ORIGINAL ARTICLE

WILEY

Robotic-assisted thoracoscopic surgery improves perioperative outcomes in overweight and obese patients with non–small-cell lung cancer undergoing lobectomy: A propensity score matching analysis

Rongyang Li | **Zheng Ma** | **Yanzhi Li** | **Chenghao Qu** | **Jianhao Qiu** |
Yu Zhang | **Kun Wang** | **Weiming Yue** | **Hui Tian** (ORCID)

Department of Thoracic Surgery, Qilu Hospital of
Shandong University, Jinan, Shandong, China

Correspondence
Hui Tian, Department of Thoracic Surgery, Qilu
Hospital of Shandong University, Jinan,
Shandong, 250000, China.
Email: tianhuiql@email.sdu.edu.cn

Abstract

Background: The effectiveness of robotic-assisted lobectomy (RAL) for patients with non–small-cell lung cancer (NSCLC) has not been fully evaluated.

Methods: This retrospective study compared the perioperative outcomes of NSCLC patients who underwent RAL and video-assisted lobectomy (VAL) using propensity score matching (PSM) analysis. Subgroup analyses were then performed.

Results: A total of 822 NSCLC patients (359 RAL cases and 463 VAL cases) were included, and there were 292 patients in each group after PSM. Compared with the VAL group, the RAL group had a significantly higher number of lymph nodes (LNs) harvested (10 vs. 8, $p < 0.001$) and more LN stations examined (6 vs. 5, $p < 0.001$). The operative duration (95 minutes vs. 115 minutes, $p < 0.001$) and intraoperative estimated blood loss (65 mL vs. 80 mL, $p < 0.001$) were significantly reduced, and the drainage volume on postoperative day (POD) 1 (240 mL vs. 200 mL, $p < 0.001$) and hospitalization costs (¥81084.96 vs. ¥66142.55, $p < 0.001$) were significantly higher in the RAL group. Subgroup analysis indicated that the incidence of postoperative complications (17.9% vs. 26.7%, $p = 0.042$) was significantly reduced in the RAL group for overweight and obese patients (body mass index [BMI] ≥ 24 kg/m^2), which became insignificant in the BMI < 24 kg/m^2 subgroup (31.0% vs. 24.8%, $p = 0.307$).

Conclusion: RAL might have potential advantages in terms of lymph node assessment, reducing intraoperative blood loss, and shortening operation duration. Overweight and obese patients could benefit more from RAL because of reduced risk of postoperative complications.

KEYWORDS
non–small-cell lung cancer, perioperative outcomes, propensity score matching analysis, robotic-assisted lobectomy, video-assisted lobectomy

INTRODUCTION

Non–small-cell lung cancer (NSCLC), the main subtype of lung cancer, remains one of the deadliest cancers worldwide.[1]

Although NSCLC usually requires multidisciplinary and systematic treatment, radical surgical resection remains the standard for diagnosis, treatment, and staging. Lobectomy is still the mainstay of surgical treatment for patients with early-stage

NSCLC and even for those with advanced-stage NSCLC.[2] Minimally invasive lobectomy, such as video-assisted lobectomy (VAL), has been proven to be feasible and oncologically acceptable compared with conventional thoracotomy.[3] As an emerging minimally invasive technique for lobectomy, robotic-assisted lobectomy (RAL) has gradually become a prevalent surgical method for patients with NSCLC.

Since the first RAL was reported by Melfi et al.[4] in 2002, the use of robotic-assisted thoracoscopic surgery has been widely applied in other aspects of thoracic surgery.[5,6] Compared with video-assisted thoracoscopic surgery, robotic-assisted systems can provide surgeons with many advantages, including naked eye three-dimensional (3D) imaging with 10 to 15 times magnification, 360° rotating mechanical arms with a reduction in hand-related tremors and better maneuverability, improved dexterity, and greater comfort.[7,8] Although there has been a recent increase in the popularity and research on robot-assisted surgery, its effectiveness in thoracic surgery remain controversial. Several studies have indicated that RAL may have potential advantages in lymph node dissection, reducing intraoperative blood loss and the incidence of postoperative complications and shortening the length of drainage and postoperative hospitalization stay.[9,10] Other studies have demonstrated that RAL exhibits similar effects compared with VAL in terms of perioperative outcomes and long-term survival.[11,12] Given the heterogeneity in previous studies, we intend to evaluate our institutional outcomes.

The aim of this study was to compare the perioperative outcomes in a large cohort of NSCLC patients who underwent RAL and VAL using propensity score matching (PSM) analysis, determine whether RAL is superior to VAL in the surgical treatment of NSCLC and explore which group of people would benefit more from RAL.

METHODS

Patient selection

A prospectively maintained departmental database of Qilu Hospital of Shandong University was retrieved for patients who underwent a lobectomy for NSCLC from September 2020 to December 2021. The inclusion criteria were NSCLC patients ages ≥18 years who underwent lobectomy with detailed medical records. Patients who underwent multiple lobectomies or lobectomies after prior pulmonary resections, patients who received preoperative neoadjuvant radiotherapy and chemotherapy, patients with a history of lung surgery, and patients with postoperative pathologically confirmed benign lesions were excluded from our study. This retrospective study was approved by The Institutional Review Board of the Qilu Hospital of Shandong University (registration no. KYLL-2020027), and all patients provided informed consent for the use of their clinical information.

Data collection and variable definitions

The following clinical data of NSCLC patients were collected from the database of Qilu Hospital: age, sex, smoking history, body mass index (BMI), percentage of predicted value for forced expiratory volume in 1 second (FEV1% predicted), American Society of Anesthesiologists (ASA) score, operative approach (RAL or VAL), resected lobe, operation duration, estimated blood loss, total number of dissected lymph node (LN), postoperative drainage volume, day of chest tube removal, postoperative numerical rating scale (NRS) pain score, postoperative complications, postoperative length of stay (LOS), total cost of hospitalization, and pathological information. The choice of surgical approach mainly depends on the patients' acceptance of robotic-assisted surgery. Based on good preoperative communication with the patients, the patients chose the surgical method independently. The clinical stages were assessed by two experienced thoracic surgeons based on the patient's preoperative findings, including computed tomography (CT), positron emission tomography (PET)-CT, Tc-99 m bone scan, and endobronchial ultrasound transbronchial needle aspirations (EBUS-TBNA). For patients with suspicious LN metastasis (short diameter of LN >1 cm) shown by contrast-enhanced CT, further PET-CT examination was performed. EBUS-TBNA was performed for patients who were expected to obtain LN pathology by biopsy to further define N staging. Pathological stages were estimated according to the pathologic tumor-node-metastasis (TNM) system (International Union Against Cancer Staging System, 8th edition). Tumor size was defined as the maximum tumor diameter. Postoperative complications were classified according to the Clavien–Dindo classification,[13] including pneumonia, persistent air leak (PAL), chylothorax, and arrhythmia. Air leaks for more than five consecutive days were defined as PAL. The volume of postoperative drainage was recorded by the nurse at 6:00 am every day after the operation. The NRS pain score was evaluated by the nurse at 24, 48, and 72 hours after surgery and was defined as the postoperative day (POD) 1, 2, and 3 NRS score.

Operative procedures

All of the surgeries were performed by three qualified surgeons in a single operation group. The patients in both groups underwent intravenous inhalation combined with anesthesia, and they were lying on the contralateral side with shoulder pads on the chest and adjusted to the folding knife position to increase the width of the intercostal space to fully reveal the hilar structure of the lung. VAL was performed using standard thoracoscopic techniques with two conventional incision operations: one 3 cm auxiliary operative incision at the 4th intercostal space (ICS) between the anterior axillary line and midclavicular line (3rd ICS for upper and middle lobectomy) and one camera port at the 6th or 7th ICS posterior axillary line. RAL was performed using the fourth-generation Da Vinci surgical

system with a four-port approach. The camera port was selected ~2 cm posterior to the seventh ICS posterior axillary line, the sixth ICS midaxillary line and 8th ICS subscapular line were the manipulator ports (the interval between the three holes was ~8 cm), and the position of the auxiliary operative incision was approximately the same as that of the VAL. Systematic hilar and mediastinal LN dissection were routinely performed according to the National Comprehensive Cancer Network (NCCN) guidelines,[14] and the station and the number of dissected LNs were marked. The disconnection of blood vessels and bronchi was completed by assistants with experience in thoracoscopy through auxiliary incision, and 1 or 2 chest tubes were placed after the operation depending on surgeon performance.

Postoperative management

All patients received postoperative analgesia with an analgesic pump, and the intravenous use of nonsteroidal anti-inflammatory drugs three times a day was applied for pain relief. The chest tube could be removed if there was no pneumonia, subcutaneous emphysema or pneumothorax with daily drainage less than 200 mL. A digital continuous

negative pressure drainage device with a negative pressure range of 6 to 10 cm water column was used for patients with persistent air leaks or poor lung re-expansion. All patients in this study were managed using an enhanced recovery after surgery program.

Propensity score matching

To increase accuracy in between-group comparisons, a 1:1 PSM analysis was applied to ensure an even distribution of confounders between two groups. R Project software (v4.1.1; http://www.R-project.org) was used to calculate the propensity score with a multivariate logistic regression model. The variables used to determine PSM were age, sex, BMI, smoking history, FEV1% predicted, ASA score, histology type, tumor size and pathological TNM (pTNM) stage, and the caliper size was selected as 0.01.

Statistical analysis

Categorical variables were compared using the Pearson χ^2 test or Fisher's exact test. Normally distributed continuous
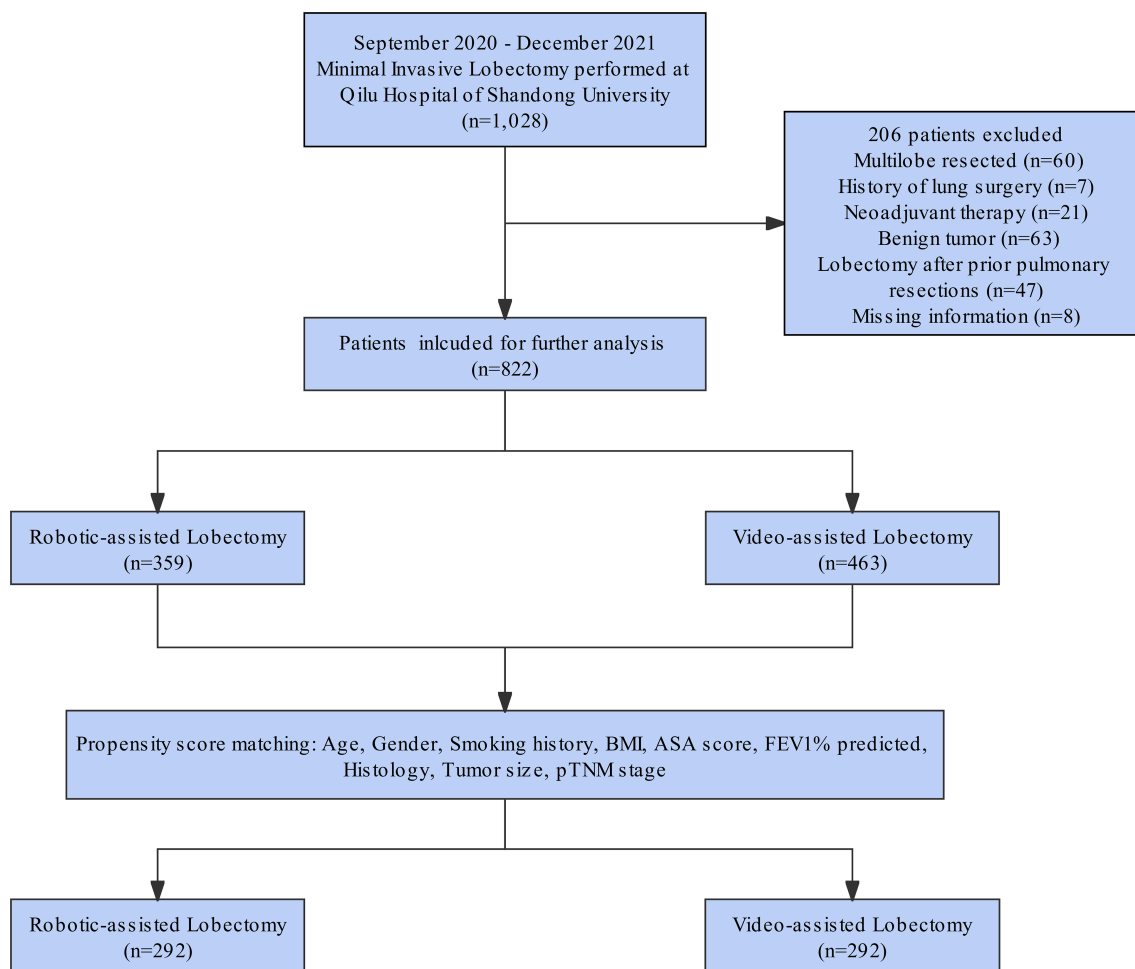

FIGURE 1 Flow diagram of patient selection through the study. ASA, American Society of Anesthesiologists; BMI, body mass index; FEV1% predicted, percentage of predicted value for forced expiratory volume in 1 s.

TABLE 1 Baseline characteristics of NSCLC patients before and after PSM

Characteristics	Before PSM			After PSM		
	RAL (n = 359)	VAL (n = 463)	p	RAL (n = 292)	VAL (n = 292)	p
Age (y), median (IQR)	58 (52–65)	60 (53–66)	0.174	59 (54–65)	59 (53–65)	0.854
Sex, No. (%)			0.125			0.738
Female	187 (52.1)	266 (57.5)		164 (56.2)	168 (57.5)	
Male	172 (47.9)	197 (42.5)		128 (43.8)	124 (42.5)	
BMI (kg/m^2), mean ± SD	24.86 ± 3.09	25.05 ± 3.10	0.376	25.08 ± 3.05	24.95 ± 2.97	0.592
Smoking history, No. (%)			0.253			0.712
Non-smoker	241 (67.1)	328 (70.8)		209 (71.6)	213 (72.9)	
Smoker	118 (32.9)	135 (29.2)		83 (28.4)	79 (27.1)	
FEV1% predicted, mean ± SD	103.63 ± 16.96	104.43 ± 16.45	0.495	104.71 ± 16.76	104.23 ± 15.67	0.723
ASA score, No. (%)			<0.001*			0.870
I	46 (12.8)	29 (6.3)		21 (7.2)	18 (6.2)	
II	310 (86.4)	414 (89.4)		270 (92.5)	273 (93.5)	
III	3 (0.8)	20 (4.3)		1 (0.3)	1 (0.3)	
No. of malignant lesions, No. (%)			0.439			0.654
1	334 (93.0)	424 (91.6)		269 (92.1)	266 (91.1)	
≥2	25 (7.0)	39 (8.4)		23 (7.9)	26 (8.9)	
Resected lobe, No. (%)			0.437			0.674
RUL	120 (33.4)	160 (34.6)		102 (34.9)	105 (36.0)	
RML	52 (14.5)	48 (10.4)		42 (14.4)	31 (10.6)	
RLL	74 (20.6)	92 (19.9)		59 (20.2)	59 (20.2)	
LUL	58 (16.2)	84 (18.1)		46 (15.8)	54 (18.5)	
LLL	55 (15.3)	79 (17.1)		43 (14.7)	43 (14.7)	
Histology, No. (%)			0.404			0.493
Adenocarcinoma	325 (90.5)	426 (92.0)		267 (91.4)	273 (93.5)	
Squamous cell carcinoma	27 (7.5)	33 (7.1)		20 (6.8)	17 (5.8)	
Other	7 (1.9)	4 (0.9)		5 (1.7)	2 (0.7)	
Tumor size (cm), median (IQR)	1.9 (1.3–2.6)	1.8 (1.3–2.5)	0.116	1.8 (1.2–2.5)	1.8 (1.2–2.3)	0.401
pTNM stage, No. (%)			0.038*			0.698
I	294 (81.9)	405 (87.5)		261 (89.4)	259 (88.7)	
II	30 (8.4)	34 (7.3)		20 (6.8)	18 (6.2)	
III	34 (9.5)	24 (5.2)		11 (3.8)	15 (5.1)	
IV	1 (0.3)	0		0	0	

Abbreviations: ASA, American Society of Anesthesiologists; BMI, body mass index; FEV1% predicted, percentage of predicted value for forced expiratory volume in 1 second; IQR, interquartile range; LUL, left upper lobe; LLL, left lower lobe; NSCLC, non–small cell lung cancer; PSM, propensity score matching; RAL, robotic-assisted lobectomy; RLL, right lower lobe; RML, right middle lobe; RUL, right upper lobe; VAL, video-assisted lobectomy. *p < 0.05.

variables are presented as the mean ± standard deviation (SD), and Student's t test was used for comparisons. For continuous variables that were not normally distributed, data are presented as the median (interquartile range [IQR]) and were compared by the Mann–Whitney U test between the groups. The test level between the two groups was set at α = 0.05 (bilateral), and a two-sided p < 0.05 was considered statistically significant. Subgroup analyses were performed for the perioperative outcomes according to the number of LNs dissected and BMI ranges. R Project software (v4.1.1; http://www.R-project.org) was used for PSM, and SPSS software v25.0 (SPSS) was used for further data analysis.

RESULTS

Patient characteristics

The procedure for the identification and selection of the relevant patients is illustrated in Figure 1. Ultimately, a total of 822 NSCLC patients (359 RAL patients and 463 VAL patients) were included for analysis. The characteristics of the patients before and after PSM are presented in Table 1. Before matching, the patients who underwent VAL and RAL were comparable in age, sex, height, weight, BMI, FEV1% predicted, smoking history, resected lobe, number

TABLE 2 Perioperative outcomes of RAL and VAL after PSM

Perioperative outcomes	RAL (n = 292)	VAL (n = 292)	p
Operation duration (min), median (IQR)	95 (75–115)	115 (90–135)	<0.001*
Estimated blood loss (mL), median (IQR)	65 (50–80)	80 (70–95)	<0.001*
Conversion to thoracotomy, No. (%)	1 (0.3)	2 (0.7)	1.000
No. of LNs, median (IQR)	10 (7–13)	8 (6–11)	<0.001*
No. of LN stations, median (IQR)	6 (5–6)	5 (5–6)	<0.001*
Nodal upstaging, No. (%)	11 (3.8)	13 (4.5)	0.677
Upstage, No. (%)			
cN0 to pN1	7 (2.4)	6 (2.1)	0.779
cN0 to pN2	2 (0.7)	5 (1.7)	0.450
cN1 to pN2	2 (0.7)	2 (0.7)	1.000
Chest tube drainage (mL), median (IQR)			
Postoperative day 1	240 (180–320)	200 (120–300)	<0.001*
Postoperative day 2	220 (160–300)	210 (140–300)	0.474
Postoperative day 3	160 (100–218)	160 (100–200)	0.380
Chest tube removal (d), median (IQR)	4 (3–5)	4 (3–5)	0.077
NRS, median (IQR)			
Postoperative day 1	3 (3–3)	3 (3–3)	0.412
Postoperative day 2	3 (3–3)	3 (3–3)	0.243
Postoperative day 3	3 (2.25–3)	3 (2–3)	0.311
Postoperative complications, No. (%)	67 (22.9)	76 (26.0)	0.386
Severity grade of complications, No. (%)			
Clavien–Dindo I	25 (8.6)	23 (7.9)	0.763
Clavien–Dindo II	36 (12.3)	42 (14.4)	0.465
Clavien–Dindo III	5 (1.7)	9 (3.1)	0.279
Clavien–Dindo IV	1 (0.3)	2 (0.7)	1.000
Clavien–Dindo ≥III	6 (2.1)	11 (3.8)	0.218
Frequent complications, No. (%)			
Persistent air leaks	50 (17.1)	53 (18.2)	0.745
Pneumonia	16 (5.5)	25 (8.6)	0.145
Chylothorax	12 (4.1)	11 (3.8)	0.832
Arrhythmia	11 (3.8)	7 (2.4)	0.338
Readmission, No. (%)	1 (0.3)	0	1.000
Postoperative LOS (d), median (IQR)	5 (4–7)	5 (4–7)	0.399
Hospitalization cost (¥), median (IQR)	81084.96 (74885.11–89728.40)	66142.55 (59300.81–73590.23)	<0.001*

Abbreviations: IQR, interquartile range; LN, lymph node; LOS, length of stay; NRS, numerical rating scale; RAL, robotic-assisted lobectomy; VAL, video-assisted lobectomy.
*$p < 0.05$.

of malignant lesions, histology type, and tumor size. However, there was a significant difference in ASA score ($p < 0.001$) and pTNM stage ($p = 0.038$) between the two groups. After PSM, 584 cases (292 RAL cases and 292 VAL cases) were included for further analysis, and there were no significant differences in any variables.

Perioperative outcomes

A comparison of the perioperative outcomes of the patients who underwent RAL or VAL after PSM is presented in Table 2. There was a significant difference in operation duration (95 minutes [IQR, 75–115] vs. 115 minutes [IQR, 90–135], $p < 0.001$) and estimated blood loss (65 mL [IQR, 50–80] vs. 80 ml [IQR, 70–95], $p < 0.001$). The drainage volume on POD1 (240 mL [IQR, 180–320] vs. 200 mL [IQR, 120–300], $p < 0.001$) and hospitalization cost (¥81084.96 [IQR, 74885.11–89728.40] vs. ¥66142.55 [IQR, 59300.81–73590.23], $p < 0.001$) were significantly increased in the RAL group. However, there were no significant differences in the rate of conversion to thoracotomy (0.3% vs. 0.7%, $p > 0.99$), drainage volume on POD2 (220 mL [IQR, 160–300] vs. 210 mL [IQR, 140–300], $p = 0.474$) and POD3

TABLE 3 Subgroup analysis of perioperative outcomes between RAL and VAL according to BMI ranges after matching

Perioperative outcomes	BMI <24 kg/m^2			BMI ≥24 kg/m^2		
	RAL (n = 113)	VAL (n = 105)	p	RAL (n = 179)	VAL (n = 187)	p
Operation duration (min), median (IQR)	90 (70–110)	105 (80–125)	0.001*	95 (80–120)	120 (90–140)	<0.001*
Estimated blood loss (mL), median (IQR)	65 (50–75)	80 (65–90)	<0.001*	70 (50–85)	85 (75–100)	<0.001*
No. of LNs, median (IQR)	10 (7–12.5)	8 (6–10)	0.003*	10 (8–14)	9 (6–12)	<0.001*
No. of LN stations, median (IQR)	6 (5–6)	5 (5–6)	0.008*	6 (5–6)	6 (5–6)	0.002*
Nodal upstaging, No. (%)	2 (1.8)	2 (1.9)	1.000	9 (5.0)	11 (5.9)	0.719
Chest tube drainage (mL), median (IQR)						
Postoperative day 1	230 (160–300)	200 (120–280)	0.010*	240 (190–330)	200 (140–300)	0.001*
Postoperative day 2	200 (120–280)	210 (140–305)	0.546	220 (180–300)	210 (140–300)	0.142
Postoperative day 3	150 (100–200)	160 (82.5–200)	0.707	165 (110–220)	160 (100–200)	0.135
Chest tube removal (d), median (IQR)	4 (3–7)	4 (3–6)	0.619	4 (3–5)	4 (3–5)	0.065
Postoperative complications, No. (%)	35 (31.0)	26 (24.8)	0.307	32 (17.9)	50 (26.7)	0.042*
Severity grade of complications, No. (%)						
Clavien–Dindo I	15 (13.3)	7 (6.7)	0.106	10 (5.6)	16 (8.6)	0.269
Clavien–Dindo II	15 (13.3)	16 (15.2)	0.678	21 (11.7)	26 (13.9)	0.535
Clavien–Dindo III	4 (3.5)	2 (1.9)	0.684	1 (0.6)	7 (3.7)	0.068
Clavien–Dindo IV	1 (0.9)	1 (1.0)	1.000	0	1 (0.5)	1.000
Clavien–Dindo ≥III	5 (4.4)	3 (2.9)	0.723	1 (0.6)	8 (4.3)	0.037*
Frequent complications, No. (%)						
Persistent air leaks	29 (25.7)	21 (20.0)	0.320	21 (11.7)	32 (17.1)	0.144
Pneumonia	5 (4.4)	10 (9.5)	0.137	11 (6.1)	15 (8.0)	0.485
Chylothorax	6 (5.3)	2 (1.9)	0.283	6 (3.4)	9 (4.8)	0.481
Arrhythmia	5 (4.4)	1 (1.0)	0.214	6 (3.4)	6 (3.2)	0.939
Postoperative LOS (d), median (IQR)	5 (4–8)	5 (4–7)	0.987	5 (4–6)	5 (4–6)	0.314

Abbreviations: BMI, body mass index; IQR, interquartile range; LN, lymph node; LOS, length of stay; RAL, robotic-assisted lobectomy; VAL, video-assisted lobectomy. *p< 0.05.

(160 mL [IQR, 100–218] vs. 160 mL [100–200], $p = 0.380$), NRS pain score on POD1 to POD3 ($p > 0.05$), day of chest tube removal (4 days [IQR, 3–5] vs. 4 days [IQR, 3–5], $p = 0.077$), postoperative LOS (5 days [IQR, 4–7] vs. 5 days [IQR, 4–7], $p = 0.399$) or 30-day readmission rate (0.3% vs. 0, $p > 0.99$). There was no in-hospital mortality in either group. No significant differences were found in the rate of postoperative complications (22.9% vs. 26%, $p = 0.386$), and the rate of complications by severity (grade I–IV) or frequency were also comparable between the two groups ($p > 0.05$). As for LN dissection and assessment, compared with VAL, the total number of LNs dissected was higher with RAL (10 [IQR, 7–13] vs. 8 [IQR, 6–11], $p < 0.001$), as was the total number of LN stations examined (6 [IQR, 5–6] vs. 5 [IQR, 5–6], $p < 0.001$). However, there were no significant differences in the nodal upstaging rate (3.8% vs. 4.5%, $p = 0.677$) between groups.

Subgroup analysis

A subgroup analysis was performed for the perioperative outcomes according to BMI ranges. The patients were divided into two groups based on their BMI: BMI <24 kg/

m^2 and BMI ≥24 kg/m^2, and the subgroup comparisons of perioperative outcomes between the RAL and VAL groups are presented in Table 3. Interestingly, we found that the incidence of postoperative complications (17.9% vs. 26.7%, $p = 0.042$) was significantly reduced in the RAL group for overweight and obese patients (BMI ≥24 kg/m^2), but there was no significant difference in the rate of postoperative complications (31.0% vs. 24.8%, $p = 0.307$) between the RAL and VAL groups in the other subgroup (BMI <24 kg/m^2). Compared with VAL, RAL had a shorter operation duration, less intraoperative estimated blood loss, higher number of LNs dissected and LN stations examined, and increased drainage volume on POD one in both subgroups ($p < 0.05$). There was no significant difference in the day of chest tube removal, drainage volume on POD2 and POD3, nodal upstaging rate, or postoperative LOS between the RAL and VAL groups in both subgroups ($p > 0.05$).

To investigate whether the increased drainage on POD1 with RAL was caused by more thorough LN dissection, we performed a subgroup analysis according to the number of LNs dissected. The patients were divided into four groups based on the number of LNs dissected (n): $n \leq 6$, $7 \leq n \leq 9$, $10 \leq n \leq 12$, and $13 \leq n$. Subgroup comparisons of perioperative outcomes between the RAL and VAL groups are

TABLE 4 Subgroup analysis of perioperative outcomes between RAL and VAL according to lymph nodes number after matching

No. of lymph nodes	No. of patients	Operation duration Min.	p	Estimated blood loss mL	p	Drainage volume (POD 1) mL	p	Chest tube removal POD	p	Postoperative complications No. (%)	p	Postoperative LOS POD	p
$n \leq 6$			<0.001*		<0.001*		0.134		0.133		0.660		0.805
RAL	49	85 (62.5–110)		55 (40–70)		200 (135–270)		4 (3–5)		10 (20.4)		5 (4–7)	
VAL	93	110 (90–133)		80 (70–93)		160 (105–255)		4 (3–5)		22 (23.7)		5 (4–6)	
$7 \leq n \leq 9$			<0.001*		<0.001*		0.113		0.129		0.305		0.093
RAL	86	95 (70–110)		65 (50–71)		230 (160–312)		4 (3–5)		15 (17.4)		5 (4–6)	
VAL	84	115 (86–134)		80 (70–94)		215 (140–260)		4 (3–5)		20 (23.8)		5 (4–6)	
$10 \leq n \leq 12$			0.012*		<0.001*		0.148		0.316		0.905		0.844
RAL	73	95 (73–118)		65 (50–75)		250 (190–300)		4 (3–6)		20 (27.4)		5 (4–8)	
VAL	60	113 (90–139)		83 (66–100)		200 (125–308)		4 (4–6.75)		17 (28.3)		5 (4–7)	
$13 \leq n$			0.017*		0.004*		0.095		0.890		0.545		0.753
RAL	84	98 (80–129)		70 (51–95)		280 (200–360)		4 (3–5)		22 (26.2)		5 (4–7)	
VAL	55	120 (90–145)		90 (75–105)		240 (160–340)		4 (3–5)		17 (30.9)		5 (4–7)	

Abbreviations: LOS, length of stay; Min, minutes; POD, postoperative day; RAL, robotic-assisted lobectomy; VAL, video-assisted lobectomy. *$p < 0.05$.

presented in Table 4 and Table S1. Notably, no significant differences were observed in drainage volume on POD1 in all subgroups ($p > 0.05$). Compared with VAL, RAL had a shorter operation duration and less intraoperative estimated blood loss across the different subgroups ($p < 0.05$). There was no significant difference in the day of chest tube removal, postoperative complication rate, complications greater than grade III, drainage volume on POD2 and POD3, or postoperative LOS between the two groups in all subgroups ($p > 0.05$).

DISCUSSION

In recent years, there has been a remarkable increase in the popularity of RAL, but its role and potential advantages have not been well illustrated. This retrospective study compared the perioperative outcomes between RAL and VAL in the surgical treatment of NSCLC. The results of our study indicated that RAL might have potential advantages compared with VAL in terms of LN dissection and assessment, reducing intraoperative blood loss, shortening operation duration, and reducing postoperative complications. Considering the higher cost of RAL, we performed a subgroup analysis based on BMI ranges and found that RAL might be more beneficial for overweight and obese patients with NSCLC. It is the first time to explore the advantages and disadvantages of RAL for NSCLC patients with different BMI ranges.

Intraoperative assessment of LNs is of critical importance in the surgical treatment of NSCLC.[15] A number of previous studies have reported that RAL was associated with an increased number of lymph nodal stations examined and a higher number of LNs harvested,[9,16] but Kneuertz et al.[17] demonstrated that the number of LNs sampled was comparable between RAL and VAL. The results of our study showed that RAL examined more nodal stations and retrieved a higher number of LNs. The subgroup analysis indicated that the RAL group had a shorter operative time and less intraoperative estimated blood loss than the VAL group, with roughly the same number of LNs dissected. This was probably because of the naked 3D visualization and better maneuverability provided by the surgical robotic system, which allows the surgeons to dissect the tissues, vessels, and bronchi surrounding the LNs more clearly. Taking the operation on the right side as an example, the surgeons could more easily and safely dissect the group two LNs beside and above the innominate vein with a robotic surgical system, but this could be more difficult in video-assisted thoracoscopic surgery. In addition, the better maneuverability and greater comfort of robotic system make surgeons more willing to perform additional LN dissections. In general, more extensive LN evaluation should result in a higher rate of nodal upstaging and better survival.[18] However, no significant difference was found in the rate of nodal upstaging between RAL and VAL, which could be attributed to the majority of included patients being at an early stage. The potential survival benefit derived from more thorough LN dissection may be

negligible, and more prospective clinical studies are needed to compare the long-term efficacy of RAL and VAL.

Regarding operation duration, a number of previous studies suggested that RAL might lead to a longer operative time because of the additional docking time and more incisions.[19,20] In this study, the operation duration of RAL was significantly shortened by ~15 minutes. The results of the subgroup analysis indicated that the use of the surgical robotic system might reduce the time spent on LN dissection. Several studies have reported that RAL was associated with an insignificant reduction in operative time.[9,11] This remarkable reduction in operative time with RAL may be attributed to the advantages of LN dissection, the surgeon's accumulated experience in minimally invasive surgery, a dedicated robotic team and other factors, such as the race of the patients. In addition, there was a small, but significantly lower intraoperative estimated blood loss in the RAL group, which might be the result of the better maneuverability of the robotic system. Therefore, we have reason to believe that both RAL and VAL are safe and feasible in terms of controlling intraoperative bleeding.

Some studies have demonstrated that RAL is associated with significantly reduced postoperative complications compared with VAL,[9,21] whereas others have suggested that the incidence of postoperative complications is comparable between the two surgical approaches.[11,22] In this study, we found no significant differences in the complication rate, severity (grade I–IV) or frequency between the two groups. However, subgroup analysis demonstrated that the incidence of postoperative complications was significantly reduced in the RAL group for overweight and obese patients. In recent years, there was a significant increase in number of obese and overweight patients with NSCLC. Thoracic surgeons would encounter great challenges when operating on overweight and obese patients because of increased internal fat, limited movements of instruments, deeper thoracic cavity, and their well-known poor outcomes.[23] In this study, we found that RAL might achieve better perioperative outcomes for overweight and obese patients, especially the lower incidence of postoperative complications. Therefore, it might be more cost-effective to select RAL for overweight and obese patients with NSCLC.

Few studies have reported the difference in the postoperative drainage volume between RAL and VAL. Li et al.[9] found that compared with VAL, RAL was associated with a reduced drainage volume on POD1, but a recently published randomized clinical trial demonstrated a larger amount of postoperative chest drainage in the RAL group.[11] Our study showed that the drainage volume was significantly increased with RAL on POD1, but became comparable on POD2 and POD3. The further subgroup analysis indicated that the difference in drainage volume on POD1 became insignificant with approximately the same number of LNs dissected, suggesting that the increased drainage on POD1 might be attributed to more extensive LN evaluation. In addition, the difference in the energy devices applied (monopolar electrocautery for RAL vs. harmonic scalpel for VAL) and greater trauma to the pleura caused by two more ports for RAL might also affect the amount of postoperative drainage.[24,25] Despite a significant increase in postoperative drainage volume, there was no significant delay in chest tube removal or patient discharge, nor was there a significant increase in postoperative complications, indicating that increased drainage was safe and did not hinder postoperative recovery of patients.

Consistent with previous studies, the total hospitalization costs with RAL in this study were significantly higher than those with VAL.[11,26] The cost of robotic technology is a real concern as health care expenditures increase. Because the surgical robotic system has a relatively high cost, it is necessary to consider cost performance when choosing RAL as a surgical treatment for NSCLC.[27] However, we believe that the device-related cost will be greatly reduced in the near future with the development of science and technology.

During the past decade, the use of completely portal robotic lobectomy (CPRL) and uniportal VAL has rapidly increased.[28,29] Without using utility incision, CPRL and uniportal VAL allow thoracic surgeons to use CO_2 insufflation to achieve a better view of the surgical field. It has been reported that CPRL could significantly reduce intraoperative blood loss and shorten operative time.[30] CPRL provides a fully enclosed thoracic operating space filled with warm CO_2. The pressure of CO_2 can push down on the diaphragm and compress the lung parenchyma, increasing the surgeon's workplace and improving the surgical field.[28] In addition, the increased pressure in the thoracic cavity can also effectively inhibit the tissue of mild bleeding.[30] CPRL can also provide surgeons with better control over the surgical field, because they did not require the assistant to help retract the lung tissue and did not spend time communicating on retraction. Considering the above advantages, CPRL followed by subcostal trans diaphragmatic specimen removal may be more beneficial for obese and overweight patients with NSCLC, which can be further explored in future studies.

This study has several limitations that should be considered. First, the single-center retrospective nature of this study makes it less persuasive than a multicenter prospective randomized controlled trial; therefore, further validation in multi-institution studies is necessary. Second, although PSM was performed to control for confounders among groups, potential selection bias was not eliminated completely. Furthermore, some outcomes, such as lymph nodal harvest, estimated blood loss, and operative duration, are closely related not only to the surgical approaches, but also to the performance of the surgeon. It is difficult to untangle the effects of the two on the outcomes. In addition, the fourth-generation DaVinci robot surgical system is typically applied for RAL, whereas a multiport thoracoscopic approach is used for VAL. Further investigation is needed to determine whether our results can be generalized to other centers where uniport thoracoscopy and other robotic systems may be more common. Finally, we were unable to obtain a long-term oncological evaluation of RAL for patients with respectable NSCLC because the follow-up period has not been

reached, and we intend to perform a prospective study to evaluate the long-term efficacy of RAL.

CONCLUSION

Compared with VAL, RAL might have potential advantages in terms of LN dissection and assessment, reducing intraoperative blood loss and shortening operation duration. Overweight and obese patients could benefit more from RAL because of reduced risk of postoperative complications. More thorough LN dissection might lead to increased drainage volume on POD1 without delaying chest tube removal and patient discharge.

CONFLICT OF INTEREST
The authors declare that they have no competing interests.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available on request from the corresponding author.

ORCID
Hui Tian https://orcid.org/0000-0002-8932-3003

REFERENCES
1. Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, et al. Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2021;71(3):209–49.
2. Hirsch FR, Scagliotti GV, Mulshine JL, Kwon R, Curran WJ Jr, Wu YL, et al. Lung cancer: current therapies and new targeted treatments. Lancet. 2017;389(10066):299–311.
3. Demmy TL, Yendamuri S, D'Amico TA, Burfeind WR. Oncologic equivalence of minimally invasive lobectomy: the scientific and practical arguments. Ann Thorac Surg. 2018;106(2):609–17.
4. Melfi FM, Menconi GF, Mariani AM, Angeletti CA. Early experience with robotic technology for thoracoscopic surgery. Eur J Cardiothorac Surg. 2002;21(5):864–8.
5. Augustin F, Schmid T, Sieb M, Lucciarini P, Bodner J. Video-assisted thoracoscopic surgery versus robotic-assisted thoracoscopic surgery thymectomy. Ann Thorac Surg. 2008;85(2):S768–71.
6. van Boxel GI, Kingma BF, Voskens FJ, Ruurda JP, van Hillegersberg R. Robotic-assisted minimally invasive esophagectomy: past, present and future. J Thorac Dis. 2020;12(2):54–62.
7. Peters BS, Armijo PR, Krause C, Choudhury SA, Oleynikov D. Review of emerging surgical robotic technology. Surg Endosc. 2018;32(4):1636–55.
8. Velez-Cubian FO, Ng EP, Fontaine JP, Toloza EM. Robotic-assisted Videothoracoscopic surgery of the lung. Cancer Control. 2015;22(3):314–25.
9. Li JT, Liu PY, Huang J, Lu PJ, Lin H, Zhou QJ, et al. Perioperative outcomes of radical lobectomies using robotic-assisted thoracoscopic technique vs. video-assisted thoracoscopic technique: retrospective study of 1,075 consecutive p-stage I non-small cell lung cancer cases. J Thorac Dis. 2019;11(3):882–91.
10. O'Sullivan KE, Kreaden US, Hebert AE, Eaton D, Redmond KC. A systematic review and meta-analysis of robotic versus open and video-assisted thoracoscopic surgery approaches for lobectomy. Interact Cardiovasc Thorac Surg. 2019;28(4):526–34.
11. Jin R, Zheng Y, Yuan Y, Han D, Cao Y, Zhang Y, et al. Robotic-assisted versus video-assisted Thoracoscopic lobectomy: short-term results of a randomized clinical trial (RVlob trial). Ann Surg. 2022;275(2):295–302.
12. Yang HX, Woo KM, Sima CS, Bains MS, Adusumilli PS, Huang J, et al. Long-term survival based on the surgical approach to lobectomy for clinical stage I nonsmall cell lung cancer: comparison of robotic, video-assisted thoracic surgery, and thoracotomy lobectomy. Ann Surg. 2017;265(2):431–7.
13. Clavien PA, Barkun J, de Oliveira ML, Vauthey JN, Dindo D, Schulick RD, et al. The Clavien-Dindo classification of surgical complications: five-year experience. Ann Surg. 2009;250(2):187–96.
14. Ettinger DS, Wood DE, Aisner DL, Akerley W, Bauman J, Chirieac LR, et al. Non-small cell lung cancer, version 5.2017, NCCN clinical practice guidelines in oncology. J Natl Compr Canc Netw. 2017;15(4):504–35.
15. Gooseman MR, Brunelli A. Intraoperative lymph node management during non-small cell lung cancer surgery. Ann Surg Oncol. 2021;28(12):6925–6.
16. Li C, Hu Y, Huang J, Li J, Jiang L, Lin H, et al. Comparison of robotic-assisted lobectomy with video-assisted thoracic surgery for stage IIB-IIIA non-small cell lung cancer. Transl Lung Cancer Res. 2019;8(6):820–8.
17. Kneuertz PJ, Cheufou DH, D'Souza DM, Mardanzai K, Abdel-Rasoul M, Theegarten D, et al. Propensity-score adjusted comparison of pathologic nodal upstaging by robotic, video-assisted thoracoscopic, and open lobectomy for non-small cell lung cancer. J Thorac Cardiovasc Surg. 2019;158(5):1457–66 e2.
18. Chen Y, Zhang J, Jiang C, Zhang H, Fan P, Yu H, et al. The number of lymph nodes examined is associated with survival outcomes and nodal upstaging in patients with stage I small cell lung cancer. Surg Oncol. 2021;37:101513.
19. Nelson DB, Mehran RJ, Mitchell KG, Rajaram R, Correa AM, Bassett RL Jr, et al. Robotic-assisted lobectomy for non-small cell lung cancer: a comprehensive institutional experience. Ann Thorac Surg. 2019;108(2):370–6.
20. Reddy RM, Gorrepati ML, Oh DS, Mehendale S, Reed MF. Robotic-assisted versus Thoracoscopic lobectomy outcomes from high-volume thoracic surgeons. Ann Thorac Surg. 2018;106(3):902–8.
21. Oh DS, Reddy RM, Gorrepati ML, Mehendale S, Reed MF. Robotic-assisted, video-assisted Thoracoscopic and open lobectomy: propensity-matched analysis of recent premier data. Ann Thorac Surg. 2017;104(5):1733–40.
22. Yang S, Guo W, Chen X, Wu H, Li H. Early outcomes of robotic versus uniportal video-assisted thoracic surgery for lung cancer: a propensity score-matched study. Eur J Cardiothorac Surg. 2018;53(2):348–52.
23. Casiraghi M, Sedda G, Diotti C, Mariolo AV, Galetta D, Tessitore A, et al. Postoperative outcomes of robotic-assisted lobectomy in obese patients with non-small-cell lung cancer. Interact Cardiovasc Thorac Surg. 2020;30(3):359–65.

24. Li J, Qiu B, Scarci M, Rocco G, Gao S. Uniportal video-assisted thoracic surgery could reduce postoperative thorax drainage for lung cancer patients. Thoracic Cancer. 2019;10(6):1334–9.

25. Zhang Z, Li L, Pang Y, Li Q, Guo C, Wang Y, et al. Comparison of harmonic scalpel and conventional technique in the surgery for breast cancer: a systematic review and meta-analysis. Indian J Cancer. 2018;55(4):348–58.

26. Paul S, Jalbert J, Isaacs AJ, Altorki NK, Isom OW, Sedrakyan A. Comparative effectiveness of robotic-assisted vs thoracoscopic lobectomy. Chest. 2014;146(6):1505–12.

27. Chen D, Kang P, Tao S, Li Q, Wang R, Tan Q. Cost-effectiveness evaluation of robotic-assisted thoracoscopic surgery versus open thoracotomy and video-assisted thoracoscopic surgery for operable non-small cell lung cancer. Lung Cancer. 2021;153:99–107.

28. Akkus M, Seyrek Y. Robot-assisted lobectomy versus completely portal robotic lobectomy: what is the difference? Turk Gogus Kalp Damar Cerrahisi Derg. 2020;28(4):648–55.

29. Dylewski MR, Ohaeto AC, Pereira JF. Pulmonary resection using a total endoscopic robotic video-assisted approach. Semin Thorac Cardiovasc Surg. 2011;23(1):36–42.

30. Ramadan OI, Wei B, Cerfolio RJ. Robotic surgery for lung resections-total port approach: advantages and disadvantages. J Vis Surg. 2017;3:22.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.