Pulmonary Open, Robotic, and Thoracoscopic Lobectomy study: Outcomes and risk factors of conversion during minimally invasive lobectomy

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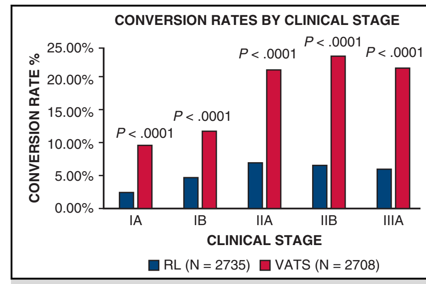
ABSTRACT

Objective: Conversion to thoracotomy continues to be a concern during minimally invasive lobectomy. The aim of this propensity-matched cohort study is to analyze the outcomes and risk factors of intraoperative conversion during video-assisted thoracoscopic surgery (VATS) and robotic lobectomy (RL).

Methods: Data from consecutive lobectomy cases performed for clinical stage IA to IIIA lung cancer was retrospectively collected from the Pulmonary Open, Robotic, and Thoracoscopic Lobectomy study consortium of 21 institutions from 2011 to 2019. The propensity-score method of inverse-probability of treatment weighting was used to balance the baseline characteristics across surgical approaches. Univariate logistic regression models were applied to test risk factors for conversion. Multivariable logistic regression analysis was conducted using a stepwise model selection method.

Results: Seven thousand two hundred sixteen patients undergoing lobectomy were identified: RL (n = 2968), VATS (n = 2831), and open lobectomy (n = 1417). RL had lower conversion rate compared with VATS (3.6% vs 12.9%; $P < .0001$). In the multivariable regression model, tumor size and neoadjuvant therapy were the most significant risk factors for conversion, followed by prior cardiac surgery, congestive heart failure, chronic obstructive pulmonary disease, VATS approach, male gender, body mass index, and forced expiratory volume in 1 minute. Conversions for anatomical reasons were more common in VATS than RL (66.6% vs 45.6%; $P = .0002$); however, conversions for vascular reasons were more common in RL than VATS (24.8% vs 14%; $P = .01$). The rate of emergency conversions was comparable between RL and VATS (0.5% vs 0.7%; $P = .25$) with no intraoperative mortalities.

Conclusions: Converted minimally invasive lobectomies were not associated with worse perioperative mortality compared with open lobectomy. Compared with VATS lobectomy, RL is associated with a lower probability of conversion in this propensity-score matched cohort study. (J Thorac Cardiovasc Surg 2023;166:251-62)



VATS has a higher risk of conversion than RL with a more significant difference in advanced disease.

CENTRAL MESSAGE

VATS approach has a higher risk for conversion than RL, with no difference in emergency conversions. Converted cases have worse outcomes than completed MIL and OL cases, with similar mortality.

PERSPECTIVE

In a matched-cohort study of OL, VATS, and RL for lung cancer, RL procedures had fewer conversions than VATS, and conversion rates increased as disease stage progressed in VATS but not RL. Converted cases had worse outcomes than nonconverted and OL cases, without a significant difference in mortality. VATS procedures were converted more for anatomy reasons and less frequently for vascular injury.

See Commentary on page 263.

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Abbreviations and Acronyms

IPTW	= inverse probability of treatment weighting
LOS	= length of stay
MIL	= minimally invasive lobectomy
OL	= open lobectomy
PORTaL	= Pulmonary Open, Robotic, and Thoracoscopic Lobectomy
RL	= robotic lobectomy
VALT	= vascular, anatomy, lymph node, and technical reasons for conversion
VATS	= video-assisted thoracoscopic surgery

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Lung resection with anatomic lobectomy is the standard of care for non–small cell lung cancer, and minimally invasive approaches have shown decreased perioperative complications and shorter length of stay (LOS) compared with open thoracotomy.[1,2] Adoption of minimally invasive surgery continues to increase in the United States, with more than 77% of lobectomies being performed using a minimally invasive lobectomy (MIL) approach with either video-assisted thoracoscopic surgery lobectomy (VATS) or robotic lobectomy (RL).[3] Among the barriers for wider adoption of MIL is the concern for intraoperative complications and conversion to thoracotomy. Conversion has been associated with higher incidence of postoperative complications, mortality, LOS, and cost compared with cases completed without thoracotomy.[4,5] As surgeons continue to adopt MIL and overcome the learning curve, patient selection often includes cases with advanced disease and challenging anatomy, which can be associated with higher conversion rates.[6]

Several studies have identified factors associated with conversion to thoracotomy in VATS, including calcified lymph nodes, increased body surface area, tumor invasion, and previous neoadjuvant therapy.[7-11] With a significant increase in the adoption of MIL, understanding the outcomes and risks of conversion with each approach is important, although there are limited reports regarding conversion in RL. A recent study analyzing results from the General Thoracic Surgery Database showed that conversion from MIL (VATS and RL) to open thoracotomy was associated with a higher mortality and postoperative complications compared with nonconverted cases.[12] In addition, there were fewer conversions in the RL group than VATS (6.3% vs 11%), but more emergency conversions and intraoperative transfusions in the RL group.[12]

In our pervious Pulmonary Open, Robotic, and Thoracoscopic Lobectomy (PORTaL) study comparing outcomes of open lobectomy (OL), VATS, and RL, there was a higher overall conversion rate to open surgery in VATS compared with RL (11.9% vs 6%).[13] However, neoadjuvant therapy patients were excluded and the reasons for conversions and outcome differences were not described. Understanding the factors increasing the risk for conversion and the expected outcomes thereafter is valuable information for surgeons embarking on these procedures. Furthermore, there are concerns of increased risk of patient harm and adverse outcomes during emergency conversion for bleeding during RL, given that the surgeon is not at the bedside and vascular control is potentially more difficult.

In this study, we sought to investigate the risk factors and outcomes related to conversion of MIL using the PORTaL multi-institution dataset. The series included cases with advanced disease and neoadjuvant therapy to have a representative sample of patients that any surgeon would encounter in practice. We hypothesized that advanced disease and neoadjuvant therapy would be significant predictors for conversion, in both VATS and RL, that MIL converted cases would have worse perioperative outcomes than MIL completed cases, and that MIL converted cases would have worse perioperative outcomes and increased mortality compared with planned OL cases.

METHODS

Data Sources

Retrospective data were collected from 21 centers in the United States (Table E1) with specific expertise in RL, VATS, and/or OL. Three surgeons with significant experience in RL (M.S.K.), VATS (M.G.H.), and OL (E.V.) were designated as co-chairs to conduct this study.

Data from all consecutive lobectomies for clinical stage IA through IIIA lung cancer from January 2013 to 30-days before institutional review board approval at each center were included. Data collection was performed in reverse chronological order in accordance with the institutional review board guidelines. A study-specific informed consent waiver for retrospective data collection was obtained from each institution's institutional review board. Information from all patients was maintained confidential and managed according to the requirements of the Health Insurance Portability and Accountability Act of 1996. Data collection closed for all centers on June 21, 2019.

Emergency cases, indications other than lung cancer, bilobectomies, and sleeve lobectomies were excluded from analysis. Data were collected on demographic characteristics; clinical and pathologic staging; induction therapy; operative details, including conversions; and perioperative complications. Data on perioperative mortality and complications were collected from the in-hospital stay as well as the final follow-up within 90 days. Operative time was inclusive of docking time for RL cases and accounted for added time in cases with major concomitant procedures such as mediastinoscopy, diagnostic wedge resection, and chest wall resection.

Statistical Analysis

Data analysis was performed on an intent-to-treat basis. Consequently, conversions were analyzed under the initial operative approach, regardless of the reason for conversion. However, conversions from RL to VATS were excluded from the outcome analysis because it would favor RL conversion, which still avoided an open thoracotomy.

Conversions were categorized by each institution as elective due to failure to progress, safety concerns or as emergency due to life-threatening hemorrhage or complication. All major complications and operative reports of conversions were independently reviewed by the site's principal investigator to ensure data integrity with assigned definitions of emergency or elective at each reporting institution.

All available operative reports were reviewed again by the study authors (blinded to surgeon and institution) to identify the reasons for conversion, and then classified using the modified vascular, anatomy, lymph nodes, and technical (VALT) assessment described previously.[14] The nature of conversion was further reclassified based on the urgency of conversion as: elective conversion, which was proactive due to failure to progress; elective conversion after a controlled event and no hemodynamic instability; and emergency conversion after vascular injury with difficult control resulting in hemodynamic compromise.

Three separate analyses were performed: predictors of conversion were analyzed using a multivariable generalized estimating equation logistic regression model using a stepwise selection procedure with potential covariates and accounting for the clustering of patients within investigational site; conversions were compared between the VATS and RL along with the different reasons for conversion; the influence of conversions on the clinical outcomes were evaluated by comparing them with the OL cohort and to MIL completed cohort. For each analysis, baseline characteristics were balanced across groups using the inverse probability of treatment weighting (IPTW) adjustment method. The method was implemented for each comparison by fitting a logistic regression model with group as the dependent variable and the following independent variables, selected based on their lack of balance across the groups, and/or their potential influence on outcomes: age, gender, race, body mass index, smoking status, Zubrod score, American Society of Anesthesiologists grade, forced expiratory volume in 1 minute, coronary artery disease, congestive heart failure, cerebrovascular accident, chronic obstructive pulmonary disease, clinical TNM stage, and prior chemo/radiation. A standardized difference of the means graph is included in Figure E1.

For each of the 2 comparisons, stabilized IPTW values were generated by dividing the predicted probability from the regression model by the proportion of patients in the group among all patients in the respective analysis. Baseline characteristics were compared across groups using $\chi 2$ or Fisher exact test for categorical variables, t test, or Wilcoxon rank sum test for continuous or ordered variables. Categorical variables were compared using a weighted χ^2 and continuous and ordered variables were compared using a weighted t test, with the stabilized IPTW values serving as the weights. All tests were 2-sided. Statistical analyses were performed with SAS 9.4.

RESULTS

The PORTaL study analyzed a total of 7216 lobectomy cases. Of these, the approach was VATS in 2831, RL in 2968, and OL in 1417. There were 491 (8.5%) cases in which a conversion occurred. A total of 366 converted from VATS to OL. Of the 125 RL cases that were converted, 106 were converted from RL to OL and 19 from RL to VATS (Figure 1). We excluded the RL to VATS conversions to ensure a more comparable group in IPTW-adjusted analysis. The rate of induction therapy was similar in both minimally invasive lobectomy cohorts (chemotherapy: 2.7% RL vs 2.7% VATS [$P < .9542$]; chemotherapy/radiation: 1.7% RL vs 2.0% VATS [$P < .40$]; radiation only: 1.6% RL vs 1.3% VATS [$P < .2709$]).

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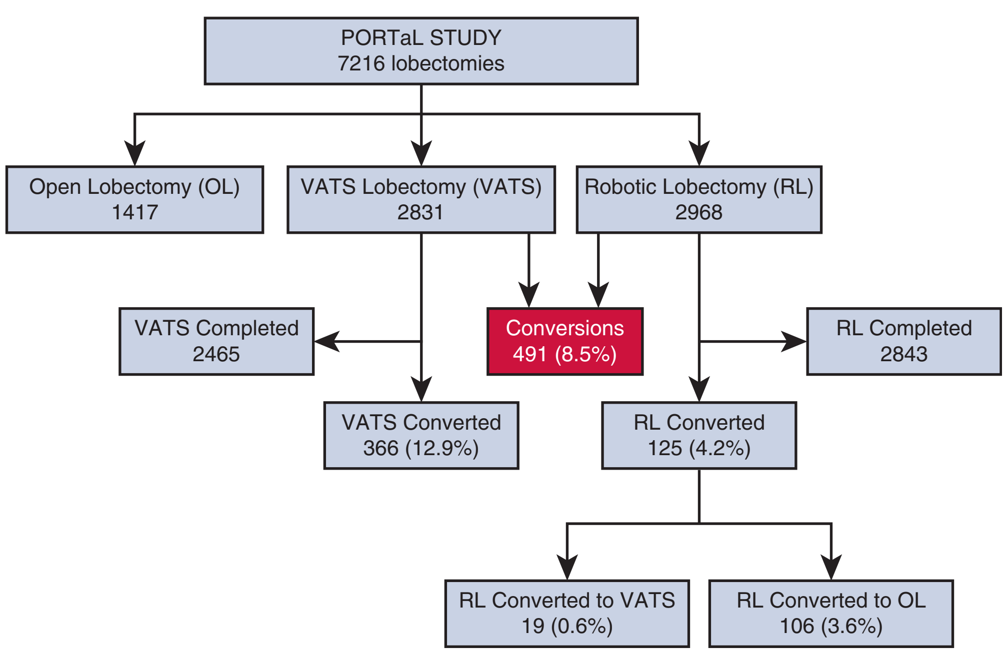

FIGURE 1. Flow chart of study population. *PORTaL*, Pulmonary Open, Robotic, and Thoracoscopic Lobectomy study; *VATS*, video-assisted thoracoscopic surgery.

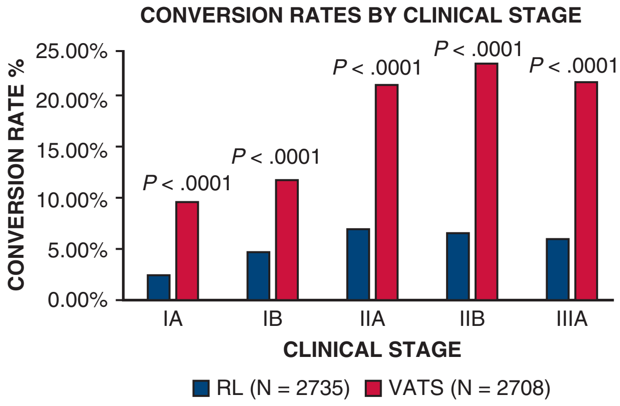

FIGURE 2. Conversion rate by clinical stage group disease stage for robotic lobectomy (*RL*) and video-assisted thoracoscopic surgery (*VATS*). Conversion rates by disease clinical stage group for RL and VATS after inverse-probability of treatment weighting adjustment.

Comparison after IPTW adjustment between RL (n = 2735) versus VATS (n = 2708) showed significant differences in conversion rates between the 2 cohorts (3.6% for RL vs 12.9% for VATS [$P < .0001$]). However, there was no difference in the rate of emergency conversions between the 2 approaches with 0.5% for RL and 0.9% for VATS ($P < .08$). The rate of conversion was higher in VATS for every clinical stage, and the rate of conversion increased more with advancing stage for VATS compared with RL (Figure 2). There was also a statistically significant decrease in the conversion rates over time for RL but not for VATS approach ($P < .0001$) (Figure 3).

Predictors of Intraoperative Conversions

Multivariable logistic generalized estimating equation regression analysis was also used to identify baseline predictors of conversion (Figure 4). The 2 most important predictors of conversion were tumor size (odds ratio [OR], 1.21 for each millimeter increase in size; 95% CI, 1.12-1.31; $P < .0001$) and induction or prior (chemotherapy/radiation) treatment (OR, 2.64; 95% CI, 2.14-3.26; $P < .0001$). The VATS surgical approach was associated with a 2.7-fold increase in probability of conversion (OR, 2.72; 95% CI, 1.35-5.46; $P < .0050$). Of the converted patients with prior therapy, 108 patients had chemotherapy and radiation, 157 patients had chemotherapy only, and 84 had radiation only.

Comparison of VATS Converted Cases Versus RL Converted Cases

Of the 491 conversions, 106 cases were converted from RL to OL and 366 converted from VATS to OL. The patients were well balanced on baseline characteristics, and after IPTW adjustment, there were 2 pairs (99 RL and 350 VATS) (Table 1).

There were no statistically significant differences in outcomes in RL and VATS conversions, including postoperative complications, LOS, blood transfusions, or mortality. However, there were fewer cases with prolonged LOS (>7 days) in the RL group (23.1% RL vs 33.3% VATS; $P < .0461$) and shorter chest tube duration (Table 2). The most common lobe in converted cases was the right upper lobe (34.2% RL and 33.5% VATS) followed by the left upper lobe (23.5% RL and 28.1% VATS) (overall $P < .0509$).

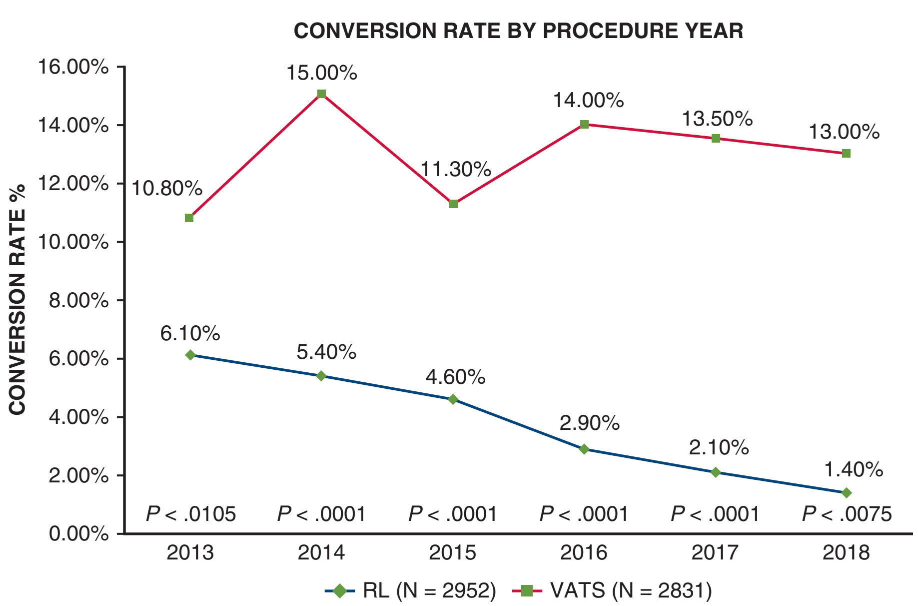

FIGURE 3. Conversion rates by procedure year for robotic lobectomy (*RL*) and video-assisted thoracoscopic surgery (*VATS*) approaches. Conversion rates by approach according to procedure year performed (unadjusted total cohort of cases submitted).

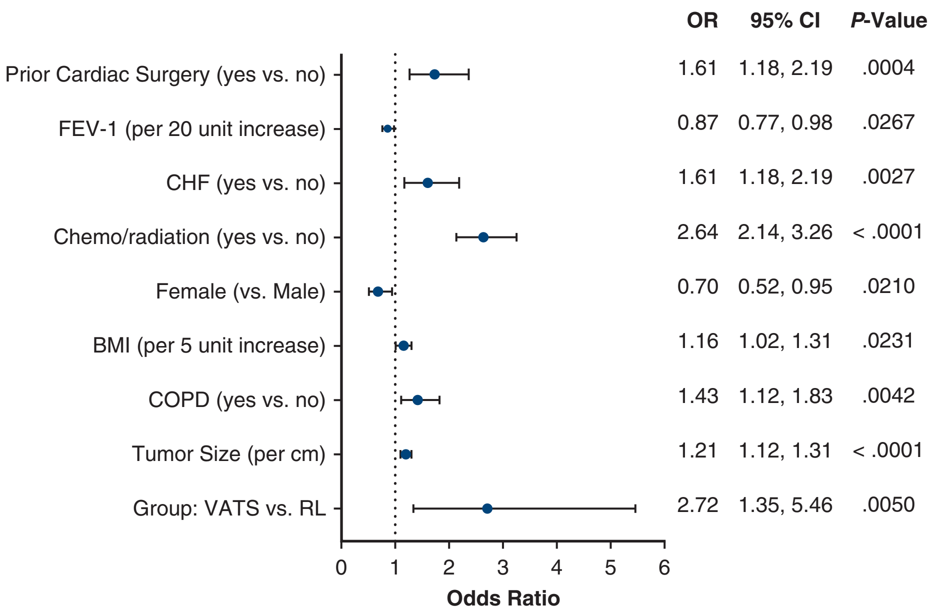

FIGURE 4. Forest plot of adjusted odds ratios (with 95% CI from multivariable Generalized Estimating Equation (GEE)) logistic regression analysis, predictors of conversion were analyzed using a multivariable GEE logistic regression model using a stepwise selection procedure with potential covariates and accounting for the clustering of patients within investigational site. *OR*, Odds ratios; *CI*, confidence interval; *FEV-1*, forced expiratory volume in 1 minute; *CHF*, congestive heart failure; *BMI*, body mass index; *COPD*, chronic obstructive pulmonary disease; *VATS*, video-assisted thoracoscopic surgery.

Reasons for Conversions in MIL

The VALT classification[14] was used to describe the nature and reasons for conversion comparing RL and VATS (Figure 5). Amongst all the conversions, anatomical factors were the primary reason for conversion. That was mainly driven by tumor size or location, adhesions, and fissure problems. A higher percentage of conversions due to vascular reasons stemming from pulmonary artery injury was observed in RL compared with VATS cases (25% RL and 14% VATS; $P < .01$). However, most of the conversions after vascular injuries were performed after adequate control of bleeding and without hemodynamic compromise. There was also no difference in estimated blood loss, or in the rate of intraoperative blood transfusions. More importantly, there were no intraoperative mortalities in either group. Technical reasons for conversion resulting from equipment failure or stapler misfire was a contributor for 1% of cases in both VATS and RL. In both groups, conversion driven by lymph nodes factors was similar, mainly contributed by malignant lymphadenopathy (10.3% in RL vs 9.9% VATS; $P =$ not significant) and less by calcified lymph nodes (1.5% RL vs 0.7% VATS; $P =$ not significant). Subclassification of the reasons for conversion within the VALT categories are described in Figure E2. Within the anatomical reasons for conversion, tumor size was the main reason (23% RL vs 28% VATS), followed by adhesions (13% RL vs 19% VATS). Fissure difficulties were significantly higher in the VATS (4% RL vs 19% VATS) presumably leading to higher percentage of proactive conversions observed in VATS cases. There were similar difficulties with lung isolation in both groups despite carbon dioxide insufflation in RL, and more conversion in RL due to difficult tumor location (Figure E2).

Among the converted cases, RL had lower percentage of proactive conversions before an event (72% RL vs 85% VATS) and higher percentage for both controlled conversions after an event (RL 19% vs 9.6% VATS) and emergency conversions in the converted population of 449 cases (9% RL vs 5% VATS) and these differences were significant (overall $P < .012$). However, the rate of emergency conversions in the overall IPTW-adjusted population ($n = 2735$ RL vs $n = 2708$ VATS) was similar in both groups (0.5% for RL and 0.9% for VATS; $P < .08$).

Influence of Conversions on the Clinical Outcomes

We hypothesized that converted MIL (VATS and RL) would have a worse outcome compared with both the OL cohort and the MIL completed cohort. After IPTW adjustment, we had 2 sets of well-paired groups with 449 MIL cases, 1313 adjusted OL cases, 449 MIL converted cases, and 4981 MIL completed cases. The MIL converted cases had worse outcomes compared with OL cases, including increased procedure duration, estimated blood loss, and higher postoperative complications (45.2% vs 38.9%; $P < .189$). However, both groups had comparable cardiopulmonary complications and mortality (Table 3).

We next compared IPTW-adjusted 449 MIL converted cases to 4981 MIL completed cases. The converted cohort

TABLE 1. Patient characteristics before and after inverse-probability of treatment weighting (IPTW) adjustment in robotic lobectomy (RL) and video-assisted thoracoscopic surgery (VATS)

	Unweighted			IPTW		
Characteristic	RL converted (n = 106)	VATS converted (n = 366)	*P* value	RL converted (n = 99)	VATS converted (n = 350)	*P* value
Age	67.7 ± 8.5	67.5 ± 9.4	.8802	67.7 ± 8.3	67.6 ± 9.4	.9309
Female sex	40.6 (43)	45.6 (167)	.3557	40.0	44.0	.4754
BMI	28.2 ± 6.4	28.6 ± 6.6	.5368	28.6 ± 6.6	28.5 ± 6.5	.9349
Smoking status			.1349			.8025
Current smoker	13.5 (14)	21.9 (80)		18.0	20.5	
Never smoked	13.5 (14)	14.5 (53)		12.4	13.6	
Past smoker	73.1 (76)	63.7 (233)		69.4	65.9	
Zubrod score			.2996			.9409
0	42.5 (45)	36.1 (132)		39.5	37.2	
1	50.0 (53)	56.6 (207)		51.7	55.9	
2	7.6 (8)	6.8 (25)		8.8	6.6	
3	0	0.6 (2)		0	0.3	
4	0	0		0	0	
ASA grade			.3694			.8932
I	1.9 (2)	0.6 (2)		0.4	0.8	
II	12.3 (13)	9.8 (36)		12.0	10.0	
III	80.2 (85)	83.9 (307)		80.9	84.1	
IV	5.7 (6)	5.7 (21)		6.5	5.1	
FEV-1	82.1 ± 17.9	81.1 ± 19.4	.6334	81.8 ± 18.3	81.3 ± 19.2	.8368
CAD	23.6 (25)	24.6 (90)	.8319	24.3%	24.9%	.9029
CHF	3.8 (4)	6.6 (24)	.2853	4.6	6.5	.4887
CVA	5.7 (6)	4.1 (15)	.4922	4.4	4.3	.9618
COPD	38.7 (41)	44.8 (164)	.2622	42.3	44.4	.7177
Clinical TNM stage			.7229			.4714
IA	39.6 (42)	43.4 (159)		46.6	43.2	
IB	18.9 (20)	17.5 (64)		17.2	17.9	
IIA	18.9 (20)	13.9 (51)		15.0	15.0	
IIB	9.4 (10)	10.7 (39)		10.9	10.4	
IIIA	13.2 (14)	14.5 (53)		10.3	13.4	

Values are presented as mean ± SD, % (n), or %. *IPTW*, Inverse-probability of treatment weighting; *RL*, robotic lobectomy; *VATS*, video-assisted thoracoscopic surgery; *BMI*, body mass index; *ASA*, American Society of Anesthesiologists; *FEV-1*, forced expiratory volume in 1 minute; *CAD*, coronary artery disease; *CHF*, congestive heart failure; *CVA*, cerebrovascular accident; *COPD*, chronic obstructive pulmonary disease; *TNM*, tumor, node, metastasis.

had longer operative times, higher estimated blood loss and blood transfusion, higher mean and prolonged LOS, more frequent return to an operating room, and more perioperative complications (44.4% MIL converted vs 28.3% MIL completed; $P < .0001$) (Table 3).

DISCUSSION

Among the barriers for the adoption of MIL is the concern of inferior outcomes related to conversions or intraoperative complications, particularly vascular injuries during the learning curve.[15] In this PORTaL study analysis, we sought to investigate the factors associated with conversion of MIL comparing VATS and RL approaches and explored the influence of conversions on perioperative outcomes. A summary of our findings can be found in Figure 6. We found a higher rate of conversions in VATS compared with RL using propensity-score matched groups. VATS also had an increasing rate of conversion as the disease stage progressed, and this effect was less pronounced in the RL approach. This is consistent with prior studies showing a lower conversion rate for robotic cases, particularly in advanced disease.[7,12,16-18] In our study, the most important predictors were tumor size and neoadjuvant/prior therapy. After accounting for patient and tumor factors, the surgical approach was also significant, with VATS having a 2.7-fold higher likelihood of conversion compared with RL. Although there are no clear reasons for this difference, the increased level of dexterity and visualization using the robotic platform may provide an advantage in more complex anatomy or advanced disease. In a National Cancer Database

TABLE 2. Perioperative outcomes of patients undergoing minimally invasive lobectomy (MIL) that was converted to open lobectomy based on surgical approach (robotic lobectomy [RL] vs video-assisted thoracoscopic surgery [VATS]) after inverse-probability of treatment weighting adjustment

Variable	RL converted (n = 99)	VATS converted (n = 350)	*P* value
Procedure duration, skin-to-skin (min)			
Mean ± SD	333.7 ± 97.5	322.6 ± 149.3	.3928
Median	335	316	
Procedure duration, major concomitant procedure (min)			
Mean ± SD	239.2 ± 99.8	300 ± 131.9	**.0013**
Median	222	289	
Estimated blood loss (mL)			
Mean ± SD	427.4 ± 484.4	424.2 ± 617.5	.9684
Median	275	250	
Chest tube duration (d)			
Mean ± SD	5.3 ± 4.5	6.8 ± 7.1	**.0484**
Median	4	4	
Min, max	1, 22	1, 50	
Length of stay (d)			
Mean ± SD	6.5 ± 5.2	8.4 ± 10.2	.0761
Median	5	6	
Prolonged length of stay, >7 d (%)	23.1	33.3	.0516
Intraoperative blood transfusion (%)	10.5	9.8	.8262
Unexpected return to operating room before discharge (%)	4.8	6.9	.4322
Postoperative complications (%)	49.0	50.5	.7949
Mortality (%)	0.0	2.4	N/A*

Bold indicates statistical significance. *RL*, Robotic lobectomy; *VATS*, video-assisted thoracoscopic surgery; *SD*, standard deviation; *N/A*, not available. *Data are too sparse to allow calculating the *P* value on the weighted dataset.

propensity-score matched study by Hendriksen and colleagues,[19] VATS had a nearly 2-fold higher conversion rate than RL. Advanced tumor stage and nodal stage were conversion risk factors for VATS but not for RL.[19]

In our study, the differences in the rate of conversions between VATS and RL also appear to result from a reduction in the frequency of conversions due to failure to progress related to difficult anatomy and tumor factors. However, conversion for vascular reasons was higher in the RL group (25% RL vs 14% VATS). RL cases seemed to progress further despite anatomical difficulties; however, the likelihood of vascular injury became higher by persisting without conversion. Knowing that vascular reasons for conversions are more important and relevant in RL, increased surgeon awareness of the possibility of vascular injury and adequate preparation in the operating room is important in cases of difficult anatomy and challenging vascular dissection. Despite this difference, the overall incidence of vascular injuries in the entire IPTW-adjusted cohort was low in both in RL (0.9%) and VATS (1.8%), with no intraoperative mortalities in either approach. With increased experience and preparation with the operating room team, most intraoperative events and vascular injuries can be handled in a controlled manner and conversions performed with less impact on perioperative outcomes.[15,20] As an example, we have included a video of an emergency conversion with significant bleeding during an RL procedure (Video 1).

In a large Society of Thoracic Surgeons database study, Servais and colleagues[12] also found that RL had a higher proportion of conversion for vascular issues (26.8% RL vs 14.3% VATS) and like our study, found higher percentage conversion for of emergency reasons in RL (17.9% RL vs 9.6% VATS) although the overall rate of emergency conversions was also low (1% for both RL and VATS).[12] Puri and colleagues[21] also used the VALT classification in a large group of VATS lobectomies and found that anatomy also was the main reason for conversion in 64% of cases, with vascular causes accounting for 25% of cases converted. In that study, 23% of the cases were converted as an emergency, mostly for vascular injuries.[21]

Understanding the influence of conversion on perioperative outcomes is important as surgeons adopt MIL for more complex cases with higher probability of conversion. In our study, we found that converted cases had worse

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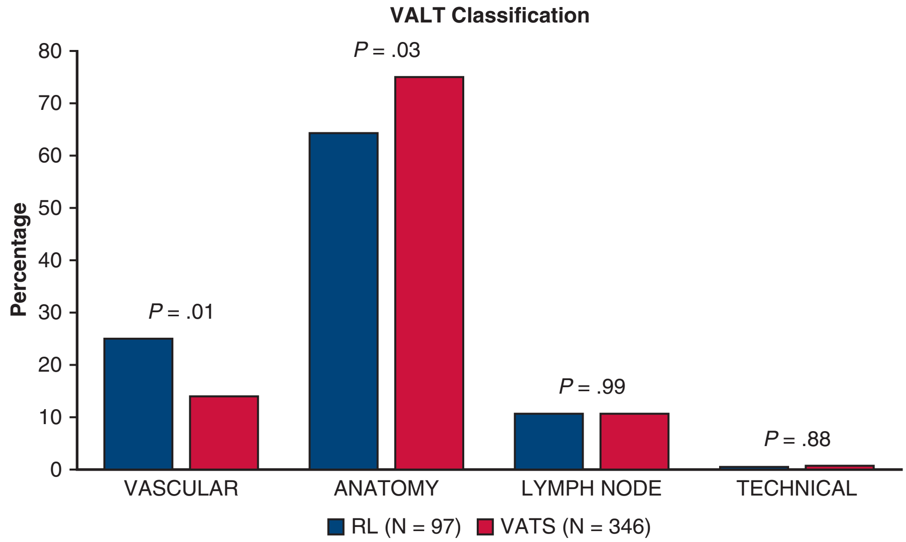


FIGURE 5. Reasons for conversions of robotic lobectomy (*RL*) and video-assisted thoracoscopic surgery lobectomy (*VATS*) using the Vascular, Anatomy, Lymph node and Technical reasons for conversion (*VALT*) classification.[12] Inverse-probability of treatment weighting (IPTW)-adjusted data are shown as percentage of total conversions per approach. RL n = 97 and VATS n = 346. The sample size is lower than the total IPTW-adjusted cohort due to unavailable operative reports (3 in RL and 4 in VATS).

perioperative outcomes than completed MIL cases but with no difference in mortality. This is consistent with other reports in the literature that emphasize the need for proper case selection to decrease the risk for conversion.[7,18] In the Society of Thoracic Surgeons database study, emergency conversions occurred more frequently in RL versus VATS and emergency conversion was associated with an increase in hospital mortality compared with elective conversions (5.5% vs 1.9%; $P < .0010$).[12] In our study, we did not find an increase in mortality in converted cases, which could be due to proper patient selection and judgment regarding timing of conversion in experienced centers. In addition, the number of overall mortalities in this study was too small to potentially detect a significant difference. This suggests

TABLE 3. Influence of conversions on the clinical outcomes: Inverse probability of treatment weighting-adjusted comparison of minimally invasive lobectomy (MIL) converted versus open lobectomy (OL) and MIL converted versus MIL completed

Variable	MIL converted (n = 449)	OL (n = 1313)	*P* value	MIL converted (n = 449)	MIL completed (n = 4981)	*P* value
Procedure duration, no concomitant procedure* (min)						
Mean ± SD	254 ± 119	165 ± 58	**<.0001**	248 ± 125	172 ± 70	**<.0001**
Median	256	155		240	160	
Estimated blood loss (mL)						
Mean ± SD	415 ± 550	238 ± 286	**<.0001**	405 ± 583	105 ± 130	**<.0001**
Median	250	150		200	50	
Length of stay (d)						
Mean ± SD	7.1 ± 8	6.6 ± 6.6	.1	7.1 ± 7.7	4.5 ± 4.9	**<.0001**
Median	5	5		5	3	
Prolonged length of stay, >7 d (%)	25.0	21.7	.1554	26.5	12.0	**<.0001**
Intraoperative blood transfusion (%)	8.8	4.2	**.0002**	9.0	0.6	**<.0001**
Unexpected return to operating room before discharge (%)	6.5	4.0	**.0363**	5.0	3.1	**.0318**
Postoperative complications (%)	45.2	38.9	**.0189**	44.4	28.3	**<.0001**
Mortality (%)	1.2	0.9	N/A†	1.4	0.3	N/A†

Bold indicates statistical significance. *MIL*, Minimally invasive lobectomy; *OL*, open lobectomy; *SD*, standard deviation; *N/A*, not available. *Skin-to-skin. †Data are too sparse to allow calculating the *P* value on the weighted dataset.

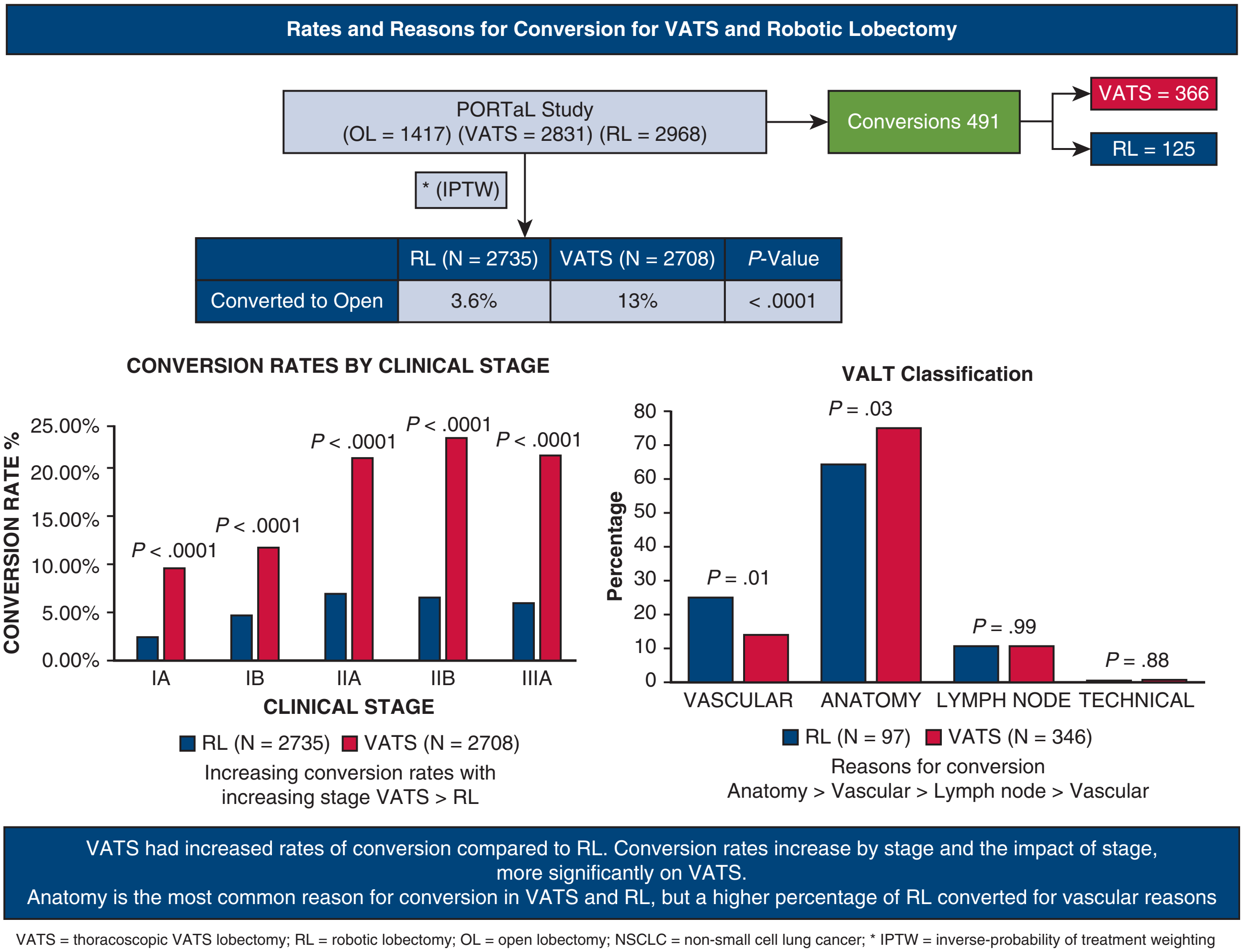
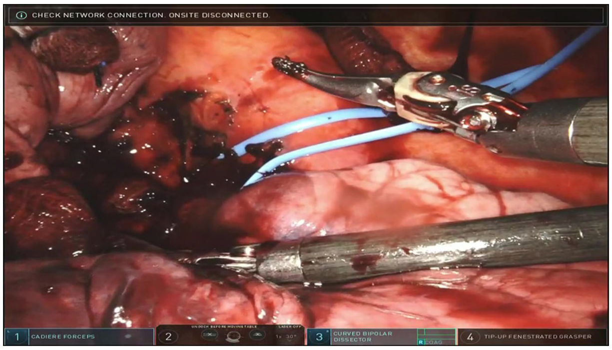


FIGURE 6. Rates of conversions and reasons for conversion for video-assisted thoracoscopic surgery lobectomy (*VATS*) and robotic lobectomy (*RL*). This is an analysis of the Pulmonary Open, Robotic and Thoracoscopic Lobectomy (*PORTaL*) multi-institution retrospective registry of lobectomies from 2013 to 2019 focused on conversions in minimally invasive lobectomy. The study was propensity matched using an inverse-probability of treatment weighting (*IPTW*) method. VATS had a higher rate of conversion than RL and this difference in conversion rate was more pronounced as disease stage increased. The main reason for conversion was anatomy, followed by vascular injury. *OL*, Open lobectomy; *VALT*, Vascular, Anatomy, Lymph node and Technical reasons for conversion.

that timely conversion when facing difficulties and failing to progress can still achieve acceptable results.

The main strengths of this multi-institution study are the large number of consecutive lobectomy cases represented in each approach, a contemporary cohort of cases, including more recent years, as well as the IPTW-adjusted analysis between the minimally invasive modalities. Furthermore, because this is not based on a national database, the analysis included more granular data and detailed operative report information to help clarify the details of the conversions. Nevertheless, there are important limitations in this study. Although we performed a propensity-score matched analysis, there are selection biases inherent in patient and surgical approach selection that may not have been captured in a retrospective study. We addressed center level variability by accounting for the clustering of patients within an investigational site in the logistic regression analysis. The study's authors personally reviewed the available operative reports to classify the reasons for conversion and obtained as much detail as possible, but with the limitations of a retrospective study there can be difficulties understanding some conversion events. A prospective study with a focus in conversions would be ideal to provide further clarity regarding these events and increase our understanding of surgical approach differences. Other factors such as perioperative pain management in anticipation of conversion, and methods of patient rescue after conversion could be better elucidated prospectively.

Other limitations of this multicenter retrospective study should also be acknowledged. Despite selecting institutions with high volume and proficiency in the technique chosen, there are inherent differences in individual surgeon



VIDEO 1. Narrated surgical video of a robotic left lower lobectomy. The mass was large and involved the anterior basilar segment artery and as well as the lingular pulmonary artery branch with malignant N1 lymph nodes. A small tunnel was created to complete the anterior fissure but bleeding from the anterior basilar segment pulmonary artery. Control of bleeding with direct pressure from one of the robotic arms allows removal of the rest of the instruments. This provides adequate exposure for open conversion in a more controlled fashion for repair. Video available at: https://www.jtcvs.org/article/S0022-5223(22)01236-3/fulltext.

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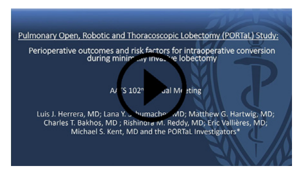
experience, personal performance, and threshold for conversion that may introduce elements of learning curve or proficiency into the study. We found a decreasing rate of conversion over time in RL, but not for VATS. This could be due to differences in learning curve and proficiency at the surgeon level or different level of participation of trainees in the procedures that could not be accounted for in RL or VATS. Also, because robotic surgery resources are limited in some institutions compared with VATS and RL is a newer approach, a bias toward more favorable patient selection in RL to avoid conversion is also possible. We could not completely adjust for these potential factors, even when adjusting for center clustering effect, unless a randomized clinical trial was performed. The sponsorship of this study by industry and the potential for reporting bias should be discussed. We acknowledge that the concern for potential bias can never be completely mitigated; however, measures were undertaken to reduce such bias and maintain data integrity. We should emphasize that collection of data was independently undertaken by investigators at each institution, who were responsible for data accuracy and submission without industry involvement. Furthermore, to minimize bias and industry influence, statistical analysis was performed by an independent biostatistician.

CONCLUSIONS

In this large, multi-institution study of experienced centers, conversion rates during MIL were more common in cases with VATS approach versus RL (Video Abstract). This difference in conversions rates was more pronounced as disease stage increased, particularly in VATS cases. The outcomes of converted MIL cases were worse than completed MIL cases and had more complications than planned OL cases. In this study, the rate of emergent conversion for life-threatening bleeding is low in both RL and VATS cases, with no intraoperative mortalities in either approach. However, RL cases converted more commonly for bleeding and less for anatomical challenges than VATS. The most important predictors of conversion were tumor size, prior or induction treatment, and the surgical approach.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/1598.



Conflict of Interest Statement

Dr Herrera is a consultant and proctor for Intuitive Surgical. Dr Schumacher is a proctor for Intuitive Surgical. Dr Hartwig is involved with research for Transmedics, the Cystic Fibrosis Foundation, and Biomed Innovations (BMI); research and consulting for Paragonix; consulting for CSL Behring; and as a proctor for Intuitive Surgical. Dr Reddy is a consultant for Intuitive Surgical and Auris Health and on the Advisory Board for Genentech, Medtronic, and Atricure. Dr Kent is a speaker for Intuitive Surgical. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: robotic lobectomy, VATS lobectomy, conversion, lung cancer, outcomes, PORTaL study

Discussion

Presenter: Dr Luis J. Herrera

Dr Harmik J. Soukiasian *(Los Angeles, Calif)*. I'd like to thank the American Association for Thoracic Surgery and the Program Committee for inviting me to discuss this manuscript and Dr Herrera and authors for sending me the manuscript on time. Conversion to thoracotomy is 1 of the barriers for adoption of minimally invasive surgery for lobectomy. And recognizing the fact that it's associated with conversion is important in order to anticipate those events and allow for proper case selection. In this Pulmonary Open, Robotic, and Thoracoscopic Lobectomy (PORTaL) study, the authors report 1 of the largest multi-institutional series of lobectomy for lung cancer, including over 5800 patients undergoing VATS or robotic lobectomy. They did use a propensity score matching that he talked about and since this is a multicenter study, the level of data granularity and outcomes reported is more comprehensive than you would see in a national database—that doesn't have all this granularity of the Society of Thoracic Surgeons database.

We did see in the presentation that after propensity score adjustment, the conversion rate of video-assisted thoracoscopic surgery (VATS) was nearly 4-fold higher than the robotic approach. But I did notice that the emergency nature was almost double in the robotic group at 9% versus 5% for VATS. And you also showed that the surgical approach was a more significant predictor of conversion than tumor characteristics, patient factors, and even neoadjuvant therapy. So with that, I have 3 questions for you. First, in the study, there were a number of cases that converted from robotic lobectomy to VATS, and this was not included in the outcome analysis. So can you explain the rationale for the exclusion of these?

Dr Luis J. Herrera *(Orlando, Fla)*. It was a small percentage, 0.6%, converted from robotic to VATS. And the reasons were mostly failure to progress or anatomical difficulties. In 1 case, the robotic instruments were not working and they had to continue VATS. But we felt that those cases did complete minimally invasive, and we felt that those outcomes would resemble more a minimally invasive approach. We thought it would favor the robotic approach if we compared those to the VATS converted to open cases.

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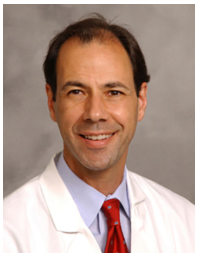
Dr Soukiasian. My second question is: You showed that the conversion rate increased in the VATS group more than the robotic group as the disease stage advanced. So conversion for anatomy not visible was also more frequent in VATS. But it is a commonly used reason for conversion. It's a subjective term. So can you provide more insight into the anatomical reasons for conversion?

Dr Herrera. Yes. Actually, I have a backup slide if I can pull that up. Anatomy was classified according to these reasons. And the most common was tumor factors, like tumor size, adhesions, tumor location, and fissure. Those were the 4 main reasons for anatomical conversion. And in reality, it's a little bit subjective when you start to break down these reasons. And some patients have more than 1 reason for conversion. But we feel that the oncologic reasons for conversion, the tumor effects, the central tumors, the hilar dissection, became less of a problem on the robotic cases overall.

Dr Soukiasian. Finally, vascular injury is the most concerning problem during minimally invasive lobectomy. And emergency conversions have been shown in other studies, like the recent study by Elliot Servais in the Society of Thoracic Surgeons database—they showed an increased complication in mortality when you had a vascular injury. In that study, vascular injury was also a more common reason for conversion in robots than in VATS, and with a high rate of emergency conversion and blood transfusions in that group. So was there a difference in outcomes between the converted robotic cases and VATS cases? And as I said, remember, the VATS cases had fewer emergency conversions at 5% versus the robotic emergent conversions at 9%.

Dr Herrera. That is a good question. We did not see a difference—well, I'm going to put it this way: The only difference between the converted VATS and converted robotic cases was prolonged length of stay. That was the only statistically significant difference between those 2, with a slightly longer prolonged length of stay on the VATS cohort versus converted robotic cohort. And chest tube duration was a little shorter on the robot cases. But the rest (mortality, transfusions, and intraoperative transfusions) was no different, which is a little bit different from what Dr Servais found on his paper.

Dr Soukiasian. Thank you.



Dr Thomas A. D'Amico *(Durham, NC)*. Great presentation, Dr Herrera, and I congratulate you and your colleagues for doing the study and your previous publications in the *Annals of Surgery*. Did you say at the beginning who funded the study?

Dr Herrera. Intuitive Surgical provided funding only for coordination of all the data collection and for statistical support. It's a third-party consultant for statistics.

Dr D'Amico. Ok, thank you; I just had missed that. Retrospectively, where did the VATS cases come from?

Dr Herrera. The VATS cases came from all these consortiums of institutions (all high-volume VATS surgeons).

Dr D'Amico. Okay. And did you correct for surgeon experience?

Dr Herrera. One of the goals for this project was to eliminate a little bit of the influence of the learning curves. So we show institutions that had surgeons with at least 50 cases under their belt with the selected approach. Fifty was the cutoff. And that's 1 of the limitations—could there be a learning curve impact within this dataset? It's possible.

Dr D'Amico. Finally, are any of the authors primarily VATS surgeons?

Dr Herrera. Yes. What we did is include the study chairs, Dr Hartwig, Dr Kent, and Dr Vallières—each 1 had specific expertise in VATS open or robotic approach.

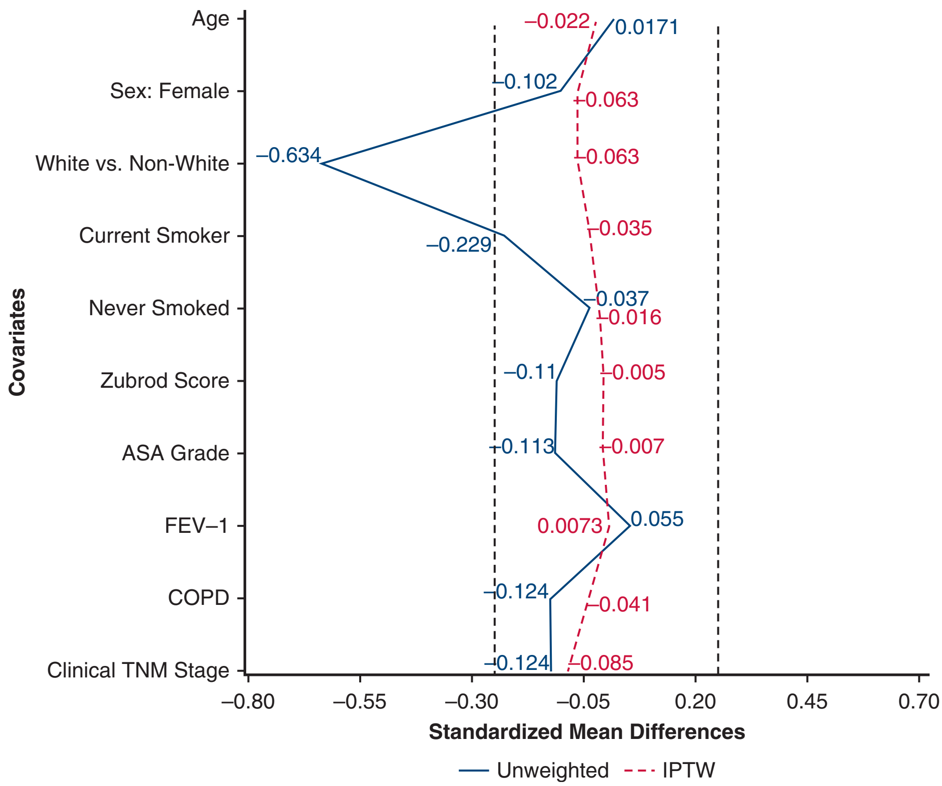


FIGURE E1. Standardized differences of the means graph for the inverse probability of treatment weighing method (*IPTW*) analysis. *ASA*, American Society for Thoracic Surgery; *FEV-1*, forced expiratory volume in 1 minute; *COPD*, chronic obstructive pulmonary disease; *TNM*, tumor, node, metastasis.

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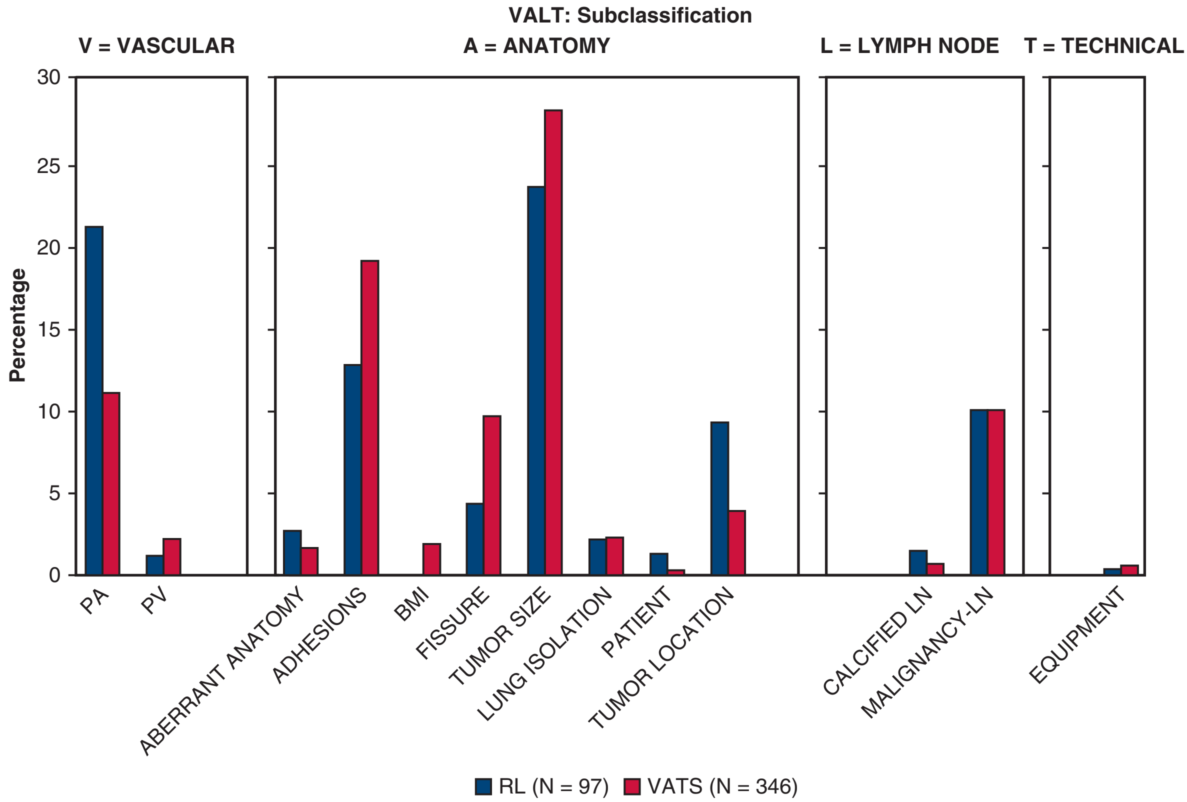

FIGURE E2. Subclassification of vascular, anatomy, lymph node and technical reasons for conversion (*VALT*) according to specific reasons for conversion within the VALT categories. Statistical analysis not possible due to small sample size in the subclassification. *RL*, Robotic lobectomy; *VATS*, video-assisted thoracoscopic surgery; *PA*, pulmonary artery; *PV*, pulmonary vein; *BMI*, body mass index; *LN*, lymph node.

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TABLE E1. Pulmonary Open, Robotic, and Thoracoscopic Lobectomy (PORTaL) Consortium participating institutions

PORTaL investigators	Participating institutions
Abbas Abbas, MD	Temple University, Philadelphia, Pa
Charles T. Bakhos, MD	Temple University, Philadelphia, Pa
Mark Dylewski, MD	Baptist Health South Florida, Miami, Fla
Robert Cerfolio, MD	New York University-Langone, New York, NY
Thomas Fabian, MD	Albany Medical Center, Albany, NY
Matthew Hartwig, MD	Duke University Medical Center, Durham, NC
Luis Herrera, MD	Orlando Health, Orlando, Fla
G. Kimble Jett, MD	Baylor Scott & White Health, Dallas, Tex
Michael Kent, MD	Beth Israel Deaconess Medical Center, Boston, Mass
Richard Lazzaro, MD	Northwell Health, New York, NY
Bryan Meyers, MD	Washington University, St Louis, Mo
Brian Mitzman, MD	New York University-Winthrop, New York, NY
Rishindra Reddy, MD	University of Michigan, Ann Arbor, Mich
Michael Reed, MD	Penn State Cancer Institute, Hershey, Pa
David Rice, MD	MD Anderson Cancer Center, Houston, Tex
Patrick Ross, MD	Main Line Health/Lankenau Institute, Wynnewood, Pa
Inderpal Sarkaria, MD	University of Pittsburgh Medical Center, Pittsburgh, Pa
Lana Schumacher Beal, MD	Allegheny Health Network, Pittsburgh, Pa
William Tisol, MD	Aurora Research Institute, Milwaukee, Wis
Eric Vallieres, MD	Swedish Cancer Institute, Seattle, Wash
Dennis Wigle, MD	Mayo Clinic, Rochester, Minn
Michael Zervos, MD	New York University-Langone Mineola, New York, NY

PORTaL, Pulmonary Open, Robotic, and Thoracoscopic Lobectomy.

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