Comparison of Robotic-Assisted and Uniportal Video-Assisted Thoracoscopic Lobectomy for Early-Stage Non-Small Cell Lung Cancer: A Retrospective Cohort Study

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AIM: This study aimed to compare perioperative outcomes, lymphadenectomy quality, postoperative recovery, pulmonary function, and short-term oncologic results between robotic-assisted thoracoscopic surgery (RATS) and uniportal video-assisted thoracoscopic surgery (U-VATS) for early-stage non-small cell lung cancer (NSCLC).

METHODS: This retrospective cohort study included 231 consecutive patients with stage I–IIA NSCLC who underwent curative-intent anatomic lobectomy at our institution between January and December 2023. Based on the surgical approach, patients were assigned to either the RATS group (n = 105) or the U-VATS group (n = 126). All procedures were performed by the same experienced surgical team using standardized perioperative protocols. Clinical characteristics, intraoperative and postoperative parameters, pulmonary function, and 12-month oncologic outcomes were collected for comparative evaluation.

RESULTS: RATS resulted in shorter operative time, reduced blood loss, and increased lymph node and mediastinal station retrieval compared with U-VATS. Postoperative pain, drainage volume, length of hospital stay, and complication rates were comparable between groups. Patients undergoing RATS demonstrated significantly higher global health and functional scores, along with lower symptom scores, during the first 6 months after surgery ($p < 0.05$). Pulmonary function recovery, 1-year disease-free survival (DFS), and overall survival (OS) did not differ significantly between the two approaches. However, hospitalization costs were higher for the RATS group ($p < 0.001$).

CONCLUSIONS: Both RATS and U-VATS are safe and effective minimally invasive approaches for anatomic lobectomy in early-stage NSCLC. RATS offers advantages in operative precision, lymph node dissection, and short-term quality of life without compromising safety or early oncologic outcomes, although it is associated with increased cost.

Keywords: non-small cell lung cancer; robotic-assisted thoracoscopic surgery; uniportal video-assisted thoracoscopic surgery; quality of life; perioperative outcomes

Introduction

Lung cancer is currently the most commonly diagnosed malignancy worldwide and the leading cause of cancer-related mortality, accounting for nearly 2.5 million new cases (12.4% of all cancers) and approximately 1.8 million deaths (18.7% of all cancer deaths) in 2022, according to the most recent Global Cancer Observatory (GLOBOCAN) analysis [1]. Non-small cell lung cancer (NSCLC) represents roughly 80–85% of all lung cancers, making it the predominant histologic subtype encountered in clinical practice [2–4]. For patients with resectable early-stage NSCLC, surgery remains the cornerstone of curative treatment, with anatomic lobectomy combined with systematic nodal evaluation endorsed by contemporary guideline frameworks [5].

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Although uniportal video-assisted thoracoscopic surgery (U-VATS) has expanded minimally invasive access for anatomic lobectomy, it continues to face inherent technical constraints, including instrument interference, limited triangulation, and suboptimal ergonomics, which can make precise hilar dissection and complete mediastinal lymph node dissection more challenging in complex anatomical settings [6]. While U-VATS has become an established minimally invasive approach for anatomical lobectomy, it requires substantial operative expertise, and the steep learning curve during early adoption may influence operative efficiency and the consistency of perioperative outcomes [7].

Robotic-assisted thoracoscopic surgery (RATS) addresses several limitations inherent to conventional thoracoscopic techniques by offering high-definition three-dimensional visualization, stable camera control, and wristed instruments with multiple degrees of freedom. Together, these features allow more precise dissection and improved lymph node retrieval, particularly within confined hilar and mediastinal spaces [8–10]. Nonetheless, cost analyses consistently demonstrate that RATS is associated with significantly higher procedural and hospitalization expenses compared with VATS, emphasizing the need to balance

technical advantages against increased resource utilization [11,12]. Moreover, evidence directly comparing RATS with U-VATS in patients with clinical stage I–IIA NSCLC remains limited, and few studies have simultaneously assessed lymphadenectomy quality, functional recovery, and patient-reported outcomes under standardized perioperative management conditions.

Therefore, this study aimed to compare perioperative outcomes, lymphadenectomy quality, postoperative pain and recovery, health-related quality of life, pulmonary function trajectories, and short-term oncologic endpoints between RATS and U-VATS lobectomy for clinical early-stage NSCLC, all performed by the same surgical team under a unified enhanced-recovery protocol. This design provides for a more focused and internally valid assessment of the potential clinical benefits associated with robotic assistance in early-stage NSCLC.

Methods

Patients

This retrospective cohort study included patients with clinically diagnosed early-stage NSCLC who underwent anatomic lobectomy using either RATS (n = 105) or U-VATS (n = 126) at The First Affiliated Hospital of University of South China between January 2023 and December 2023. All patients underwent contrast-enhanced chest computed tomography (CT) for staging. Positron emission tomography-computed tomography (PET-CT) was performed when the primary tumor exceeded 2 cm or when lymph node enlargement or distant disease was suspected on CT.

Inclusion criteria included: (1) age $\geq$18 years; (2) preoperative imaging indicating resectable pulmonary malignant lesions, pathologically confirmed as NSCLC postoperatively; (3) clinical stage I or IIA disease according to the 8th edition of the American Joint Committee on Cancer (AJCC) Tumor-Node-Metastasis (TNM) staging system [13]; (4) patients who underwent anatomic lobectomy with systematic lymph node dissection; and (5) availability of complete clinicopathological and follow-up data.

Exclusion criteria included: (1) patients with suspected lymph node or distant metastasis on preoperative imaging, or those found to have pathological nodal metastasis (N^+) or pathological stage beyond IIA after surgery; (2) receipt of neoadjuvant chemotherapy, radiotherapy, targeted therapy, or immunotherapy before surgery; (3) coexistence of other active malignancies; (4) severe cardiopulmonary dysfunction, uncorrectable coagulopathy, or other severe comorbidities that precluded general anesthesia or thoracic surgery; (5) requirement for extended resections, including bilobectomy, pneumonectomy, or bilateral procedures; (6) intraoperative conversion to thoracotomy due to tumor invasion or bleeding; (7) incomplete or missing clinical records; and (8) loss to follow-up within 12 months postoperatively.

All patients underwent a preoperative multidisciplinary team (MDT) evaluation involving specialists from thoracic surgery, respiratory medicine, oncology, radiology, and anesthesiology. The final surgical approach (RATS or U-VATS) was recommended by the attending thoracic surgeon based on tumor- and patient-related factors, and was confirmed through shared decision-making with the patient. The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Ethics Committee of The First Affiliated Hospital of University of South China (Approval No. 20250311). Written informed consent was obtained from all patients prior to treatment.

Surgical Methods

All patients were managed using a standardised enhanced recovery after surgery (ERAS) protocol. Preoperative preparation included routine laboratory testing, chest contrast-enhanced computed tomography, electrocardiography, transthoracic echocardiography when clinically indicated, and pulmonary function assessment. Prophylactic antibiotics were administered within 60 minutes before incision. General anesthesia was induced with double-lumen endotracheal intubation to enable single-lung ventilation. Patients were positioned in the full lateral decubitus position with the operative side up. The table was flexed to widen the intercostal spaces, and all pressure points were carefully padded. Intraoperative monitoring included continuous electrocardiography, pulse oximetry, capnography, and invasive arterial blood pressure measurement.

Multimodal analgesia was employed, including intravenous patient-controlled analgesia with optional paravertebral or intercostal nerve blocks at the discretion of the anesthesiologist. All regional blocks followed a unified institutional protocol that specified indications, block levels, local anesthetic selection and dosage, and procedural steps, and were performed by the same anesthesiology team. All surgical procedures were performed by the same thoracic surgical team. Anatomic lobectomy with systematic lymph node dissection was the planned oncologic procedure for both groups. When the preoperative diagnosis of malignancy remained uncertain, a wedge resection for frozen-section examination was performed first; confirmed malignancy was followed by a completion lobectomy and nodal dissection.

RATS: A standardized three-arm, four-port configuration of the da Vinci system was adopted. Port placement consisted of a 1.0-cm camera port at the mid-axillary line in the 8th intercostal space (ICS); two 0.8–1.0-cm robotic instrument ports at the subscapular line in the 8th ICS and the anterior axillary line in the 5th ICS; and a 3–4-cm utility/assistant incision between the anterior and mid-axillary lines in the 7th ICS with a wound protector. After docking, an energy hook and a bipolar grasper were typically used through the robotic ports, while suction and stapling were performed via the assistant incision. Hilar dissection proceeded in a fissure-based or fissureless approach, depending on fissural

development, with sequential division of lobar arteries, pulmonary vein, and lobar bronchus using endoscopic staplers. The specimen was removed in a protective bag. Systematic lymph node dissection was performed according to guideline standards, including N1 (hilar and interlobar) and N2 stations with at least three mediastinal stations, including the subcarinal station. On the left, stations 4L, 5, 6, 7, 8, and 9 were sampled or dissected; on the right, stations 2R, 4R, 7, 8, and 9 were addressed.

U-VATS: A single 3–4-cm incision was created at the 4th or 5th ICS between the mid-axillary and anterior axillary lines, and a wound protector was applied. A thoracoscope and endoscopic instruments were introduced through this single incision. Following exploration and adhesiolysis when required, wedge resection for frozen-section examination was performed if the preoperative diagnosis remained indeterminate; otherwise, lobectomy was initiated. Vascular structures and the lobar bronchus were divided using endoscopic staplers, and fissure management was tailored to individual anatomical variation. The resected lobe was retrieved in a protective bag. Systematic lymph node dissection followed the same protocol used in the RATS group, including N1 nodes and at least three N2 mediastinal stations as described above.

For both approaches, meticulous hemostasis was confirmed. The pleural cavity was irrigated with warm sterile saline to remove residual fluid or blood clots. An underwater air-leak test was performed by reinflating the lung to 20–25 cm H_2O to assess the integrity of the bronchial stump and staple line. One 24-Fr chest tube was placed: through the camera port for RATS and at the posterior aspect of the uniportal incision for U-VATS. All port sites and the incision were closed in layers.

Postoperative care followed an enhanced-recovery protocol. Incentive spirometry and ambulation were initiated on the day of surgery or postoperative day 1, and oral intake was resumed as tolerated. Multimodal analgesia was continued, with non-opioid or opioid rescue medications administered when necessary.

At the completion of the procedure, a single chest tube was routinely placed in all patients. In the RATS group, the tube was inserted through the assistant port, whereas in the U-VATS group, it was positioned through the uniportal incision. The chest tube was connected to a standard water-seal drainage system with low negative-pressure suction (approximately –10 to –15 cmH_2O) during the early postoperative period. Once lung re-expansion was confirmed on chest radiography and no significant pneumothorax was observed, the system was transitioned to water seal. Criteria for chest-tube removal were identical in both groups: (1) absence of visible air leak for at least 24 hours; (2) drainage volume $<$200 mL over the preceding 24 hours; and (3) complete lung re-expansion on chest radiograph. Venous thromboembolism prophylaxis and pulmonary rehabilitation were provided according to institutional standards. All postoperative management measures were standardized across groups and supervised by the same multidisciplinary care team to ensure consistency in care. Postoperative complications were prospectively recorded and graded using standardized definitions.

Observation Indicators

All clinical data were retrospectively obtained from the hospital's electronic medical record system. The following indicators were reviewed and analyzed to compare perioperative characteristics between the RATS and U-VATS groups. Baseline variables included patient demographics (age, sex, and body mass index [BMI]), smoking and alcohol consumption history, and the presence of comorbidities such as hypertension, diabetes mellitus, coronary artery disease, and chronic obstructive pulmonary disease. Tumor-related variables included maximum tumor diameter measured by preoperative imaging, tumor location, histological subtype, and pathological TNM stage based on the 8th edition of the AJCC staging system. Preoperative functional assessments included pulmonary function parameters (forced vital capacity (FVC)% predicted and forced expiratory volume in one second (FEV_1)% predicted).

Intraoperative indicators comprised surgical approach (RATS or U-VATS), operative time, anesthesia duration, intraoperative blood loss, the number of dissected lymph nodes and mediastinal stations, and resection margin status. Operation time was defined as the interval from skin incision to final skin closure. For robotic procedures, this definition included docking and undocking, whereas room setup and draping before incision were excluded for both groups. Anesthesia duration was defined as the interval from induction of anesthesia to exit from the operating room. Mediastinal lymph node stations were counted according to the International Association for the Study of Lung Cancer (IASLC) map, and only the N2 stations were included. Although both N1 and N2 stations were routinely dissected during lobectomy, only N2 nodes were analyzed because mediastinal nodal yield represents the standard metric for assessing oncologic thoroughness in early-stage NSCLC.

Postoperative parameters included chest tube indwelling time, total thoracic drainage volume, length of postoperative hospital stay, and total hospitalization cost. Acute postoperative pain was assessed at rest at 24, 48, and 72 hours after surgery by trained nursing staff using a visual analogue scale (VAS) [14] ranging from 0 to 10, and the highest score at each time point was recorded using an identical protocol in both groups.

Postoperative Follow-up

Postoperative follow-up was performed through scheduled outpatient visits or structured telephone interviews at 1, 3, 6, and 12 months after surgery (minimum follow-up for survivors: 12 months). Early postoperative complications within 30 days were identified from the medical record and graded according to the Clavien–Dindo classification.

Table 1. Baseline characteristics of patients with NSCLC undergoing RATS or U-VATS.

Variable	RATS group, n = 105	U-VATS group, n = 126	*p*-value
Age, years	61.0 (56.0–66.0)	61.0 (54.0–66.0)	0.733
Male, n (%)	61 (58.1)	73 (57.9)	0.981
BMI (kg/m^2)	21.9 (19.4–24.1)	22.2 (19.2–23.6)	0.909
Smoking, n (%)	42 (40.0)	49 (38.9)	0.863
Alcohol consumption history, n (%)	33 (31.4)	31 (24.6)	0.248
Hypertension, n (%)	41 (39.0)	47 (37.3)	0.786
Diabetes, n (%)	12 (11.4)	10 (7.9)	0.368
Coronary heart disease, n (%)	11 (10.5)	13 (10.3)	0.988
Chronic obstructive pulmonary disease, n (%)	16 (15.2)	20 (15.9)	0.895
Tumor diameter (cm)	2.3 (1.9–2.7)	2.3 (1.8–2.9)	0.730
Tumor location, n (%)			0.935
Right upper	43 (41.0)	51 (40.5)	
Right middle	8 (7.6)	11 (8.7)	
Right lower	20 (19.0)	19 (15.1)	
Left upper	23 (21.9)	31 (24.6)	
Left lower	11 (10.5)	14 (11.1)	
Histological subtype, n (%)			0.557
Adenocarcinoma	53 (50.5)	61 (48.4)	
Squamous cell carcinoma	39 (37.1)	43 (34.1)	
Others	13 (12.4)	22 (17.5)	
Clinical TNM stage, n (%)			0.385
I	51 (48.6)	58 (46.0)	
IIA	54 (51.4)	68 (54.0)	
FVC% predicted	86.7 ± 5.9	87.6 ± 6.2	0.278
FEV_1% predicted	80.4 (76.0–86.1)	79.5 (75.2–85.8)	0.766

Notes: Data are presented as mean ± standard deviation for normally distributed variables (FVC) and as median (IQR) for non-normally distributed variables (age, BMI, tumor diameter, and FEV_1).

NSCLC, non-small cell lung cancer; RATS, robotic-assisted thoracoscopic surgery; U-VATS, uniportal video-assisted thoracoscopic surgery; BMI, body mass index; IQR, interquartile range; TNM, Tumor-Node-Metastasis; FVC, forced vital capacity; FEV_1, forced expiratory volume in one second.

Health-related quality of life was assessed at 1, 3, 6, and 12 months using the European Organisation for Research and Treatment of Cancer Quality of Life Questionnaire-Core 30 (EORTC QLQ-C30), with scores transformed to a 0–100 scale according to the official EORTC scoring manual. All items were converted into standardized scores ranging from 0 to 100, following the same guidelines. To describe overall postoperative recovery, two composite indices were calculated: a Functional score, defined as the arithmetic mean of the five functional subscales, and a Symptom score, defined as the arithmetic mean of all symptom scales and single-item symptoms.

Pulmonary function was re-evaluated at each follow-up visit using spirometry performed according to American Thoracic Society/European Respiratory Society (ATS/ERS) standards, recording FVC and FEV_1 as percentages of predicted values. Disease surveillance followed institutional protocols, which included clinical evaluation at each visit and chest CT scans at 6 and 12 months, with additional imaging performed as clinically indicated. Recurrence was confirmed radiologically or pathologically. Disease-free survival (DFS) was defined as the interval from the date of surgery to the first recurrence or death from any cause, and overall survival (OS) as the interval from surgery to death from any cause. 30-day mortality was defined as all-cause mortality within 30 days after surgery. Patients who were alive without an event were censored at the time of their last contact. All perioperative and follow-up data were obtained from the institutional electronic medical record system, where these variables are routinely collected under standardized postoperative follow-up protocols.

Statistical Analysis

All statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA) and GraphPad Prism version 9.0 (GraphPad Software, San Diego, CA, USA). The normality of continuous variables was evaluated using the Shapiro–Wilk test. Continuous variables were expressed as mean ± standard deviation (SD) for normally distributed data, or as median (interquartile range [IQR]) for non-normally distributed data. Between-group comparisons were performed using the independent-samples *t*-test or the Mann–Whitney U test, as appropriate. Categor-

Table 2. Intraoperative and postoperative outcomes in the RATS and U-VATS groups.

Variable	RATS group, n = 105	U-VATS group, n = 126	*p*-value
Operation time (min)	143.0 (130.0–154.5)	161.0 (147.0–180.0)	<0.001
Anesthesia duration (min)	186.0 (171.0–200.0)	186.5 (168.8–205.0)	0.503
Intraoperative blood loss (mL)	80.8 ± 18.1	102.9 ± 26.6	<0.001
No. of lymph nodes dissected	15.0 (12.0–17.0)	10.0 (8.0–11.0)	<0.001
No. of mediastinal stations dissected	6.0 (5.0–6.0)	4.0 (3.0–5.0)	<0.001
Chest tube indwelling time (days)	4.0 (3.0–5.0)	4.0 (2.0–5.0)	0.736
Total thoracic drainage (mL)	666.0 (581.0–765.0)	639.0 (528.0–765.0)	0.119
Postoperative hospital stay (days)	6.0 (5.0–7.0)	6.0 (5.0–7.0)	0.439
Total hospitalization cost (USD)	9991.0 (9408.0–10,751.5)	8218.0 (7611.3–8645.8)	<0.001
Paravertebral block, n (%)	31 (29.5)	33 (26.2)	0.573
Intercostal block, n (%)	35 (33.3)	39 (30.1)	0.699
VAS pain score (24 h)	3.7 (3.0–4.0)	3.6 (3.2–4.0)	0.321
VAS pain score (48 h)	3.1 (2.4–3.5)	3.0 (2.6–3.4)	0.942
VAS pain score (72 h)	1.9 ± 0.8	1.9 ± 0.8	0.707

Notes: VAS, visual analogue scale; USD, United States dollar.

Data are presented as mean ± standard deviation for normally distributed variables (intraoperative blood loss, VAS pain scores at 72 h) and as median (IQR) for non-normally distributed variables (operation time, anesthesia duration, No. of lymph nodes dissected, No. of mediastinal stations dissected, chest tube indwelling time, total thoracic drainage, postoperative hospital stay, total hospitalization cost, VAS pain scores at 24 h and 48 h).

ical variables were presented as frequencies and percentages, and compared using the chi-square test or Fisher's exact test. To examine within-subject changes over time and between-group differences, repeated-measures analysis of variance (ANOVA) was applied to parameters recorded at multiple postoperative time points (VAS pain score, EORTC QLQ-C30 domains, FVC, and FEV_1). When the assumption of sphericity was violated, the Greenhouse–Geisser correction was applied. When a significant time-by-group interaction is detected, conduct post-hoc simple effects analyses to compare groups at each postoperative time point. One-year DFS and OS were estimated using the Kaplan–Meier method, and survival curves were compared between the RATS and U-VATS groups using the log-rank test. A p-value < 0.05 was considered statistically significant.

Table 3. Repeated-measures ANOVA of postoperative VAS pain scores.

Effect	df	F	*p*-value	Partial η^2
Time	1.941	388.664	<0.001	0.629
Group	1	0.046	0.830	<0.001
Time × Group	1.941	0.447	0.633	0.002

Notes: VAS, visual analogue scale; ANOVA, analysis of variance; df, degrees of freedom.

Results

Baseline Comparisons

A total of 231 patients (105 in the RATS group and 126 in the U-VATS group) were included in the analysis. Baseline demographic and clinical characteristics were well balanced between the two groups. The median age was 61.0 years (IQR, 56.0–66.0) in the RATS group and 61.0 years (IQR, 54.0–66.0) in the U-VATS group ($p = 0.733$). The proportion of male patients was comparable between the two groups (58.1% vs. 57.9%, $p = 0.981$). The median body mass index (BMI) did not differ significantly between groups (21.9 [19.4–24.1] vs. 22.2 [19.2–23.6], $p = 0.909$). Rates of smoking (40.0% vs. 38.9%, $p = 0.863$) and alcohol consumption (31.4% vs. 24.6%, $p = 0.248$) were also comparable. No significant differences were observed in the prevalence of hypertension (39.0% vs. 37.3%, $p = 0.786$), diabetes (11.4% vs. 7.9%, $p = 0.368$), coronary heart disease (10.5% vs. 10.3%, $p = 0.988$), or chronic obstructive pulmonary disease (15.2% vs. 15.9%, $p = 0.895$) between the two groups. Additionally, there were no statistically significant differences between the two groups in terms of tumor diameter, tumor location, histological subtype, TNM stage, FVC, or FEV_1 (Table 1).

Intraoperative and Postoperative Outcomes

Complete tumor resection with negative surgical margins (R0) was achieved in 221 of the 231 patients (95.7%). Compared with the U-VATS group, the RATS group demonstrated significantly shorter operative time and lower intraoperative blood loss ($p < 0.001$). Furthermore, the RATS group yielded a higher number of dissected lymph nodes and mediastinal stations ($p < 0.001$). No significant differences were observed between the two groups in anesthesia duration, chest tube indwelling time, total thoracic drainage volume, or postoperative hospital stay. Total hospitalization costs, however, were significantly higher in the RATS group ($p < 0.001$). Postoperative pain intensity, measured

Table 4. Postoperative complications classified according to the Clavien–Dindo system.

Variable	RATS group, n = 105	U-VATS group, n = 126	*p*-value
Any complication, n (%)	36 (34.3)	41 (32.5)	0.779
Grade I–II, n (%)	33 (31.4)	37 (29.4)	0.734
Grade ≥III, n (%)	3 (2.9)	4 (3.2)	0.889
30-day mortality	0	0	

Note: 30-day mortality refers to all-cause mortality within 30 days after surgery.

Table 5. Comparison of postoperative EORTC QLQ-C30 scores between the RATS and U-VATS groups.

Time point	Variable	RATS group, n = 105	U-VATS group, n = 126	*p*-value
1 month	Global health score	75.0 (71.0–79.0)	70.0 (64.8–73.3)	<0.001
	Functional score	84.0 (81.5–88.0)	79.0 (76.0–83.0)	<0.001
	Symptom score	16.0 (13.0–20.0)	21.0 (17.8–25.0)	<0.001
3 months	Global health score	79.0 (73.0–82.0)	73.0 (70.0–77.0)	<0.001
	Functional score	86.0 (83.0–90.0)	81.0 (77.0–85.0)	<0.001
	Symptom score	13.0 (9.0–18.0)	19.0 (16.0–24.0)	<0.001
6 months	Global health score	81.0 (77.0–85.0)	77.0 (74.0–82.3)	<0.001
	Functional score	86.0 (84.0–90.0)	84.5 (80.8–87.0)	<0.001
	Symptom score	14.0 (10.5–16.5)	15.0 (12.0–19.0)	0.001
12 months	Global health score	81.0 (78.0–86.0)	80.0 (77.0–84.0)	0.151
	Functional score	88.0 (85.0–91.5)	87.0 (84.0–91.0)	0.248
	Symptom score	14.0 (9.0–16.5)	14.0 (11.0–17.0)	0.138

Notes: EORTC QLQ-C30, European Organisation for Research and Treatment of Cancer Quality of Life Questionnaire-Core 30.

All data are presented as median (IQR) for non-normally distributed variables.

using VAS scores at 24, 48, and 72 hours, did not differ significantly between the two surgical approaches (Table 2). Repeated measures ANOVA demonstrated a significant main effect of time on postoperative pain ($p < 0.001$), with no significant time-by-group interactions ($p = 0.633$, Table 3).

Postoperative Complications

Postoperative complications were evaluated using the Clavien–Dindo classification system (Table 4). The overall incidence of postoperative complications did not differ significantly between the RATS and U-VATS groups (34.3% vs. 32.5%, $p > 0.05$). Severe complications (Clavien–Dindo ≥ Grade III) were uncommon in both groups, with no significant difference ($p > 0.05$). Notably, no 30-day mortality occurred in either group.

Postoperative Health-Related Quality of Life

Health-related quality of life (HRQoL) was assessed using the EORTC QLQ-C30 questionnaire at 1, 3, 6, and 12 months after surgery, with scores standardized to a 0–100 scale according to the EORTC scoring manual (Table 5). At 1 month postoperatively, patients in the RATS group exhibited significantly higher global health and functional scores, as well as lower symptom scores, compared with those in the U-VATS group ($p < 0.001$). At 3 and 6 months, this advantage of the RATS group persisted, although the magnitude of difference gradually declined over time ($p < 0.05$). Repeated-measures ANOVA showed a significant main effect of time and a significant interaction of time and group on overall health, functioning, and symptom scores (all $p < 0.001$, Table 6), suggesting that the two populations had different trajectories of QLQ-C30 over time.

Pulmonary Function Recovery Over One Year

Pulmonary function was reassessed at 1, 3, 6, and 12 months after surgery using spirometry performed according to ATS/ERS standards, with FVC and FEV_1 expressed as percentages of predicted values. Both groups demonstrated gradual improvement in pulmonary function over time. No statistically significant differences in FVC% predicted, or FEV_1% predicted were observed between the RATS and U-VATS groups at any follow-up time point ($p > 0.05$, Table 7). Repeated-measures ANOVA revealed significant main effects of time on FVC (Table 8, $p < 0.001$) and FEV_1 ($p < 0.001$). No significant time-by-group interactions were observed for FVC ($p = 0.536$) or FEV_1 ($p = 0.776$).

Disease-Free and Overall Survival

During the 12-month postoperative follow-up, tumor recurrence occurred in 5 patients (4.8%) in the RATS group and 7 patients (5.6%) in the U-VATS group. Within one year after surgery, 2 patients (1.9%) in the RATS group and 3 patients (2.4%) in the U-VATS group died. As shown in Fig. 1, Kaplan–Meier survival analysis demonstrated no statisti-

Table 6. Repeated-measures ANOVA for postoperative EORTC QLQ-C30 scores.

Outcome	Effect	df	F	*p*-value	Partial η^2
Global health score	Time	2.951	146.849	<0.001	0.391
	Group	1	116.138	<0.001	0.336
	Time × Group	2.951	9.488	<0.001	0.040
Functional score	Time	2.971	86.857	<0.001	0.275
	Group	1	135.605	<0.001	0.372
	Time × Group	2.971	16.450	<0.001	0.067
Symptom score	Time	2.972	65.284	<0.001	0.222
	Group	1	158.289	<0.001	0.409
	Time × Group	2.972	22.612	<0.001	0.090

Table 7. Comparison of postoperative pulmonary function between the RATS and U-VATS groups.

Time point	Variable	RATS group, n = 105	U-VATS group, n = 126	*p*-value
1 month	FVC% of preoperative	76.0 (72.0–80.0)	77.0 (72.8–81.0)	0.423
	FEV_1% of preoperative	76.0 (72.0–82.0)	77.0 (72.8–80.0)	0.948
3 months	FVC% of preoperative	84.0 (79.5–86.5)	83.0 (79.0–87.0)	0.999
	FEV_1% of preoperative	82.0 (78.0–85.0)	82.0 (78.8–85.0)	0.322
6 months	FVC% of preoperative	87.0 (84.0–90.0)	86.0 (82.0–89.0)	0.164
	FEV_1% of preoperative	86.0 (83.0–89.5)	86.0 (83.0–89.0)	0.886
12 months	FVC% of preoperative	88.0 (84.0–91.0)	87.0 (84.0–91.3)	0.651
	FEV_1% of preoperative	88.0 (84.0–91.0)	87.5 (85.0–90.0)	0.808

Notes: All data are presented as median (IQR) for non-normally distributed variables.

Table 8. Repeated-measures ANOVA for postoperative pulmonary function.

Outcome	Effect	df	F	*p*-value	Partial η^2
FVC% of preoperative	Time	2.854	279.997	<0.001	0.550
	Group	1	0.154	0.695	0.001
	Time × Group	2.951	0.716	0.536	0.003
FEV_1% of preoperative	Time	2.919	309.392	<0.001	0.575
	Group	1	0.378	0.540	0.002
	Time × Group	2.919	0.360	0.776	0.002

cally significant differences between the two groups in 1-year DFS or OS (DFS: $p = 0.788$; OS: $p = 0.805$, log-rank test).

Discussion

Summary of Key Findings

Early-stage NSCLC represents the subgroup of lung cancer most amenable to curative-intent surgical resection, and even minor differences in perioperative or oncologic outcomes may influence long-term management strategies [15, 16]. In this study of stage I–IIA NSCLC, RATS achieved more extensive lymph node dissection and demonstrated superior intraoperative performance, while maintaining comparable safety and oncologic outcomes to U-VATS. Moreover, patients who underwent RATS reported better short-term postoperative quality of life. These findings suggest that RATS reported better short-term recovery and surgical precision. However, given the limited number of events and the 12-month follow-up period, the present study cannot determine whether long-term oncologic outcomes differ between the two surgical approaches.

Comparison With Literature

Both RATS and VATS have been established as safe and effective minimally invasive approaches for lobectomy in patients with non-small cell lung cancer. Recent institutional and multicenter studies have reported intraoperative advantages of RATS, including reduced blood loss and shorter hospitalization, even among patients with more advanced NSCLC, which supports its technical precision and feasibility across disease stages [17]. Similarly, other reports have shown that RATS allows for more thorough lymph node dissection and lower drainage volumes without increasing perioperative mortality or the need for conversion to thoracotomy [18]. Furthermore, direct comparisons between multiportal RATS and uniportal VATS have demonstrated that RATS provides superior lymph node retrieval and reduced intraoperative blood loss, consistent with our current findings, although transiently higher postoperative pain during hospitalization was noted in some cases [19].

Beyond perioperative advantages, the extent and quality of lymph node dissection have notable prognostic implications in early-stage NSCLC. Wu *et al*. [20] evaluated more than

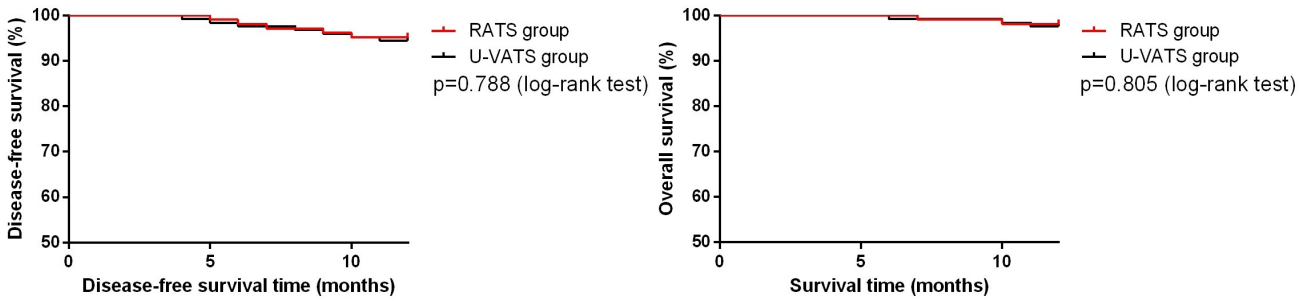

Fig. 1. Kaplan–Meier curves for 1-year disease-free survival (DFS) and overall survival (OS) in the RATS and U-VATS groups. Follow-up time is presented in months. Survival differences were assessed using the log-rank test (DFS: $p = 0.788$; OS: $p = 0.805$).

seven thousand patients with stage IA NSCLC and found that removal of more than five lymph nodes was independently associated with improved cancer-specific and overall survival, even for tumors smaller than 2 cm. In our study, RATS achieved a significantly greater number of dissected lymph nodes and mediastinal stations compared with U-VATS, suggesting that enhanced visualization and precision of robotic instruments may facilitate more accurate pathological N staging. Whether such improvements translate into superior long-term oncologic outcomes remains hypothetical and will require future investigations with extended follow-up. Moreover, meta-analyses have indicated that although RATS is frequently associated with longer operative times and higher costs, it does not compromise perioperative safety or short-term outcomes [21]. Collectively, existing evidence and our present findings confirm that RATS provides enhanced surgical precision and hemostasis with equivalent perioperative safety relative to VATS, reinforcing its role as a reliable minimally invasive approach for early-stage NSCLC.

In recent years, increasing attention has been directed toward patient-reported outcomes following minimally invasive pulmonary resections. In our study, patients undergoing RATS demonstrated superior short-term quality of life within the first six months after surgery, particularly in physical functioning and postoperative pain relief, although these benefits diminished by 12 months. This observation is consistent with emerging evidence suggesting that RATS may offer superior early recovery experiences compared with video- or uniportal-assisted thoracoscopic approaches. A large-scale analysis demonstrated that, compared with VATS, RATS was associated with reduced postoperative pain and higher quality-of-life scores in the pain and physical functioning domains, despite its greater hospitalization costs [22]. Similarly, a prospective trial comparing RATS and uniportal VATS confirmed improved postoperative appetite, gastrointestinal comfort, and cough-related symptoms among patients undergoing RATS, suggesting enhanced short-term postoperative well-being [23]. Recent evidence further indicates that RATS yields the highest global and functional quality-of-life scores among minimally invasive approaches, with significantly lower fatigue, dyspnea, and postoperative pain compared with VATS or thoracotomy [24]. Taken together, current evidence and our results support the concept that RATS enhances early postoperative recovery and patient-perceived quality of life, especially during the critical first few months following lobectomy for early-stage NSCLC.

Postoperative quality of life (QoL) represents not only an indicator of short-term recovery but also a potential determinant of long-term outcomes in patients with malignancies. Qiu *et al.* [25] conducted a prospective longitudinal study in patients with esophageal cancer undergoing curative resection and reported that deterioration in several QoL domains, including role function, emotional function, and dyspnea, was independently associated with reduced overall survival. These findings suggest that the QoL metric may serve as early indicators of patient prognosis beyond conventional clinical variables. Within this framework, the better QoL observed in the RATS group in our study may reflect not only more rapid postoperative recovery but also potential long-term benefits in functional status and overall prognosis. These findings emphasize the clinical significance of incorporating patient-centered QoL assessment into minimally invasive thoracic surgery practice. However, the QoL instruments applied in this study have inherent limitations, and certain functional or activity-related differences may not have been fully detected. These constraints should be considered when interpreting the QoL findings.

Economic considerations remain central to the adoption of novel surgical technologies. In our cohort, total hospitalization costs were significantly higher for RATS than for U-VATS, despite comparable mid-term clinical outcomes. This finding is consistent with previous cost analyses and systematic reviews, which demonstrate that robotic lobectomy is generally more expensive than VATS, largely due to capital expenditures for the robotic system, elevated instrument costs, and greater operating room resource utilization, even when complication rates and length of stay are comparable [26,27]. Additional cost-effectiveness evaluations across different healthcare systems indicate that although the incremental cost of RATS may be partially mitigated in high-volume centers, its overall cost remains higher than that of VATS for many patients with early-stage lung cancer [28]. Our findings therefore reinforce the principle that,

although RATS offers technical and short-term QoL advantages, these benefits must be balanced against the increased resource utilization, especially in settings with constrained budgets or limited access to robotic platforms.

Non-Significant Results and Possible Reasons

Pain is one of the perioperative outcomes of greatest significance to patients. However, in our cohort, VAS scores at all postoperative time points did not differ significantly between the RATS and U-VATS groups. Similar findings have been reported in other studies [24,29]. In contrast, several recent patient-reported outcome studies directly comparing multiportal RATS with uniportal VATS have observed higher early postoperative pain scores and greater activity limitation after RATS during hospitalization and in the early weeks after discharge [19,30]. Taken together, these data suggest that the relative impact of the surgical approach on pain may depend on the comparator technique as well as the perioperative care pathway.

In our study, postoperative analgesia was administered according to a standardized ERAS-based multimodal protocol for all patients. Both groups underwent surgery through small, non-rib-spreading incisions, with identical chest tube placement and removal criteria. These factors likely minimized differences in chest wall trauma and nociceptive stimulation attributable solely to the surgical approach. Furthermore, although the study was powered to detect key perioperative and quality-of-life outcomes, the sample size may still have been insufficient to detect very small or transient differences in acute pain. This combination of standardized analgesia, uniform chest tube management, and a limited sample size may therefore explain why RATS demonstrated postoperative pain outcomes comparable to those of U-VATS in our cohort. Moreover, postoperative pain was assessed only at rest, which may underestimate differences in pain during movement or routine activities between the two groups. This measurement limitation should be considered when interpreting our pain-related findings.

Other key perioperative recovery indicators, including chest tube indwelling time, postoperative drainage volume, and length of hospital stay, also did not differ significantly between the two groups in our study. Increasing evidence from high-volume centers, randomized or multicenter cohorts, and large registry analyses has shown that, once minimally invasive programs reach maturity, postoperative length of stay and chest tube-related outcomes tend to converge between RATS and VATS [31,32]. A key explanation is the widespread adoption of standardized ERAS pathways and protocol-driven chest tube management, which markedly reduces the overall length of stay and decreases perioperative variability across surgical approaches [33]. In our cohort, both RATS and U-VATS were performed by experienced surgeons under an identical chest tube protocol (single-tube placement, low-pressure suction in the early postoperative period, and unified removal criteria) within a uniform ERAS framework. Under these conditions, the technical advantages of RATS in precise dissection and hemostasis are unlikely to result in substantial differences in air-leak duration or pleural drainage, and discharge decisions are determined primarily by standardized institutional thresholds rather than subtle differences in surgical technique.

Lung function recovery represents another critical dimension of postoperative outcomes in lung cancer surgery. In the present study, serial spirometry at 1, 3, 6, and 12 months postoperatively showed comparable trajectories of FVC% and FEV_1% (expressed as percentages of preoperative values) between the RATS and U-VATS groups, with both cohorts demonstrating an early postoperative decline followed by gradual partial recovery. These findings are consistent with previous evidence indicating that minimally invasive lobectomy is generally associated with improved early preservation of pulmonary function compared with thoracotomy. However, differences among minimally invasive approaches themselves are modest and often transient [34,35]. Although robotic-assisted procedures may theoretically reduce muscular trauma and improve precise hilar dissection, the extent of anatomical resection is primarily determined by oncologic requirements and remains similar between RATS and VATS [36]. Moreover, all patients in our study received standardized postoperative respiratory physiotherapy, which may have further mitigated any minor differences in postoperative pulmonary mechanics resulting from the surgical approach. Given the similar recovery trajectories observed, the surgical approach appears to exert only a limited long-term influence on major spirometric parameters when minimally invasive techniques and standardized rehabilitation protocols are consistently applied.

Research Limitations

Several limitations should be acknowledged when interpreting our findings. First, the single-center, retrospective design may introduce selection bias despite the overall comparability of baseline characteristics. Second, although the sample size was sufficient to detect key perioperative and early postoperative differences, it may not provide adequate statistical power for evaluating survival outcomes beyond the first postoperative year. Third, the follow-up period was limited to 12 months, which restricted the evaluation of late oncologic outcomes, such as long-term recurrence patterns and multi-year disease-free survival. Fourth, although postoperative quality of life was assessed using validated instruments, subjective variation and cultural influences may affect patient-reported outcomes. Additionally, potential sources of bias should be acknowledged, including surgical selection bias between approaches, variations in surgeon experience with each technique, and the potential influence of patient economic considerations on the choice of surgical modality. These concerns may limit causal interpretations of the observed outcomes. Future multicenter, prospective randomized trials with extended follow-up and formal cost-

effectiveness analyses are warranted to further validate and generalize these findings.

Clinical Significance and Future Research Directions

Our findings support a pragmatic, value-based framework for selecting the surgical approach in stage I–IIA NSCLC. Robotic-assisted thoracic surgery provided clearer intraoperative advantages, including reduced blood loss, shorter operative duration, more precise lymph node dissection, and improved early postoperative quality of life. However, mid-term recovery profiles, complication rates, and pulmonary function at 1–12 months were comparable between the two approaches. For 1-year DFS and OS, the present data suggest no evidence of inferior 1-year oncological outcomes between the two surgical approaches. However, the limited number of events and the 12-month follow-up duration preclude any definitive conclusions regarding long-term oncologic outcomes. Given the higher hospitalization costs associated with RATS, its use may be most appropriate for patients who could benefit from greater technical precision, such as those with complex hilar anatomy, incomplete fissures, obesity, or dense pleural adhesions, as well as for individuals who prioritize early recovery and symptom relief. Conversely, for standard lobectomies or in resource-limited settings, U-VATS remains an appropriate and oncologically sound option. The choice of surgical approach should be guided by multidisciplinary discussion and shared decision-making, balancing economic considerations with expected short-term benefits. Future research should include formal cost-effectiveness analyses and long-term patient-reported outcome measures to better clarify the added value of robotic surgery.

Conclusions

In summary, both RATS and U-VATS are safe and effective minimally invasive approaches for anatomic lobectomy in patients with early-stage NSCLC. RATS demonstrates advantages in operative efficiency, intraoperative blood loss, lymph node dissection, and early postoperative quality of life, while showing no significant differences in pulmonary function recovery, complication rates, or 1-year survival. Although hospitalization costs were higher, RATS may be a reasonable option for selected patients when resources permit.

Availability of Data and Materials

The data used and analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

Guarantor of integrity of the entire study: JZ; study concepts: JZ; definition of intellectual content: JZ; literature research: YN; clinical studies: YN; data acquisition: JZ; data analysis: YN; statistical analysis: YN; manuscript preparation: YN; manuscript editing: YN; manuscript review: JZ. Both authors contributed to the critical revision of the manuscript for important intellectual content. Both authors read and approved the final manuscript. Both authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Ethics Committee of The First Affiliated Hospital of University of South China (Approval No. 20250311). All patients provided informed consent prior to treatment.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Bray F, Laversanne M, Sung H, Ferlay J, Siegel RL, Soerjomataram I, *et al*. Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA: A Cancer Journal for Clinicians. 2024; 74: 229–263. https://doi.org/10.3322/caac.21834.

[2] Wang T, Wang Y, Luo Y, Chen H. Longitudinal Study on Changes of Cancer-Related Fatigue in Elderly Patients with Postoperative Chemotherapy for Non-Small Cell Lung Cancer. Annali Italiani Di Chirurgia. 2024; 95: 22–29.

[3] Alduais Y, Zhang H, Fan F, Chen J, Chen B. Non-small cell lung cancer (NSCLC): A review of risk factors, diagnosis, and treatment. Medicine. 2023; 102: e32899. https://doi.org/10.1097/MD.0000000000032899.

[4] Xiong A, Wang J, Zhou C. Immunotherapy in the First-Line Treatment of NSCLC: Current Status and Future Directions in China. Frontiers in Oncology. 2021; 11: 757993. https://doi.org/10.3389/fonc.2021.757993.

[5] Ettinger DS, Wood DE, Aisner DL, Akerley W, Bauman JR, Bharat A, *et al*. Non-Small Cell Lung Cancer, Version 3.2022, NCCN Clinical Practice Guidelines in Oncology. Journal of the National Comprehensive Cancer Network. 2022; 20: 497–530. https://doi.org/10.6004/jnccn.2022.0025.

[6] Watanabe A, Miyajima M, Mishina T, Tsuruta K, Takahashi Y, Maki R, *et al*. Video-assisted thoracoscopic surgery node dissection for lung cancer treatment. Surgery Today. 2017; 47: 1419–1428. https://doi.org/10.1007/s00595-017-1494-x.

[7] Song Z, Yuan Y, Cheng C, Luo Q, Cheng X. The learning curve on uniportal video-assisted thoracoscopic lobectomy with the help of postoperative review of videos. Frontiers in Oncology. 2023; 13: 1085634. https://doi.org/10.3389/fonc.2023.1085634.

[8] Kumar A, Asaf BB. Robotic thoracic surgery: The state of the art. Journal of Minimal Access Surgery. 2015; 11: 60–67. https://doi.org/10.4103/0972-9941.147693.

[9] Latif MJ, Park BJ. Robotics in general thoracic surgery procedures. Journal of Visualized Surgery. 2017; 3: 44. https://doi.org/10.21037/jovs.2017.03.14.

[10] Tung KH, Yendamuri S, Seastedt KP. Adoption of the Robotic Plat-

form across Thoracic Surgeries. Journal of Clinical Medicine. 2024; 13: 5764. https://doi.org/10.3390/jcm13195764.

[11] Zeng L, He T, Hu J. Minimally invasive thoracic surgery: robot-assisted versus video-assisted thoracoscopic surgery. Videosurgery and Other Miniinvasive Techniques. 2023; 18: 436–444. https://doi.org/10.5114/wiitm.2023.128714.

[12] Harrison OJ, Maraschi A, Routledge T, Lampridis S, LeReun C, Bille A. A cost analysis of robotic vs. video-assisted thoracic surgery: The impact of the learning curve and the COVID-19 pandemic. Frontiers in Surgery. 2023; 10: 1123329. https://doi.org/10.3389/fsurg.2023.1123329.

[13] Lababede O, Meziane MA. The Eighth Edition of TNM Staging of Lung Cancer: Reference Chart and Diagrams. The Oncologist. 2018; 23: 844–848. https://doi.org/10.1634/theoncologist.2017-0659.

[14] Gift AG. Visual analogue scales: measurement of subjective phenomena. Nursing Research. 1989; 38: 286–288.

[15] Hardavella G, Magouliotis DE, Chalela R, Januszewski A, Dennstaedt F, Putora PM, *et al*. Stage I and II nonsmall cell lung cancer treatment options. Breathe. 2024; 20: 230219. https://doi.org/10.1183/20734735.0219-2023.

[16] Li T, Zhang Y, Fu F, Chen H. The evolution of the treatment of non-small cell lung cancer: A shift in surgical paradigm to a more individualized approach. The Journal of Thoracic and Cardiovascular Surgery. 2025; 169: 737–744.e2. https://doi.org/10.1016/j.jtcvs.2024.07.040.

[17] Nakamura R, Okuda K, Hosokawa S, Yobita S, Chiba K, Oda R, *et al*. Robotic versus video-assisted thoracoscopic surgery for pathological stage II-IIIB non-small cell lung cancer: evaluation of perioperative and survival outcomes. Journal of Thoracic Disease. 2025; 17: 5429–5441. https://doi.org/10.21037/jtd-2025-553.

[18] Dai F, Xu S, Xu W, Ding R, Liu B, Meng H, *et al*. A Paired Case Controlled Study Comparing the Short-term Outcomes of Da Vinci RATS and VATS Approach for Non-small Cell Lung Cancer. Chinese Journal of Lung Cancer. 2018; 21: 206–211. https://doi.org/10.3779/j.issn.1009-3419.2018.03.18. (In Chinese)

[19] Zhang K, Liu W, Zhao Y, Gao X, Dai W, Zhou X, *et al*. Comparison of early postoperative patient-reported outcomes after multiportal robotic-assisted thoracoscopic surgery and uniportal video-assisted thoracoscopic surgery for non-small cell lung cancer. European Journal of Surgical Oncology. 2024; 50: 108481. https://doi.org/10.1016/j.ejso.2024.108481.

[20] Wu LL, Lai JJ, Liu X, Huang YY, Lin P, Long H, *et al*. Association between number of dissected lymph nodes and survival in stage IA non-small cell lung cancer: a propensity score matching analysis. World Journal of Surgical Oncology. 2020; 18: 322. https://doi.org/10.1186/s12957-020-02090-5.

[21] Hu X, Wang M. Efficacy and Safety of Robot-assisted Thoracic Surgery (RATS) Compare with Video-assisted Thoracoscopic Surgery (VATS) for Lung Lobectomy in Patients with Non-small Cell Lung Cancer. Combinatorial Chemistry & High Throughput Screening. 2019; 22: 169–178. https://doi.org/10.2174/1386207322666190411113040.

[22] Huang L, Liang S, He J, Qin J, Wei J, Huang J, *et al*. Impact of robotic-assisted versus video-assisted thoracoscopic surgery on efficacy and quality of life in patients with pulmonary opacities: a propensity score-matched analysis. Frontiers in Oncology. 2025; 15: 1598990. https://doi.org/10.3389/fonc.2025.1598990.

[23] Diao H, Xu L, Li X, Wang Y, Peng Z. Comparison Results of Three-Port Robot-Assisted and Uniportal Video-Assisted Lobectomy for Functional Recovery Index in the Treatment of Early Stage Non-small Cell Lung Cancer: A Propensity Score-Matched Analysis. Annals of Surgical Oncology. 2024; 31: 2470–2481. https://doi.org/10.1245/s10434-023-14767-8.

[24] Asemota N, Maraschi A, Lampridis S, Pilling J, King J, Le Reun C, *et al*. Comparison of Quality of Life after Robotic, Video-Assisted, and Open Surgery for Lung Cancer. Journal of Clinical Medicine. 2023; 12: 6230. https://doi.org/10.3390/jcm12196230.

[25] Qiu LH, Liang SH, Wu L, Huang YY, Yang TZ, Li CZ, *et al*. Longitudinal assessment of quality of life indicators and prognosis in esophageal cancer patients with curative resection. Journal of Thoracic Disease. 2024; 16: 6064–6080. https://doi.org/10.21037/jtd-24-311.

[26] Keeney-Bonthrone TP, Frydrych LM, Karmakar M, Hawes AM, Reddy RM. Robot-assisted vs. video-assisted thoracoscopic lobectomy: a systematic review of cost effectiveness. Video-Assisted Thoracic Surgery. 2020; 5. https://doi.org/10.21037/vats.2019.12.07.

[27] Singer E, Kneuertz PJ, D'Souza DM, Moffatt-Bruce SD, Merritt RE. Understanding the financial cost of robotic lobectomy: calculating the value of innovation? Annals of Cardiothoracic Surgery. 2019; 8: 194–201. https://doi.org/10.21037/acs.2018.05.18.

[28] 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. https://doi.org/10.1016/j.lungcan.2020.12.033.

[29] Jin R, Zhang Z, Zheng Y, Niu Z, Sun S, Cao Y, *et al*. Health-Related Quality of Life Following Robotic-Assisted or Video-Assisted Lobectomy in Patients With Non-Small Cell Lung Cancer: Results From the RVlob Randomized Clinical Trial. Chest. 2023; 163: 1576–1588. https://doi.org/10.1016/j.chest.2022.12.037.

[30] Tulinský L, Jarošová N, Adamica D, Bujok P, Mitták M, Kondé A, *et al*. Pain and recovery after robotic vs. uniportal lobectomy for lung cancer: a comparative analysis. Surgical Endoscopy. 2025; 39: 7181–7190. https://doi.org/10.1007/s00464-025-12083-8.

[31] Mirza W, Javid A, Khan ME, Uneeb M, Khan A, Khan HM, *et al*. Robotic-assisted vs video-assisted thoracoscopic lobectomy for non-small cell lung cancer: a GRADE-assessed systematic review and meta-analysis of randomized controlled trials on surgical quality, perioperative, and oncologic outcomes. Journal of Robotic Surgery. 2025; 19: 651. https://doi.org/10.1007/s11701-025-02852-x.

[32] Bottet B, Gillibert A, Seguin-Givelet A, Falcoz PE, Pagès PB, Sage E, *et al*. Comparative short-term outcomes of robotic-assisted vs video-assisted thoracic surgery in lung cancer: a multicenter retrospective study from EPITHOR with a quality audit. Journal of Robotic Surgery. 2025; 19: 68. https://doi.org/10.1007/s11701-024-02174-4.

[33] Forster C, Doucet V, Perentes JY, Abdelnour-Berchtold E, Zellweger M, Faouzi M, *et al*. Impact of an enhanced recovery after surgery pathway on thoracoscopic lobectomy outcomes in non-small cell lung cancer patients: a propensity score-matched study. Translational Lung Cancer Research. 2021; 10: 93–103. https://doi.org/10.21037/tlcr-20-891.

[34] Nakata M, Saeki H, Yokoyama N, Kurita A, Takiyama W, Takashima S. Pulmonary function after lobectomy: video-assisted thoracic surgery versus thoracotomy. The Annals of Thoracic Surgery. 2000; 70: 938–941. https://doi.org/10.1016/s0003-4975(00)01513-7.

[35] Guo X, Liu D, Shao Z, Meng Y, Huang B, Song X. Safety, efficacy, and postoperative pulmonary function recovery of uniportal and multiportal thoracoscopic lung segmentectomy. Journal of Thoracic Disease. 2025; 17: 3118–3127. https://doi.org/10.21037/jtd-2024-1930.

[36] Mao J, Tang Z, Mi Y, Xu H, Li K, Liang Y, *et al*. Robotic and video-assisted lobectomy/segmentectomy for non-small cell lung cancer have similar perioperative outcomes: a systematic review and meta-analysis. Translational Cancer Research. 2021; 10: 3883–3893. https://doi.org/10.21037/tcr-21-646.