–	
S^6+S^8	–	1 (0.2)		–	–	
S^6+S^9a	–	1 (0.2)		–	1 (0.4)	
S^6+S^{10}	1 (0.3)	1 (0.2)		1 (0.4)	1 (0.4)	
S^7	1 (0.3)	1 (0.2)		1 (0.4)	1 (0.4)	
S^7+S^8	–	1 (0.2)		–	1 (0.4)	
S^8	12 (4.0)	12 (2.5)		10 (3.9)	9 (3.5)	
S^8+S^9	1 (0.3)	3 (0.6)		0	2 (0.8)	
S^9	1 (0.3)	1 (0.2)		1 (0.4)	–	
S^9+S^8b	1 (0.3)	–		1 (0.4)	–	
S^9+S^{10}	6 (2.0)	–		4 (1.6)	–	
Left lung						
S^1	1 (0.3)	2 (0.4)		1 (0.4)	1 (0.4)	
S^{1+2}	29 (9.8)	62 (13.1)		23 (8.9)	30 (11.7)	
$S^{1+2}a$	–	1 (0.2)		–	1 (0.4)	
$S^{1+2}b$	1 (0.3)	–		–	–	
$S^{1+2}c$	2 (0.7)	2 (0.4)		2 (0.8)	–	
$S^{1+2}(a+b)$	2 (0.7)	13 (2.7)		1 (0.4)	6 (2.3)	
$S^{1+2}+S^3c$	2 (0.7)	4 (0.8)		1 (0.4)	3 (1.2)	
S^2	4 (1.3)	2 (0.4)		2 (0.8)	1 (0.4)	
S^3	5 (1.7)	8 (1.7)		5 (1.9)	3 (1.2)	
$S^4+S^5+S^6$	2 (0.7)	–		2 (0.8)	–	
$S^4+S^5+S^9$	1 (0.3)	–		1 (0.4)	–	
S^6+S^8	1 (0.3)	–		1 (0.4)	–	
S^6+S^{10}	–	1 (0.2)		–	–	
$S^6+S^9+S^{10}$	–	1 (0.2)		–	1 (0.4)	
S^8	4 (1.3)	14 (2.9)		2 (0.8)	7 (2.7)	

(Continued)

TABLE 2. Continued

Type of segmentectomy*	Before propensity score matching			After propensity score matching		
	Robotic (n = 298)	VATS (n = 476)	*P* value	Robotic (n = 257)	VATS (n = 257)	*P* value
S^8+S^9	2 (0.7)	–		2 (0.8)	–	
S^9	1 (0.3)	–		1 (0.4)	–	
S^{10}	2 (0.7)	3 (0.6)		1 (0.4)	1 (0.4)	
S^9+S^{10}	–	2 (0.4)		–	1 (0.4)	

VATS, Video-assisted thoracic surgery. *Categoric data are expressed as n (%).

DISCUSSION

With the development of the minimally thoracic surgery, the robotic system might offer the additional advantages of greater dexterity, 3-dimensional vision, and greater surgeon comfort compared with conventional VATS, thereby facilitating precise anatomical pulmonary dissection. In 2016, Cerfolio and colleagues[17] reported their initial experience of 100 patients who underwent robotic segmentectomies and concluded that robotic anatomical segmentectomy is safe and effective and offers outstanding intraoperative, 30-day, and 90-day results with the median length of stay of 3 days and major morbidity, which occurred in 2 patients. Recently, Cerfolio and colleagues[24] updated their data with a series of 245 consecutive patients representing the largest series of robotic segmentectomy. The median operative time was 86 minutes, overall postoperative complications occurred in 65 patients (26.5%)—3 of which were major; there was no 30- or 90-day mortality and the average length of stay was 3.1 days. As for the comparison of robotic and VATS approaches for anatomical segmentectomy, Rinieri and colleagues[25] compared 32 video- and 16 robot-assisted segmentectomy, and reported that the short-term results were similar for the 2 groups with less estimated blood loss in the robotic group. Demir and colleagues[26] reported comparable morbidity and mortality rates with a longer operative time in a comparison of 34 robotic and 65 VATS segmentectomies. However, both case series

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TABLE 3. Perioperative outcomes

Characteristic*	Before propensity score matching			After propensity score matching		
	Robotic (n = 298)	VATS (n = 476)	*P* value	Robotic (n = 257)	VATS (n = 257)	*P* value
Operative time, min	147.41 ± 50.39	149.94 ± 48.67	.488	147.91 ± 52.42	149.23 ± 49.66	.773
Blood loss (IQR), mL	50 (50-100)	50 (30-100)	.048	50 (50-100)	100 (30-100)	.177
Conversion to thoracotomy	1 (0.3)	7 (1.5)	.162	1 (0.4)	3 (1.2)	.624
Conversion to lobectomy	0	1 (0.2)	1.000	0	1 (0.4)	1.000
30-Day morbidity	55 (18.5)	68 (14.3)	.123	46 (17.9)	38 (14.8)	.340
Clavien I-II	40 (13.4)	61 (12.8)	.807	33 (12.8)	31 (12.1)	.694
Atrial fibrillation	3 (1.0)	5 (1.1)	1.000	3 (1.2)	1 (0.4)	.624
Air leak	18 (6.0)	11 (2.3)	.008	11 (4.3)	5 (1.9)	.128
Pleural effusion	6 (2.0)	24 (5.0)	.034	6 (2.3)	14 (5.4)	.068
Pneumonia	13 (4.4)	20 (4.2)	.914	13 (5.1)	10 (3.9)	.671
Wound infection	0	1 (0.2)	1.000	0	1 (0.4)	1.000
Clavien III-IV	15 (5.0)	7 (1.5)	.004	13 (5.1)	7 (2.7)	.168
Air leak	4 (1.3)	1 (0.2)	.075	3 (1.2)	1 (0.4)	.624
Pleural effusion	9 (3.0)	6 (1.3)	.084	9 (3.5)	6 (2.3)	.432
Pneumonia	1 (0.3)	0	.385	0	0	–
Wound infection	1 (0.3)	0	.385	1 (0.4)	0	1.000
Readmission, n (%)	7 (2.3)	6 (1.3)	.252	6 (2.3)	4 (1.6)	.523
In-hospital mortality	0	0	–	0	0	–
30-Day mortality	0	0	–	0	0	–
Median duration of drainage (IQR), d	3 (2-4)	2 (2-3)	.001	3 (2-4)	3 (2-4)	.121
Median LOS (IQR), d	4 (3-5)	4 (3-5)	.606	4 (3-5)	4 (3-5)	.417

VATS, Video-assisted thoracic surgery; *IQR*, interquartile range; *LOS*, length of stay. *Categoric data are expressed as n (%) and continuous data as mean ± standard deviation or median (interquartile range).

TABLE 4. Pathological outcomes

Characteristic*	Before propensity score matching			After propensity score matching		
	Robotic (n = 298)	VATS (n = 476)	P value	Robotic (n = 257)	VATS (n = 257)	P value
Histology lung cancer			.691			.606
Adenocarcinoma	297 (99.7)	474 (99.6)		256 (99.6)	255 (99.2)	
Squamous-cell carcinoma	0	1 (0.2)		0	1 (0.4)	
Other	1 (0.3)	1 (0.2)		1 (0.4)	1 (0.4)	
R0 resection	298 (100)	475 (99.8)	1.000	257 (100)	256 (99.6)	1.000
pT stage lung cancer			.552			.774
Tis	14 (4.7)	20 (4.2)		9 (3.5)	13 (5.1)	
T1a	218 (73.2)	334 (70.2)		191 (74.3)	187 (72.8)	
T1b	63 (21.1)	112 (23.5)		55 (21.4)	56 (21.8)	
T1c	3 (1.0)	10 (2.1)		2 (0.8)	1 (0.4)	
pN stage lung cancer			.654			.499
N0	296 (99.3)	473 (99.4)		255 (99.2)	257 (100)	
N1	0	1 (0.2)		0	0	
N2	2 (0.7)	2 (0.4)		2 (0.8)	0	
T upstaged	3 (1.0)	10 (2.1)	.249	2 (0.8)	1 (0.4)	.624
N upstaged	2 (0.7)	3 (0.6)	.945	2 (0.8)	0	.249
N1 upstaged	0	1 (0.2)	1.000	0	0	–
N2 upstaged	2 (0.7)	2 (0.4)	.636	2 (0.8)	0	.249
Median LN1 stations (IQR)	3 (2-3)	2 (1-3)	<.01	3 (2-3)	2 (1-3)	<.01
Median LN2 stations (IQR)	3 (3-4)	3 (2-3)	<.01	3 (2.5-4)	3 (2-4)	.131
Median number of LN1 (IQR)	4 (2-6)	3 (1-5)	<.01	4 (2-6)	3 (2-4)	<.01
Median number of LN2 (IQR)	4 (3-6)	4 (2-7)	.208	4 (3-7)	4 (2-7)	.511

VATS, Video-assisted thoracic surgery; *LN*, lymph node; *IQR*, interquartile range. *Categoric data are expressed as n (%) and continuous data as mean ± standard deviation or median (interquartile range).

contained relatively small numbers of patients, and the pathology included primary, metastatic, and benign pulmonary nodules. Moreover, most types of segmentectomy in both case series were typical segmentectomies.[25,26]

The results of our study show that robotic anatomical segmentectomy resulted in comparable perioperative outcomes with a higher mean number of dissected N1 lymph nodes compared with VATS segmentectomy for early-stage NSCLC. Notably, our current report includes a larger number of cases from multiple institutions, focuses on early-stage NSCLC, covers nearly all types of segmentectomies, and is the first, to our knowledge, to apply a PSM study design to minimize potential selection bias.

Lymph node assessment including the number of dissected lymph nodes and the rate of nodal upstaging is an important component of minimally invasive segmentectomy for lung cancer. In our series, the number and the stations of N1 lymph nodes retrieved using the robotic approach were higher than those achieved using VATS. Our finding was in line with recent reports. Mungo and colleagues[27] reported that robot-assisted anatomical lung resection was associated with more lymph node retrieval than the VATS approach. Robotic segmentectomy with

TABLE 5. Cost analysis

Characteristic*	Before propensity score matching			After propensity score matching		
	Robotic (n = 298)	VATS (n = 476)	P value	Robotic (n = 257)	VATS (n = 257)	P value
Total cost ($)	11,930.90 ± 1652.10	7841.30 ± 1404.30	<.01	12,019.30 ± 1678.30	7834.80 ± 1291.20	<.01
Direct cost ($)	7631.10 ± 1642.10	7512.20 ± 1400.30	.283	7719.00 ± 1668.50	7496.40 ± 1285.60	.072
Indirect cost ($)	4299.80 ± 22.40	336.90 ± 16.60	<.01	4300.20 ± 23.00	338.30 ± 19.80	<.01

VATS, Video-assisted thoracic surgery. *Continuous data are presented as mean ± standard deviation.

the wrist arms technique might provide better dissection capabilities around smaller vessels and the lymph nodes around lobar and segment bronchi. In addition, in the immediacy of the operation it allows easier and safer passage of the stapler. Another important surrogate for completeness of nodal evaluation and quality of surgery is the rate of pathological nodal upstaging. Wilson and colleagues[28] reported that the rate of nodal upstaging for robotic anatomical resection including lobectomy and segmentectomy appeared to be superior to VATS and similar to thoracotomy for stage I NSCLC. They postulated that this was attributable to the robot allowing the interlobar fissure to be directly dissected and hilar nodes removed along the pulmonary vessels and the bronchus, in a similar manner to the open procedure. In our study, there were 2 pathologic nodule upstagings because of N2 lymph nodes metastasis in the robotic group, whereas there was 1 N1 upstaging in the VATS group. The possible reasons for this low rate of nodule upstaging were the careful determination of clinical stage with positron emission tomography and other methods, and strict selection of slowly growing ground-glass nodule for procedures in both cohorts.

Another major concern surrounding the use of the robotic approach for segmentectomy is the economic viability of the technology, which has been also a main point of criticism since its early adoption in anatomical lung resection. Several previous studies have compared the costs of robotic surgery with the VATS approach and consistently have reported them to be higher.[29,30] Some have not shown a difference in cost.[31] However, most of these reports focused on lobectomies accomplished in the United States or Europe. Musgrove and colleagues[32] recently reported comparable direct costs of robotic and VATS pulmonary segmentectomy in a small cohort study. With regard to the cost analysis of the present study, there was no difference in the direct costs of the 2 groups, although the robotic group was associated with higher total and indirect costs. The China National Health Insurance System covers perioperative care for both procedures, part of the operation fees for VATS segmentectomy, and none of the operation fees for robotic segmentectomy. The indirect cost, which was US $3961.90 more for the robotic than the for VATS group, mostly included the robotic-specific supplies and depreciation.

Limitation

This study has several limitations. First, it was conducted in a nonrandomized retrospective manner. Second, the use of the robotic system was on the basis of the patients' economic levels and their own preferences, which might cause selection bias. Even with the PSM analysis, this selection bias could not be ruled out. Third, although the difference in N1 dissection might reflect the advantages of robotic surgical systems in lobar lymph node dissection, the care with which surgeons and pathologists distinguished and labeled these lymph nodes also affected the results to some extent. Finally, the goal of the study was to gain short-term perioperative outcomes, and a longer follow-up is necessary to compare long-term outcomes of these 2 approaches.

CONCLUSIONS

We reported the comparative perioperative outcomes of robotic and VATS anatomical segmentectomy for early-stage NSCLC treatment. A potential benefit of robotics might relate to an improved N1 lymph node retrieval.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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