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RESEARCH

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

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Abstract

Advancements in diagnostic imaging and surgical techniques have significantly evolved the treatment landscape of non-small cell lung cancer (NSCLC). The shift toward parenchymal-sparing approaches, such as segmentectomy for cT1a-bN0 tumors, is challenging the traditional lobectomy. This retrospective multicenter cohort study evaluates short-term outcomes of Video-Assisted Thoracoscopic Surgery (VATS) and Robotic-Assisted Thoracic Surgery (RATS) in NSCLC patients using data from the French EPITHOR registry, enhanced by an in-depth quality audit. The audit ensured the completeness and accuracy of the data by monitoring and improving the quality of data entry at participating centers. We included patients who underwent mini-invasive lobectomy or segmentectomy between January 2016 and December 2020. The primary outcome was the length of hospital stay (LOS), with secondary outcomes including complications, 90-day rehospitalization, and mortality. A total of 5687 interventions were analyzed, including 3692 VATS and 1995 RATS procedures. The unadjusted mean LOS was slightly shorter for RATS (7.61 days) compared to VATS (8.04 days), though this difference was not statistically significant after adjustment ($p = 0.073$). No significant differences were found in secondary outcomes, including complication rates and 90-day mortality. The integration of a comprehensive quality audit allowed for a robust comparison of outcomes, ensuring reliable and accurate data across all centers. While RATS showed a trend toward shorter hospital stays, this study did not find statistically significant differences in short-term outcomes between RATS and VATS after adjusting for confounders. Both RATS and VATS are viable options for lung resections, with the choice potentially guided by surgeon expertise and institutional resources.

Keywords Lung surgery · Robotic surgery · Video-assisted surgery · Segmentectomy · Lobectomy · Audit quality

Abbreviations

ASA	American society of anesthesiologists
CCI	Charlson comorbidity index
COPD	Chronic obstructive pulmonary disease
CT	Computed tomography
DLCO	Diffusing capacity for carbon monoxide
ECOG	Eastern cooperative oncology group
ERAS	Enhanced recovery after surgery

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FEV1	Forced expiratory volume in 1 second
LOS	Length of stay
NSCLC	Non-small cell lung cancer
RATS	Robotic-assisted thoracic surgery
VATS	Video-assisted thoracoscopic surgery
WHO	World health organization

Introduction

The therapeutic landscape of non-small cell lung cancer (NSCLC) has evolved substantially, influenced by advancements in diagnostic imaging and surgical techniques. The rise of lung cancer screening with low-dose chest CT [1] have revolutionized the detection of very early NSCLC eligible for surgical management. Moreover, the shift toward parenchymal-sparing approaches has redefined surgical standards; lobectomy, gold standard for early stage NSCLC [2], is now challenged by segmentectomy for treating cT1a-bN0 tumors, (less than 2 cm without nodal involvement) [3]. This evolution is further illustrated by recent randomized trials by Saji et al. and Altorki et al. [4, 5], which have highlighted the importance of segmentectomy in early stage management.

Compared to lobectomy, segmentectomy is more challenging, due to inter-individual anatomical variations, segmental lymph-node dissection, and intersegmental plane. In France, the 2000s marked a significant shift toward video-assisted thoracic surgery (VATS), which has been associated with reduced postoperative pain, intraoperative bleeding, and shorter hospital stays compared to open thoracotomy [6–8].

The Robotic-Assisted Thoracic Surgery (RATS) approaches to lung resection have been popularized in recent years in France [9], offering the advantages of articulating instrumentation, improved maneuverability, better ergonomics, and superior three-dimensional visualization compared to VATS techniques. Despite these advantages, cost considerations present a notable barrier, with robotic procedures incurring higher expenses than VATS and open surgery [10, 11]. Nonetheless, Gondé et al. demonstrated that in experienced centers, the additional cost of RATS may be justified, offering a balance between economic feasibility and clinical benefits [12]. A recent randomized trial suggested that RATS was cost-effective and associated with comparable short-term patient-reported health utility scores compared to VATS [13].

While RATS has been shown to improve short-term outcomes and reduce adverse events and hospital stays compared to thoracotomy [14, 15], the comparison with VATS remains a subject of ongoing debate, with no consensus on superiority regarding minimally invasive approaches [16–20].

The aim of this study is to evaluate the short-term outcomes of VATS and RATS segmentectomies and lobectomies with a focus on the implications of surgical volume and surgeon expertise.

Materials and methods

Setting and population

This is an observational retrospective multicenter cohort study based on the EPITHOR database. EPITHOR is a French registry recording preoperative, peroperative, and postoperative data about thoracic surgery interventions. The EPITHOR registry is prospectively fed by thoracic surgeons and a data manager. To improve data completeness, 15 centers who had already average or low missing data rates for pulmonary cancer interventions were selected for improvement (Table S1 and S2). EPITHOR includes a quality index that allows each center to monitor its performance. This index comprises the rate of compliant files, the rate of follow-up beyond 90 days, the average rate of data completeness, and the rate of length of stay without discordances. To further improve data quality, a data manager provided on-site training to surgeons, ensuring accurate and comprehensive data entry, particularly for key preoperative and postoperative variables. These variables included ECOG/WHO performance status, American Society of Anesthesiologists (ASA) score, comorbidities, preoperative TNM staging, type and duration of intervention, preoperative FEV1, histological type, postoperative TNM staging, 90-day postoperative complications and their grading, as well as length of hospital stay.

Patients aged > = 18 years recruited in one of the 15 participating centers were included in this study if they had an elective mini-invasive (VATS or RATS) lobectomy or segmentectomy with curative intent for a histologically confirmed primitive NSCLC performed between January 1st 2016 and December 31th 2020. Patients with emergency surgery, non-anatomic resection (e.g., wedge resection), a bilobectomy or pneumonectomy were excluded. Patients who had several independent pulmonary cancer interventions (e.g., adenocarcinoma of the right lung, then squamous cell carcinoma of the left lung) were included more than once; the cancers could either be synchronous (e.g., two interventions fewer than 90 days apart) or asynchronous (e.g., two interventions 2 years apart).

Outcomes

The primary outcome was length of hospital stay (LOS), defined as the delay between the day of end of hospitalization and the day of surgery, with a minimal theoretical value of one for a patient who would be discharged on the day of surgery. The LOS could be 1-day shorter than the complete duration of hospitalization for patients who were hospitalized the day before the surgery.

Secondary outcomes were: complications with Clavien–Dindo grade > = 2, complication with Clavien–Dindo grade > = 3, 90-day rehospitalization, 90-day death. Post hoc outcomes included prolonged air leak, atelectasis, N0- > N1 or N2 upstaging.

Statistics

The primary analysis was performed in analysis of covariance (ANCOVA) models with the length of stay (LOS) as dependent variable and the intervention type (VATS or RATS) and adjustment variables as independent variables. Adjustment variables were: age (< 64,65–74,75–84, ≥ 85 years), WHO/ECOG performance status (categorical), ASA status (categorical), Charlson comorbidity index (CCI, linear effect), personal history of COPD, smoking status (never, former, current), preoperative TNM status (categorical, from 0 to IV), FEV1 (%, linear effect), preoperative carbon monoxide diffusing capacity (DLCO) (linear effect), lobectomy or segmentectomy, surgeon, and tumor histology (adenocarcinoma, squamous cell carcinoma, carcinoid tumor, and others). Secondary and post hoc outcomes were also compared between RATS and VATS in ANCOVA models, since the large sample size guaranteed that the normal approximation is good enough for binary outcomes, permitting the estimation of absolute percentage differences, which are more clinically relevant than odds ratio of logistic regressions.

As the rate of RATS interventions was very surgeon-dependent, a post hoc ecological sensitivity analysis, immune to the indication bias but prone to surgeon's related confounders, was performed: the exposure variable was defined as the rate of RATS performed by the surgeon (between 0 and 100%) rather than the intervention that the patient actually received. For this sensitivity analysis, all surgeons who had more than 30 interventions fulfilling inclusion criteria were included. An ANCOVA with the outcome as dependent variable and the surgeon and all adjustment variables as independent variables was estimated. The type of mini-invasive treatment (VATS vs RATS) was not used as the independent variable in this model. From this model, the effect associated with each surgeon was extracted, and then, it was used as dependent variable in a simple linear regression explaining surgeon's average outcome by surgeon's overall RATS use rate (from 0 to 100%). The slope of this linear regression was then interpreted as the average difference of the outcome between a surgeon who would always use RATS compared to a surgeon who would always use VATS, adjusted on the same variables as the primary analysis.

Missing data were multiply imputed by fully conditional specification for all comparative adjusted analyses except 90-day death and 90-day rehospitalization, simply imputed as "alive" and "not rehospitalized" respectively. Predictive mean matching models were used to impute quantitative variables (preoperative FEV1, preoperative DLCO, and length of hospital stay), binary logistic regressions were used for binary variables (grade ≥ 2 complications, grade ≥ 3 complications, and 90-day rehospitalization), and multinominal logistic regressions were used for categorical variables (ECOG/WHO, ASA, preoperative TNM stage, and postoperative histology). The primary outcome, secondary outcomes, planned adjustment variables, and primary exposure (VATS vs RATS) were used as multiple imputation predictors, but post hoc outcomes (atelectasis, upstaging, prolonged air leak) were not used. Rubin's rule was used to pool the results of analyses in the 30 multiply imputed data sets. For some variables (atelectasis complication, prolonged air leak, COPD, tobacco use, and Charlson comorbidity index components), there was no way to distinguish missing data and the absence of the complication or comorbidity; therefore, no imputation could be performed for these variables.

Subgroup analyses were performed in segmentectomy and lobectomy subgroups. Categorical variables were described by their frequency and percentages, while quantitative variables were described by their mean and standard deviations. Percentages were compared by Fisher's exact tests when possible and Chi-square tests on categorical variables with too many categories to compute Fisher's exact test. Means were compared by Student's t tests.

R software (version 4.2, The R Foundation for Statistical Computing, Vienna, Austria) with 'mice' package was used for all statistical analyses. All statistical tests were two-sided with significance threshold set at 5%, without multiple testing procedure.

Results

Flowchart and preoperative/peroperative characteristics

A total of 6040 interventions for pulmonary cancer with mini-invasive segmentectomy or lobectomy were exported from the EPITHOR registry. A total of 353 interventions were excluded (Fig. 1), and eventually, 3692 RATS interventions and 1995 RATS interventions were included for a total of 5687 interventions included in 15 centers. In the 5687 patients, there were 2 missing data on ECOG/WHO status, 2 on ASA status, 179 (3.1%) on preoperative FEV1, 2376 (41.8%) on preoperative DLCO, 456 (8.0%)

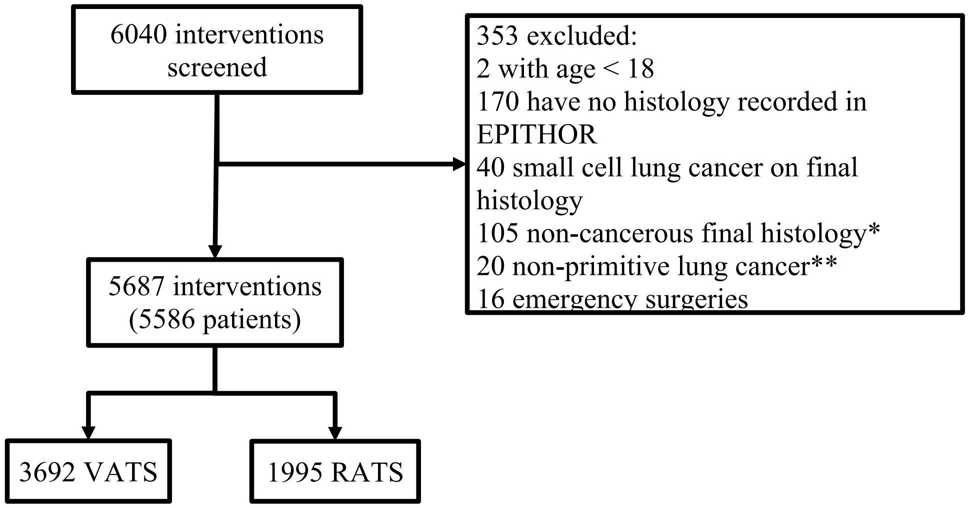

Fig. 1 Flowchart of interventions included in the study. *non-cancerous final histology findings that could be explained by a neoadjuvant treatment, such as the "absence of residual tumoral tissue" were not excluded. ** on-primitive lung cancers were lung metastases of distant cancers

on preoperative TNM stage, 42 (0.7%) on final histology, 504 (8.9%) on node upstaging, 39 (0.7%) on postoperative complications, 35 (0.6%) on length of stay, 179 (3.1%) on 90-day rehospitalization, and 38.6% on 90-day death (simply imputed as alive).

Table 1 shows the preoperative and peroperative characteristics of patients. In the 15 centers, the median number of interventions included was 330 (interquartile range [IQR]: 166.5 to 521), with 104 interventions minimum and 870 interventions maximum. In the 15 centers, the proportion of RATS in mini-invasive procedures ranged from 0 to 100% with a median at 43.7% (IQR: 24.7%; 77.6%). Patients who had RATS had a higher ASA score ($p < 0.0001$), but slightly lower Charlson comorbidity index (3.28 ± 1.72 for RATS vs 3.51 ± 1.87 for VATS, $p < 0.0001$). Although the difference of distribution of stage was significant ($p < 0.0001$) between RATS and VATS group, it was moderate (70.0% of stage IA for RATS vs 63.6% of stage IA for VATS). The proportion of segmentectomy vs lobectomy was not significantly different between RATS and VATS groups (20.8% for VATS vs 22.1% for RATS, $p = 0.30$). The proportion of RATS in segmentectomy slightly increased from 2016 to 2020 (Fig. 2), but this increase was not significant ($p = 0.67$). Multi-incision was significantly less common ($p < 0.0001$) with VATS (86.0%) than with RATS (94.7%), while frozen section procedures were more common with VATS (50.7%) than with RATS (41.9%), without taking in account the surgeon's cluster effect. Although the difference of mean duration of intervention was significant (without taking in account the surgeon's cluster effect), it was small (151.92 ± 53.5 for VATS vs 157.38 ± 63.23 for RATS, $p < 0.0001$). The absence of lymphadenectomy was rare, but more frequent ($p < 0.0001$) with VATS (2.2%) than RATS (0.8%).

Temporal trends in surgical practice

Overall, there were fewer RATS ($n = 1995$) than VATS ($n = 3692$) from 2016 to 2020, although the selection of centers, favoring centers with RATS activity, made this figure non-representative of the French thoracic surgery activity. In these 15 centers, the RATS/VATS ratio ranged from 49/137 (0.36) in 2017 to 104/134 (0.78) in 2018 for stage ≤ I segmentectomy (Fig. 2). However, according to simple linear regressions, there was no significant linear trend for increase or decrease of the proportion of RATS among mini-invasive procedures between 2016 and 2020 for stage ≤ I segmentectomy (+3.4% RATS/year, 95% CI −2.6 to 9.5%, $p = 0.17$), stage ≥ II segmentectomy (5.5%/year, 95% CI −13.7 to 24.6%, $p = 0.43$), stage ≤ I lobectomy (+0.9%/year, 95% CI −2.3 to 4.0%, $p = 0.44$), or stage ≥ II lobectomy (−0.8%, 95% CI −3.6 to 1.9%, $p = 0.40$).

Post-operative outcomes

Tables 2, 3 shows postoperative outcomes of all patients. The differences in histology distributions between RATS and VATS groups were negligible. The proportion of R1/R2 resection margins were not significantly different between groups ($p = 0.088$).

The 5687 interventions were performed by 80 primary surgeons. After excluding the 36 surgeons who had included 29 interventions or fewer, 5361 interventions (3418 VATS, 1943 RATS) performed by 44 surgeons were included in the sensitivity analysis. Among the 44 surgeons included, 21 (47.7%) had performed less than 10% RATS, 8 (18.2%) had performed more than 90% RATS, and 15 (34.1%) had performed between 10 and 90% RATS. Figure S1 shows the distribution of the proportions of mini-invasive procedures performed by RATS, according

Table 1 Pre-operative characteristics and peroperative characteristics of the patients in VATS and RATS groups

	VATS $n = 3692$ n/N (%)	RATS $n = 1995$ n/N (%)	P value
Age (years), mean ± SD [n]	66.37 ± 9.4 [3692]	66.5 ± 9.39 [1995]	0.60
Female sex			0.38
WHO performance status			
0	2186/3691 (59.2)	1232/1994 (61.8)	0.0514
1	1297/3691 (35.1)	670/1994 (33.6)	
2	200/3691 (5.4)	84/1994 (4.2)	
3	8/3691 (0.2)	8/1994 (0.4)	
ASA			
1	582/3692 (15.8)	179/1993 (9)	< 0.0001
2	1896/3692 (51.4)	946/1993 (47.5)	
3	1199/3692 (32.5)	852/1993 (42.7)	
4	15/3692 (0.4)	16/1993 (0.8)	
Smoking			
Never	1565/3692 (42.4)	743/1995 (37.2)	< 0.0001
Former	349/3692 (9.5)	340/1995 (17)	
Current	1778/3692 (48.2)	912/1995 (45.7)	
Preoperative FEV1 (% of theoretical), mean ± SD [n]	88.69 ± 19.36 [3575]	89.28 ± 20.48 [1933]	0.29
Preoperative DLCO, mean ± SD [n]	73.13 ± 18.13 [2368]	74.16 ± 18.9 [943]	0.15
Charlson comorbidity index, mean ± SD [n]	3.51 ± 1.87 [3692]	3.28 ± 1.72 [1995]	< 0.0001
COPD	723/3692 (19.6)	493/1995 (24.7)	< 0.0001
Asthma	80/3692 (2.2)	56/1995 (2.8)	0.16
Sleep apnea syndrome	203/3692 (5.5)	144/1995 (7.2)	0.012
History of thoracic surgery	201/3692 (5.4)	97/1995 (4.9)	0.38
History of cancer	1211/3692 (32.8)	644/1995 (32.3)	0.71
History of lung cancer	115/3692 (3.1)	47/1995 (2.4)	0.12
Preoperative TNM stage			
Stade 0	13/3377 (0.4)	18/1854 (1)	< 0.0001
Stade IA	2147/3377 (63.6)	1298/1854 (70)	
Stade IB	525/3377 (15.5)	256/1854 (13.8)	
Stade IIA	121/3377 (3.6)	23/1854 (1.2)	
Stade IIB	326/3377 (9.7)	146/1854 (7.9)	
Stade IIIA	142/3377 (4.2)	64/1854 (3.5)	
Stade IIIB	21/3377 (0.6)	6/1854 (0.3)	
Stade IIIC	1/3377 (0)	0/1854 (0)	
Stade IV	81/3377 (2.4)	43/1854 (2.3)	
Missing	315/3692 (8.5)	141/1995 (7.1)	
Cancer in left lung	1491/3691 (40.4)	820/1989 (41.2)	0.56
Upper lobe	1978/3312 (59.7)	1124/1878 (59.9)	0.95
No preoperative chemotherapy or radiotherapy	3551/3692 (96.2)	1915/1995 (96)	0.24
Index of prolonged air leak, mean ± SD [n]	6.51 ± 4.14 [3692]	6.66 ± 4.32 [1995]	0.20
Type of intervention			
Lobectomy	2923/3692 (79.2)	1555/1995 (77.9)	0.30
Segmentectomy	769/3692 (20.8)	440/1995 (22.1)	
Duration of intervention (min), mean ± SD [n]	151.92 ± 53.5 [3685]	157.38 ± 63.23 [1972]	0.0006
Multi-incision	3174/3690 (86)	1881/1986 (94.7)	< 0.0001
Frozen section procedure	1865/3675 (50.7)	832/1987 (41.9)	< 0.0001

Table 1 (continued)

	VATS $n = 3692$ n/N (%)	RATS $n = 1995$ n/N (%)	P value
Lymphadenectomy			
None	82/3691 (2.2)	16/1992 (0.8)	< 0.0001
Biopsy	8/3691 (0.2)	4/1992 (0.2)	
Lobe-oriented	224/3691 (6.1)	171/1992 (8.6)	
Radical	3377/3691 (91.5)	1801/1992 (90.4)	

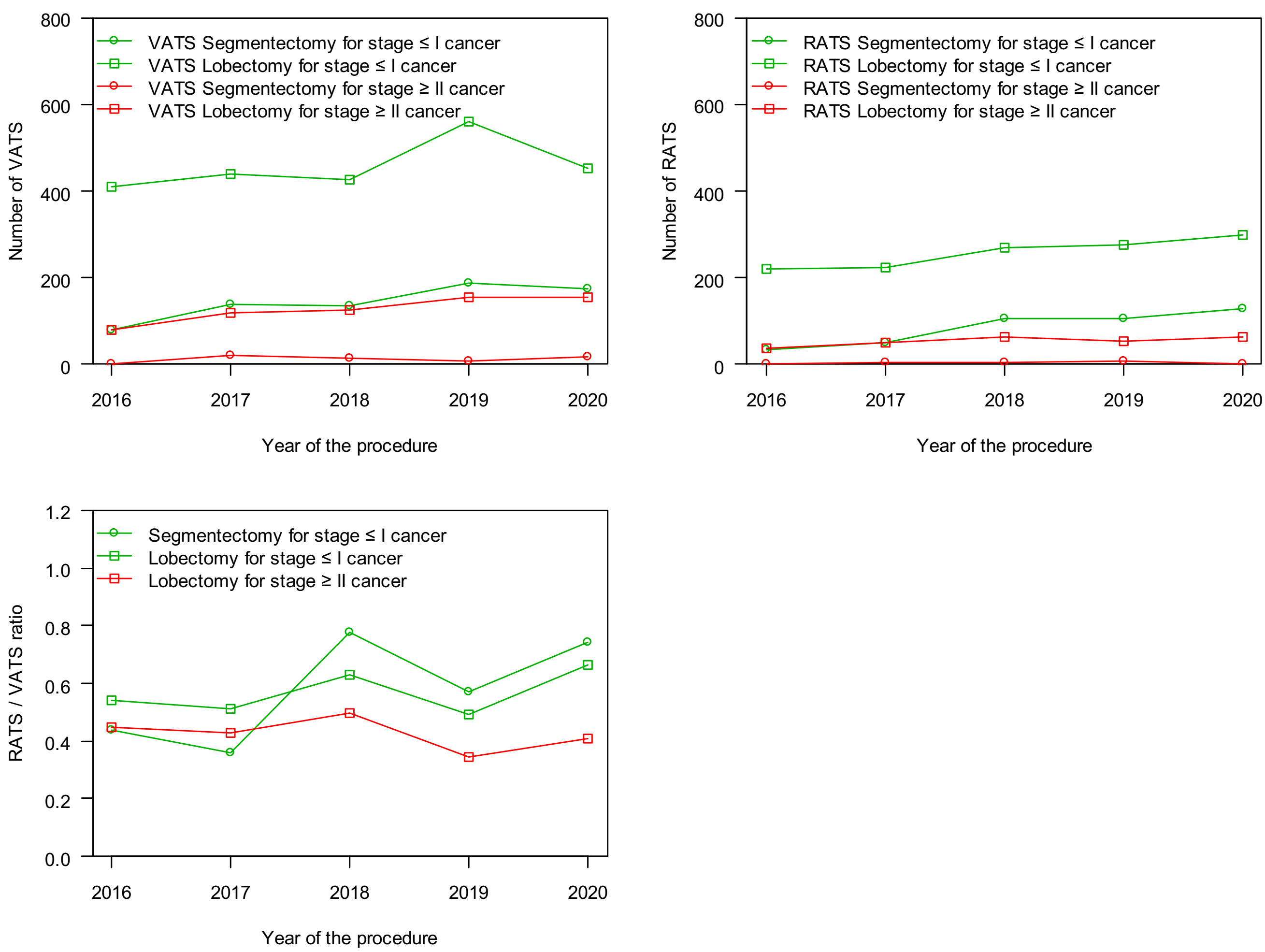

Fig. 2 Trends of the proportion of RATS among mini-invasive procedures (VATS + RATS) from 2016 to 2020; the trend is not represented for the RATS/VATS ratio of segmentectomy for stage ≥ II cancer due to very small sample sizes and large sampling fluctuations

to the surgeon, and the association between the proportion of procedures performed by RATS and the mean length of stay of patients operated by the surgeon. The unadjusted and adjusted regression slopes, showing the associations between the mean rate of RATS and mean outcomes, are shown in Table S3. These regression slopes can be interpreted as the mean difference of outcome between a surgeon who would perform 100% of RATS interventions compared to a surgeon who would perform 100% of VATS interventions, and so, can be interpreted as the mean outcome difference between RATS and VATS interventions. None of the unadjusted and adjusted effects were statistically significant (Table S3).

Table 2 Post-operative characteristics and outcomes in VATS and RATS groups

	VATS $n=3692$ n/N (%)	RATS $n=1995$ n/N (%)	P value
Final histology			
Adenocarcinoma	2714/3668 (74)	1486/1977 (75.2)	0.04
Squamous cell carcinoma	589/3668 (16.1)	280/1977 (14.2)	
Typical carcinoid tumor	150/3668 (4.1)	110/1977 (5.6)	
Large cell neuroendocrine carcinoma	65/3668 (1.8)	24/1977 (1.2)	
Large cell undifferentiated carcinoma	40/3668 (1.1)	28/1977 (1.4)	
Atypical carcinoid tumor	35/3668 (1)	18/1977 (0.9)	
Sarcomatoid carcinoma	12/3668 (0.3)	6/1977 (0.3)	
Other primitive lung cancer	63/3668 (1.7)	25/1977 (1.3)	
Resection margins			
Irrelevant	4/3615 (0.1)	0/1955 (0)	0.088
R0	3450/3615 (95.4)	1889/1955 (96.6)	
R1	155/3615 (4.3)	62/1955 (3.2)	
R2	6/3615 (0.2)	4/1955 (0.2)	
Upstaging N0—> N1 or N2	379/3692 (10.3)	229/1995 (11.5)	0.17
Upstaging N0—> N2	194/3692 (5.3)	106/1995 (5.3)	0.97
Worst Clavien–Dindo complication			
No complication	2397/3682 (65.1)	1281/1966 (65.2)	0.32
Grade I	333/3682 (9)	182/1966 (9.3)	
Grade II	633/3682 (17.2)	341/1966 (17.3)	
Grade IIIa	162/3682 (4.4)	76/1966 (3.9)	
Grade IIIb	93/3682 (2.5)	42/1966 (2.1)	
Grade IVa	36/3682 (1)	16/1966 (0.8)	
Grade IVb	3/3682 (0.1)	2/1966 (0.1)	
Grade V	25/3682 (0.7)	26/1966 (1.3)	
Most common complications			
Post-operative infection	348/3578 (9.7)	195/1940 (10.1)	0.73
Air leak > 5 days	482/3692 (13.1)	218/1995 (10.9)	0.021
Pneumonia	214/3692 (5.8)	92/1995 (4.6)	0.065
Cardiac rhythm disorder	147/3692 (4)	95/1995 (4.8)	0.19
Other infection	125/3692 (3.4)	84/1995 (4.2)	0.13
Urological complication	106/3692 (2.9)	63/1995 (3.2)	0.60
Atelectasis	78/3692 (2.1)	85/1995 (4.3)	< 0.0001
Pleural effusion	85/3692 (2.3)	48/1995 (2.4)	0.87
Respiratory failure	64/3692 (1.7)	39/1995 (2)	0.62
Recurrent laryngeal nerve paralysis	63/3692 (1.7)	16/1995 (0.8)	0.006
Postoperative bleeding	48/3692 (1.3)	21/1995 (1.1)	0.50
Digestive complication	35/3692 (0.9)	22/1995 (1.1)	0.67
Thrombo-embolic complication	26/3692 (0.7)	19/1995 (1)	0.39
Renal failure	28/3692 (0.8)	16/1995 (0.8)	0.97
Delirium	30/3692 (0.8)	11/1995 (0.6)	0.34
Lymphatic leak	17/3692 (0.5)	15/1995 (0.8)	0.23
Other iatrogenic complication	21/3692 (0.6)	9/1995 (0.5)	0.71
Anastomosis or suture complication	13/3692 (0.4)	7/1995 (0.4)	1.00
Hospital length of stay (days), mean ± SD [n]	8.04 ± 6.76 [3678]	7.61 ± 5.76 [1974]	0.017
90-day rehospitalization	146/3569 (4.1)	86/1939 (4.4)	0.59
90-day death	83/3692 (2.2)	39/1995 (2)	0.53

The unadjusted means (SD) hospital length of stay (LOS) for VATS and RATS interventions were, respectively, 8.04 (6.76) and 7.61 (5.76) days with an unadjusted difference estimated at −0.43 (95% confidence interval (CI): − 0.78 to + 0.08, $p=0.016$) for RATS vs VATS (Table 3); after adjustment, it was estimated at − 0.54 (− 1.13 to + 0.05, $p=0.073$, primary analysis)

Table 3 Comparison between VATS and RATS groups of unadjusted and adjusted outcomes, overall, and in subgroups

	VATS n/N (%) or mean ± SD	RATS n/N (%) or mean ± SD	Unadjusted (RATS—VATS) difference estimate (95% CI) p	Adjusted* (RATS—VATS) difference estimate (95% CI) p
Lobectomy + Segmentectomy	$n=3692$	$n=1995$		
Hospital length of stay (days) (primary analysis)	8.04 ± 6.76	7.61 ± 5.76	−0.43 (−0.78 to −0.08) $p=0.016$	−0.54 (−1.13 to 0.05) $p=0.073$
Grade ≥ 2 complication (secondary)	952/3682 (25.9%)	503/1966 (25.6%)	−0.2% (−2.6 to 2.1%) $p=0.84$	−2.3% (−6.5 to 1.9%) $p=0.28$
Grade ≥ 3 complication (secondary)	319/3682 (8.7%)	162/1966 (8.2%)	−0.4% (−2 to 1.1%) $p=0.58$	0.5% (−2.2 to 3.2%) $p=0.72$
90-day rehospitalization (secondary)	146/3569 (4.1%)	86/1939 (4.4%)	0.4% (−0.7 to 1.5%) $p=0.51$	−1% (−2.9 to 1%) $p=0.35$
90-day death (secondary)	83/3692 (2.2%)	39/1995 (2%)	−0.3% (−1.1 to 0.5%) $p=0.47$	−0.2% (−1.5 to 1.2%) $p=0.83$
Prolonged air leak (post hoc)	482/3692 (13.1%)	218/1995 (10.9%)	−2.1% (−3.9 to −0.3%) $p=0.02$	−1.5% (−4.7 to 1.6%) $p=0.34$
Atelectasis (post hoc)	78/3692 (2.1%)	85/1995 (4.3%)	2.1% (1.2 to 3.1%) $p<0.0001$	0% (−1.6 to 1.6%) $p=0.99$
N0—> N1 or N2 upstaging (post hoc)	379/3692 (10.3%)	229/1995 (11.5%)	1.2% (−0.5 to 2.9%) $p=0.16$	−0.2% (−3.2 to 2.8%) $p=0.88$
Segmentectomy subgroup	$n=769$	$n=440$		
Hospital length of stay (days)	6.93 ± 4.97	6.42 ± 4.42	−0.51 (−1.07 to 0.06) $p=0.078$	−0.06 (−1.12 to 1.01) $p=0.91$
Grade ≥ 2 complication	171/769 (22.2%)	98/437 (22.4%)	0.2% (−4.7 to 5.1%) $p=0.93$	−2.1% (−11.8 to 7.5%) $p=0.67$
Grade ≥ 3 complication	57/769 (7.4%)	26/437 (5.9%)	−1.4% (−4.4 to 1.6%) $p=0.36$	−1% (−7 to 5%) $p=0.74$
90-day rehospitalization	32/752 (4.3%)	9/436 (2.1%)	−2.1% (−4.3 to 0%) $p=0.0522$	−5.2% (−9.6 to −0.9%) $p=0.019$
90-day death	20/769 (2.6%)	3/440 (0.7%)	−1.9% (−3.5 to −0.3%) $p=0.019$	−2.6% (−5.8 to 0.6%) $p=0.11$
Prolonged air leak	89/769 (11.6%)	34/440 (7.7%)	−3.8% (−7.4 to −0.3%) $p=0.033$	0.1% (−7 to 7.1%) $p=0.99$
Atelectasis	12/769 (1.6%)	16/440 (3.6%)	2.1% (0.3 to 3.8%) $p=0.021$	−0.1% (−3.7 to 3.5%) $p=0.97$
N0—> N1 or N2 upstaging	41/769 (5.3%)	29/440 (6.6%)	1.3% (−1.5 to 4%) $p=0.37$	2.9% (−2.6 to 8.5%) $p=0.30$
Lobectomy subgroup	$n=2923$	$n=1555$		
Hospital length of stay (days)	8.34 ± 70.13	7.95 ± 60.04	−0.39 (−0.81 to 0.03) $p=0.067$	−0.68 (−1.38 to 0.03) $p=0.0598$
Grade ≥ 2 complication	781/2913 (26.8%)	405/1529 (26.5%)	−0.3% (−3 to 2.4%) $p=0.82$	−2.1% (−6.8 to 2.7%) $p=0.39$
Grade ≥ 3 complication	262/2913 (9%)	136/1529 (8.9%)	−0.1% (−1.9 to 1.6%) $p=0.88$	1.1% (−2 to 4.2%) $p=0.50$
90-day rehospitalization	114/2817 (4%)	77/1503 (5.1%)	1.1% (−0.2 to 2.4%) $p=0.099$	0.4% (−1.9 to 2.7%) $p=0.73$
90-day death	63/2923 (2.2%)	36/1555 (2.3%)	0.2% (−0.7 to 1.1%) $p=0.73$	0.5% (−1.1 to 2.1%) $p=0.55$
Prolonged air leak	393/2923 (13.4%)	184/1555 (11.8%)	−1.6% (−3.7 to 0.4%) $p=0.13$	−1.9% (−5.6 to 1.7%) $p=0.30$
Atelectasis	66/2923 (2.3%)	69/1555 (4.4%)	2.2% (1.1 to 3.2%) $p<0.0001$	0.3% (−1.5 to 2.2%) $p=0.74$
N0—> N1 or N2 upstaging	338/2923 (11.6%)	200/1555 (12.9%)	1.3% (−0.7 to 3.3%) $p=0.20$	−0.7% (−4.2 to 2.8%) $p=0.71$

There were 319 (8.7%) postoperative complications of Clavien–Dindo grade ≥ 3 after VATS interventions and 162 (8.2%) after RATS interventions with an unadjusted difference estimated at − 0.4% (− 2.0 to 1.1%, $p=0.58$, secondary analysis) and an adjusted difference estimated at + 0.5% (− 2.2 to 3.2%, $p=0.72$). Post-operative atelectasis was found in 78 (2.1%) patients after VATS and 85 (4.3%) patients after RATS for an unadjusted difference at 2.1% (1.2 to 3.1%, $p<0.0001$) and an adjusted difference at + 0.0% (−1.6 to 1.6%, $p=0.99$, post hoc analysis). There was no significant difference on any secondary or post hoc outcome after adjustment (all $p>0.28$)

*Adjusted on age, WHO/ECOG performance status, ASA, CCI, COPD, smoking, preoperative TNM stage, FEV1, DLCO, lobectomy or segmentectomy, surgeon, and histology

Discussion

This multicenter retrospective cohort study aimed to evaluate the short-term outcomes of VATS and RATS with a focus on the influence of surgical volume and surgeon expertise. Our findings suggest that while the unadjusted mean hospital length of stay (LOS) was marginally shorter for RATS compared to VATS, the difference was not statistically significant after adjustment for confounders.

The literature is fraught with controversy. There are divergent results on LOS. Indeed, some studies report significant reductions in length of stay in favor of RATS [16, 18, 21, 22], while others find no significant differences [9, 17, 23, 24]. One reason for our findings could be related to the widespread adoption of enhanced recovery after surgery programs across French thoracic surgery centers [25–28], which have been successful in reducing the LOS for VATS patients. Additionally, the fact that VATS has been a mainstay in France for a longer time may play a role; as RATS is still relatively new to some centers, some surgeons have not passed through their learning curve, which could affect our results. However, the post hoc ecological sensitivity analysis according to surgeon experience and volume of activity showed no significant difference.

In our investigation, we observed a non-significant increase in the number of segmentectomy procedures compared to lobectomies. This shift aligns with the trend toward lung-sparing strategies for managing early stage cT1a-bN0 lung lesions [3]. Data from The National Cancer Database revealed a significant rise in the adoption of minimally invasive surgical techniques for segmentectomies, from 35.1% of cases in 2010 to 64.9% in 2017 ($p < 0.01$) [29]. This progression could be attributed to two principal factors. First, the multiplication of early lung cancer screening programs has led to the identification of more early stage lesions, which are often suitable candidates for these lung-sparing surgeries. Second, advancements in robotic surgery, which offer enhanced dexterity, precision, and visual clarity, have facilitated the performance of more complex surgical procedures. Zhou et al. have reported a substantial rise in the execution of complex segmentectomies using RATS compared to VATS (45% vs. 15%; $p < 0.001$) [30].

Our study has revealed a gap in the utilization of robotic surgery across surgical practices. Specifically, our data indicate that while nearly half of the surgeons in the study (47.7%) perform RATS in less than 10% of their cases, a smaller subset (18.2%) employs it in more than 90% of their operations. This disparity is indicative of barriers to accessing the robotic platform. The significant financial investment required for acquiring and maintaining this equipment is a primary challenge for the institution. Additionally, unlike VATS, the robotic platform is shared between several disciplines. Gondé et al. suggest that the investment in robotic surgery can be economically viable in expert centers, with the cost difference between robotic and traditional video-assisted surgeries being under €2,000 [12].

One of the key strengths of this study lies in the comprehensive quality audit, an aspect rarely seen in other non-randomized studies. The inclusion of a quality audit minimizes potential biases due to missing or incomplete data, providing a more reliable comparison of outcomes between VATS and RATS.

Our study has several limitations. First, this is a retrospective study that introduces potential biases associated with data collection, details of segmentectomies performed were not available. Despite efforts to ensure data completeness through targeted training and on-site data management, the variability in data quality across centers may have influenced our findings. Furthermore, the analysis might not fully account for the rapid evolution of surgical techniques and equipment. The learning curve associated with RATS, which varies significantly among surgeons, also complicates the evaluation of this approach's effectiveness and efficiency compared to VATS.

The French experience in the management of lung cancer is in line with the global trend toward more widespread use of segmentectomy. The gradual adoption of the robotic platform to perform segmentectomies marks a crucial evolution in the surgical landscape. However, uneven access to robotic technology and its availability in different centers introduces a degree of variability that could influence the generalizability of our results. More uniform adoption of robotic surgery should pave the way for more consistent results.

Conclusion

In conclusion, RATS showed a trend toward shorter hospital stays, but this was not statistically significant after adjustment. There were no significant differences in complication rates, 90-day rehospitalization, or mortality between RATS and VATS. We observed a trend toward increased use of segmentectomy, and robotic surgery appears to be the tool of choice for performing this procedure due to its increased dexterity and precision.

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Authors contribution All authors contributed to the study conception, design and data collection. Material preparation and analysis were performed by BB, HM, AG, FM and JMB. The first draft of the manuscript was written by BB, HM, AG, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest Jean-Marc Baste reported consulting for Intuitive Surgical Inc (Sunnyvale, California) outside the submitted work. All other authors have no relevant conflict of interest to declare.

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