The role of thoracoscopic pneumonectomy in the management of non–small cell lung cancer: A multicenter study

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ABSTRACT

Objective: The objective of this study was to evaluate the impact of the video-assisted thoracoscopic (VATS) approach on the outcomes of patients who underwent pneumonectomy.

Methods: The effect of the surgical approach on perioperative complications and survival in patients who underwent pneumonectomy for nonmetastatic non–small cell lung cancer across 3 institutions (2000–2016) was assessed using multivariable logistic regression, Cox proportional hazards analysis, and propensity-score matching. Completion pneumonectomies were excluded from this study, and an “intent-to-treat” analysis was performed.

Results: During the study period, 359 patients met inclusion criteria and underwent pneumonectomy for nonmetastatic non–small cell lung cancer; 124 (35%) underwent pneumonectomy via VATS and 235 (65%) via thoracotomy. Perioperative mortality (VATS, 7% [n = 9] vs open, 8% [n = 19]; $P = .75$) and morbidity (VATS, 28% [n = 35] vs open, 28% [n = 65]; $P = .91$) were similar between the groups, even after multivariable adjustment. VATS showed similar 5-year survival when compared with thoracotomy in unadjusted analysis (47% [95% confidence interval (CI), 36–56] vs 33% [95% CI, 27–40]; $P = .19$), even after multivariable adjustment (hazard ratio, 0.76 [95% CI, 0.50–1.18]; $P = .23$). In a propensity score–matched analysis that balanced patient characteristics, there were no significant differences found in overall survival between the 2 groups ($P = .69$).

Conclusions: Although the role of VATS pneumonectomy will likely become clearer as more surgeons report results, this multicenter study suggests that the VATS approach for pneumonectomy can be performed safely, with at least equivalent oncologic outcomes when compared with thoracotomy. (J Thorac Cardiovasc Surg 2019;158:252–64)

Overall survival for patients undergoing VATS versus open pneumonectomy for NSCLC.

Central Message

In this multicenter study, the VATS approach for pneumonectomy was found to be feasible and effective, with at least equivalent oncologic outcomes compared with an open approach.

Perspective

The safety and feasibility of the VATS approach to pneumonectomy are not well characterized. In this multi-institutional study, there were no significant differences between VATS and open pneumonectomy with regard to perioperative mortality and long-term survival when compared with an open approach.

See Commentaries on pages 265 and 267.

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The video-assisted thoracoscopic (VATS) approach to lobectomy has been demonstrated to be a safe and appropriate treatment modality for early-stage non–small cell lung

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Abbreviations and Acronyms

CI	= confidence interval
DLCO	= diffusing capacity of the lung for carbon monoxide
FEV1	= forced expiratory volume in 1 second
IQR	= interquartile range
NSCLC	= non-small cell lung cancer
VATS	= video-assisted thoracoscopic

cancer (NSCLC).^{1,2} However, there are few studies regarding the safety and feasibility of the VATS approach to pneumonectomy. To date, there have been only 2 single-center studies that have compared the outcomes of VATS with open pneumonectomy for NSCLC; in those studies, no significant differences in perioperative complications and 30-day mortality were found.^{3,4}

The purpose of this study was to build on the current data regarding the safety and feasibility of VATS pneumonectomy by assessing the short- and long-term outcomes among patients undergoing VATS versus open pneumonectomy for NSCLC in a multicenter setting. Our objective was to test the hypothesis that the VATS approach in appropriately selected patients is not associated with significant differences in perioperative and oncologic outcomes when compared with pneumonectomy by thoracotomy.

MATERIALS AND METHODS

A retrospective analysis was performed of patients with nonmetastatic NSCLC who underwent a pneumonectomy across 3 institutions (Duke University Medical Center, Roswell Park Cancer Institute and Cedars Sinai Medical Center) from 2000 to 2016. The study received Institutional Review Board approval from all 3 institutions with individual patient consent being waived; all records were from Duke University Medical Center, Roswell Park Cancer Institute, and Cedars Sinai Medical Center. Patients who underwent a completion pneumonectomy or who had clinical M1 disease were excluded from the analysis. Baseline variables and outcome variables included demographics, pulmonary function (forced expiratory volume in 1 second [FEV1] and diffusing capacity of the lung for carbon monoxide [DLCO]), comorbidities, histology, preoperative clinical stage, pathologic stage, chest tube duration, length of hospitalization, estimated blood lost during surgery, length of surgery, acute pain syndrome, number of lymph nodes dissected, number of stations dissected, number of N2 stations dissected, atrial fibrillation, empyema, pneumonia, pericardial effusion, myocardial infarction, and overall and recurrence-free survival. VATS pneumonectomy was defined as anatomic pneumonectomy using videoscopic guidance, an access incision (4-7 cm), and 1 to 3 other port incisions, without using a rib retractor (see Video 1).

Overall survival was determined from the date of pneumonectomy to death from any cause, with patients censored at the time of last known follow-up. Recurrence-free survival was determined from the date of pneumonectomy to death or recurrence as evaluated by biopsy or imaging seen during follow-up, with patients censored at the time of last follow-up.

Postdischarge follow-up data were collected through direct contact with patients and physicians, clinic notes, and a national death registry. Preoperative staging was determined before resection based on computed

VIDEO 1. Left video-assisted thoracoscopic pneumonectomy. Video available at: [https://www.jtcvs.org/article/S0022-5223\(18\)33419-6/fulltext](https://www.jtcvs.org/article/S0022-5223(18)33419-6/fulltext).

tomography scan, positron emission tomography scan, brain imaging with computed tomography or magnetic resonance imaging, bronchoscopy, mediastinoscopy, thoracoscopic staging, and needle biopsy. The final pathology report was used to determine postoperative pathologic stage.

Statistical Analysis

Baseline characteristics and outcomes were compared between the VATS and open groups using the Student unpaired *t* test or the Wilcoxon rank-sum test when applicable for continuous variables and the Pearson's chi-square test or Fisher exact test when applicable for categorical variables. Patients who underwent conversions from VATS to open pneumonectomy were assessed using an intent-to-treat analysis.

Overall and recurrence-free survival were evaluated using the Kaplan-Meier method and log-rank test. A Cox proportional hazards model was used to compare overall survival between the open and VATS groups, adjusting for variables chosen on the basis of clinical relevance, which included age, sex, FEV1, DLCO, diabetes, congestive heart failure, chronic obstructive pulmonary disease, coronary artery disease, clinical T status, clinical N status, tumor size, neoadjuvant chemotherapy, neoadjuvant radiation, history of smoking, and operative year. Complete case analysis was used for this adjusted model. The proportional hazards assumption was tested for all Cox models using smooth scaled Schoenfeld residual plots—no violations of assumptions were found—with linearity confirmed for all continuous predictors included in Cox regression analysis using Martingale residuals. A logistic regression model was developed to identify predictors of conversions in the VATS pneumonectomy group, adjusting for variables chosen on the basis of clinical relevance, which included tumor size, pathologic N stage, laterality of pneumonectomy, and use of induction therapy (including chemotherapy, radiation therapy, or chemoradiation therapy).

A propensity score-matched analysis of open versus VATS pneumonectomy cases was performed to further evaluate potential differences in perioperative outcomes and survival between groups. Propensity scores were developed and defined as the treatment probability with the VATS approach versus open approach conditional on measured covariates. Variables included in the propensity score model were age, sex, race, FEV1, DLCO, tumor size, pathologic T status, pathologic N status, histology, diabetes, coronary artery disease, history of smoking, neoadjuvant chemotherapy, neoadjuvant radiation, hypertension, and operative year. A 1:1 nearest neighbor matching algorithm with a caliper distance of 0.01 and no replacement was then used to match patients. After propensity-score matching, patient demographics and outcomes were assessed using standardized differences, as well as Pearson's chi-square test or Fisher exact test when applicable for categorical variables and the Student unpaired *t* test or Wilcoxon rank-sum test when applicable for continuous variables. In addition, the Kaplan-Meier method and

TABLE 1. Baseline patient characteristics

Characteristic	Open approach (n = 235)	VATS approach (n = 124)	P value
Female sex (n, %)	77 (33)	57 (46)	.01
Age (mean $\pm$ SD) (y)	60.2 $\pm$ 11.6	62.3 $\pm$ 11.3	.07
Ethnicity (n, %)			.31
White	186 (79)	89 (72)	
Black	24 (10)	6 (5)	
Hispanic	0 (0)	0 (0)	
Native American	3 (1)	0 (0)	
Asian	4 (2)	4 (3)	
Middle Eastern	3 (1)	2 (2)	
Unknown	15 (6)	23 (19)	
FEV1 (mean $\pm$ SD) (% predicted)*	71.6 $\pm$ 19.8	77.4 $\pm$ 19.3	.03
DLCO (mean $\pm$ SD) (% predicted)†	71.2 $\pm$ 20.3	75.2 $\pm$ 18.7	.06
History of diabetes (n, %)	22 (9)	8 (6)	.34
Hypertension (n, %)	81 (34)	54 (44)	.12
COPD (n, %)	47 (20)	33 (27)	.09
Congestive heart failure (n, %)	2 (1)	2 (2)	.61
Coronary artery disease (n, %)	31 (13)	22 (18)	.25
Stroke (n, %)	4 (2)	0 (0)	.30
Pulmonary embolism (n, %)	2 (1)	0 (0)	.55
History of smoking (n, %)	200 (85)	106 (85)	.82
Smoking, pack year (mean $\pm$ SD)‡	39.3 $\pm$ 27.8	38.4 $\pm$ 28.2	.47
Neoadjuvant chemotherapy (n, %)	73 (31)	37 (30)	.81
Neoadjuvant radiation (n, %)	44 (19)	16 (13)	.16
Surgical laterality (n, %)			.41
Left	135 (57)	66 (53)	
Right	88 (37)	52 (42)	
Unknown	12 (5)	6 (5)	
Operative year (n, %)			<.001
2000-2005	107 (46)	22 (18)	
2006-2010	78 (33)	45 (36)	
2011-2016	50 (21)	57 (46)	

VATS, Video-assisted thoracoscopic; SD, standard deviation; FEV1, forced expiratory volume in 1 second; DLCO, diffusing capacity of the lung for carbon monoxide; COPD, chronic obstructive pulmonary disease. *Data only available for 318 of 359 patients (open: n = 200, VATS: n = 118). †Data only available for 302 of 359 patients (open: n = 190, VATS: n = 112). ‡Data only available for 347 of 359 patients (open: n = 225, VATS: n = 122).

log-rank test were used to evaluate overall and recurrence-free survival. All statistical analyses were performed using Stata version 13.0 (StataCorp LP, College Station, Tex).

RESULTS

Patient and Treatment Characteristics

Of the 359 patients who met study inclusion criteria, 124 (65%) underwent pneumonectomy via thoracotomy, and the remaining 235 (35%) underwent thoracoscopic pneumonectomy. Table 1 shows the baseline characteristics of the patients in each group. When compared with patients in the open group, patients in the VATS group were more likely to be female and to have higher FEV1 (% predicted) (Table 1). Operative year also differed significantly between

the groups; there was a higher percentage of patients who underwent VATS in more recent years (Figure E1). Eighty-nine percent (n = 318/359) of the cases were done by surgeons who have performed both thoracoscopic and open pneumonectomies. There were no other significant differences in baseline characteristics between the 2 groups.

Table 2 presents tumor characteristics for the 2 groups. Patients in the open group had lower clinical N status and higher pathologic T status when compared with patients in the VATS group. There was a significant difference in histology between the 2 groups, with adenocarcinoma being the most common histology in the VATS group and squamous cell carcinoma being the most common histology in the open group. There were no significant differences in

TABLE 2. Tumor characteristics

Characteristic	Open approach (n = 235)	VATS approach (n = 124)	P value
Clinical T status (n, %)			.57
1a	9 (4)	7 (6)	
1b	10 (4)	8 (6)	
2a	70 (30)	39 (31)	
2b	33 (14)	13 (10)	
3	58 (25)	25 (20)	
4	21 (9)	7 (6)	
Unknown	34 (14)	25 (20)	
Clinical N status (n, %)			.001
0	110 (47)	51 (41)	
1	37 (16)	30 (24)	
2	49 (21)	14 (11)	
3	0 (0)	4 (3)	
Unknown	39 (17)	25 (20)	
Clinical stage (n, %)			.72
IA	7 (3)	6 (5)	
IB	44 (19)	22 (18)	
IIA	36 (15)	15 (12)	
IIB	39 (17)	26 (21)	
IIIA	62 (26)	28 (23)	
IIIB	10 (4)	6 (5)	
Unknown	37 (16)	21 (17)	
Pathologic T status (n, %)			.01
0	0 (0)	4 (3)	
1a	9 (4)	8 (6)	
1b	4 (2)	5 (4)	
2a	84 (36)	55 (44)	
2b	25 (11)	8 (6)	
3	80 (34)	29 (23)	
4	22 (9)	10 (8)	
Unknown	11 (5)	5 (4)	
Pathologic N status (n, %)			.12
0	71 (30)	41 (33)	
1	102 (43)	64 (52)	
2	52 (22)	17 (14)	
Unknown	10 (4)	3 (2)	
Pathologic stage (n, %)			.05
0	0 (0)	4 (3)	
IA	4 (2)	5 (4)	
IB	20 (9)	16 (13)	
IIA	49 (21)	28 (23)	
IIB	49 (21)	25 (20)	
IIIA	94 (40)	37 (30)	
IIIB	8 (3)	4 (3)	
IV	2 (1)	0 (0)	
Unknown	9 (4)	5 (4)	
Tumor size (mean $\pm$ SD) (cm)	5.6 $\pm$ 3.7	4.8 $\pm$ 2.3	.07
Histology (n, %)			.07
Adenocarcinoma	60 (26)	47 (38)	
Squamous	113 (48)	51 (41)	
Adenosquamous	1 (<1)	1 (1)	

(Continued)

TABLE 2. Continued

Characteristic	Open approach (n = 235)	VATS approach (n = 124)	P value
Large cell	9 (4)	5 (4)	
Carcinoid and neuroendocrine	5 (2)	7 (6)	
Poorly differentiated	7 (3)	1 (1)	
Other	22 (9)	10 (8)	
Unknown	18 (8)	3 (2)	

VATS, Video-assisted thoracoscopic; SD, standard deviation.

pathologic N status or pathologic stage between the 2 groups (Table 2).

Perioperative Outcomes

Table 3 shows the perioperative outcomes of patients in the 2 groups. Patients who underwent thoracoscopic pneumonectomy had a shorter chest tube duration ($P = .01$), longer operative time ($P < .001$), greater number of lymph nodes dissected ($P < .001$), and greater number of N2 stations dissected ($P < .001$) compared with patients who underwent pneumonectomy by thoracotomy. A VATS approach was associated with a higher incidence of pneumonia ($P = .05$) and higher incidence of pericardial effusion ($P = .02$). There were no significant differences in 30-day or 90-day all-cause mortality, length of hospitalization, and overall perioperative complications between the 2 groups.

Conversions

Twenty-three (19%) of the VATS cases were converted to open during surgery. The baseline characteristics and tumor characteristics for the patients who underwent a conversion are detailed in Table E1. The conversion rate across all 3 centers decreased over time (Figure E1). The 30-day mortality for patients who underwent conversions was 17% ($n = 4$); of note, there were no intraoperative deaths, and none of these 4 patients died of massive intraoperative hemorrhage. The laterality, tumor size, and T and N status of these 4 patients were as follows: right, T2aN1, 4.5 cm; right, T1bN0, 2.7 cm; right, T2aN2, 5.0 cm; left, T2bN1, 6.1 cm. The causes of death, respectively, were postoperative pulmonary embolism, postoperative right-sided heart failure, pneumonia, and postoperative cardiac arrest. There were no significant differences in 30-day mortality between the conversions group and the open group ($P = .14$). In multivariable logistic regression modeling, there were no variables found to be significantly associated with increased likelihood of converting from VATS to open (Table E2).

Survival Analysis

The median follow-up for the thoracotomy group was 21.0 months (interquartile range [IQR], 8.8-63.9), and the median follow-up for the VATS group was 22.1 months

TABLE 3. Perioperative outcomes

Characteristic	Open approach (n = 235)	VATS approach (n = 124)	P value
30-d mortality (n, %)	19 (8)	9 (7)	.75
90-d mortality (n, %)	32 (14)	19 (15)	.66
Length of hospitalization, median (IQR),* d	5 (4-7)	5 (4-7)	.39
Chest tube duration, median (mean $\pm$ SD),† d	1.5 $\pm$ 1.4	1.2 $\pm$ 1.4	.01
Estimated blood loss (mean $\pm$ SD) (mL)‡	404 $\pm$ 321	467 $\pm$ 508	.70
Length of surgery (mean $\pm$ SD) (min)§	234 $\pm$ 109	321 $\pm$ 149	<.001
Acute pain syndrome (n, %)	15 (7)	7 (7)	.77
Lymph nodes dissected (mean $\pm$ SD)¶	13.1 $\pm$ 9.4	22.0 $\pm$ 15.3	<.001
Lymph node stations dissected (mean $\pm$ SD)#	4.2 $\pm$ 2.3	4.5 $\pm$ 3.7	.96
N2 stations dissected (mean $\pm$ SD)**	3.7 $\pm$ 1.8	4.7 $\pm$ 2.1	<.001
Overall morbidity (n, %)	65 (28)	35 (28)	.91
Atrial fibrillation	48 (20)	20 (16)	.39
Bronchopleural fistula	12 (5)	5 (4)	.65
Empyema	8 (3)	2 (2)	.35
Pneumonia	16 (7)	16 (13)	.05
Pericardial effusion	2 (1)	6 (5)	.02
Myocardial infarction	3 (1)	2 (2)	1.00

VATS, Video-assisted thoracoscopic; IQR, interquartile range; SD, standard deviation. *Data only available for 315 of 359 patients (open: n = 209, VATS: n = 106). †Data only available for 269 of 359 patients (open: n = 150, VATS: n = 87). ‡Data only available for 184 of 359 patients (open: n = 73, VATS: n = 111). §Data only available for 214 of 359 patients (open: n = 103, VATS: n = 111). ||Data only available for 309 of 359 patients (open: n = 202, VATS: n = 107). ¶Data only available for 289 of 359 patients (open: n = 189, VATS: n = 100). #Data only available for 312 of 359 patients (open: n = 207, VATS: n = 105). **Data only available for 293 of 359 patients (open: n = 206, VATS: n = 87).

(IQR, 8.9-54.6). There were no significant differences in median overall survival between the VATS and open groups (45.7 months [95% confidence interval (CI), 29.0-65.5] vs 24.6 months [95% CI, 19.1-30.9]). The VATS approach did not significantly differ in long-term overall survival when compared with the open approach (5-year survival: 47% [95% CI, 36-56] vs 33% [95% CI, 27-40]; log-rank, $P = .19$) (Figure 1, A). In multivariable analysis, the VATS approach was not associated with improved survival when compared with the open approach (hazard ratio, 0.76; 95% CI, 0.50-1.18; $P = .23$) (Table 4).

There were no significant differences in recurrence rates between the VATS and open groups (26% vs 29%, $P = .57$). With regard to recurrence-free survival, there were no significant differences between the VATS and open groups in median survival (24.1 months [95% CI, 15.4-40.9] vs 16.5 months [95% CI, 13.8-22.3]) or 5-year survival (36% [95% CI, 26-46] vs 31% [95% CI, 25-37]; log-rank, $P = .52$) (Figure 1, B). In multivariable analysis, a VATS approach was found to have no significant difference in recurrence-free survival when compared with an open approach (hazard ratio, 0.83; 95% CI, 0.55-1.25; $P = .38$).

Propensity Analysis

Propensity-score matching was used to create 2 groups of 50 patients each who received an open or VATS

pneumonectomy. Comparison of baseline patient characteristics after propensity-score matching between the 2 groups showed no statistically significant differences (Table 5). After propensity-score matching, there were no significant differences in 30-day and 90-day mortality, length of hospitalization, estimated blood loss during surgery, length of surgery, and perioperative complications between the 2 groups (Table 6). Chest tube duration was significantly shorter with the VATS approach compared with the open approach (median, 1 day [IQR, 1-2] vs 2 days [IQR, 1-2]; $P = .04$). In addition, the VATS approach was associated with a greater number of lymph nodes dissected ($P = .01$) and a greater number of N2 stations dissected ($P = .001$) when compared with pneumonectomy by thoracotomy.

After propensity-score matching, the median follow-up for the VATS group was 40.4 months (IQR, 16.9-61.2), and the median follow-up for the thoracotomy group was 26.9 months (IQR, 12.0-66.7). There were no significant differences in median survival between the VATS (63.1 months [95% CI, 42.0-81.3]) and open (38.4 months [95% CI, 21.7-100.2]) approaches. In addition, there were no significant differences in long-term survival between the VATS and open approach (5-year survival: 60% [95% CI, 43-74] vs 44% [95% CI, 29-58]; log-rank, $P = .69$) (Figure 2, A). With regard to recurrence-free survival, there were no significant differences between the VATS and open

FIGURE 1. Overall and recurrence-free survival for patients undergoing VATS versus open pneumonectomy for NSCLC. A, Overall survival. This figure depicts the Kaplan–Meier overall survival estimates of the open (solid line) versus VATS group (dashed line). B, Recurrence-free survival. This figure depicts the Kaplan–Meier recurrence-free survival estimates of the open (solid line) versus VATS group (dashed line). Tick marks represent censored subjects. VATS, Video-assisted thoracoscopic.

groups in median survival (39.7 months [95% CI, 17.4-65.5] vs 27.0 months [95% CI, 14.9-70.8]) or 5-year survival (34% [95% CI, 19-50] vs. 39% [95% CI, 25-53]; log-rank, $P = .65$) (Figure 2, B).

DISCUSSION

This study compared outcomes of patients who underwent VATS or open pneumonectomy for NSCLC across 3 institutions. The VATS approach was associated with a longer operative time, greater number of lymph nodes dissected, and greater number of N2 stations dissected when compared

with pneumonectomy by thoracotomy. There were no significant differences between the groups with regard to perioperative complications and 30-day mortality. In unadjusted and multivariable analyses, there were no significant differences between the VATS and open approaches with regard to overall and recurrence-free survival. In addition, in propensity score–matched analysis, there were no significant differences in overall and recurrence-free survival between the 2 approaches. These results suggest that the use of the VATS approach for pneumonectomy is feasible in appropriately selected patients.

TABLE 4. Multivariable Cox proportional hazards model

Characteristic	Hazard ratio (95% CI)	P value
VATS	0.76 (0.50-1.18)	.23
Age	1.03 (1.01-1.05)	.002
Sex		
Male	Ref (Ref)	Ref
Female	0.96 (0.66-1.39)	.81
FEV1 (% predicted)	1.00 (0.99-1.01)	.46
DLCO (% predicted)	1.00 (0.99-1.01)	.55
Diabetes	2.27 (1.27-4.06)	.01
Congestive heart failure	1.17 (0.27-5.03)	.83
Coronary artery disease	1.03 (0.64-1.64)	.90
COPD	1.37 (0.90-2.09)	.14
Clinical T status		
1a	Ref (Ref)	Ref
1b	2.72 (0.97-7.62)	.06
2a	1.70 (0.72-3.99)	.23
2b	2.16 (0.81-5.80)	.13
3	1.21 (0.47-3.12)	.69
4	1.91 (0.71-5.14)	.20
Clinical N status		
0	Ref (Ref)	Ref
1	1.22 (0.79-1.88)	.37
2	1.41 (0.90-2.22)	.13
Tumor size	1.04 (0.97-1.12)	.29
Neoadjuvant chemotherapy	1.99 (1.21-3.25)	.01
Neoadjuvant radiation	0.58 (0.32-1.02)	.06
History of smoking	0.85 (0.45-1.62)	.63
Operative year	0.96 (0.92-1.00)	.07

CI, Confidence interval; VATS, video-assisted thoracoscopic; FEV1, forced expiratory volume in 1 second; DLCO, diffusing capacity of the lung for carbon monoxide; COPD, chronic obstructive pulmonary disease; .

This study is the first multicenter study reporting the outcomes of thoracoscopic pneumonectomy. The first reports demonstrating technical feasibility of thoracoscopic pneumonectomy were published in the early 1990s, but since then, studies have been limited largely to case reports.⁵⁻¹⁵ There have been only 2 other studies that have evaluated the outcomes of VATS versus open pneumonectomy in patients with NSCLC,^{3,4} with findings similar to those reported in the present study. Battoo and colleagues³ found that in their single-center experience of 107 patients, of whom 67 (63%) underwent a VATS approach, there were no significant differences in perioperative complications and overall survival between VATS and open pneumonectomy.³ Their conversion rate reported was 16%, which is similar to the conversation rate of 19% in this study. Liu and colleagues⁴ also found no significant differences in perioperative complication rates between VATS and open pneumonectomy.

In the present study, the VATS approach was associated with a greater number of lymph nodes dissected and lymph node stations sampled. We speculate that the reason why fewer lymph nodes were dissected in the open group may have been because more patients in the open group underwent induction radiation. In the open group, use of radiation may have obliterated planes or lymph nodes, which may have led to fewer lymph nodes dissected. Of note, the median number of N2 lymph node stations dissected in both groups was more than 3, suggesting that both approaches allowed for appropriate hilar and mediastinal dissection.

In the present study, 19% of the VATS group underwent a conversion to an open pneumonectomy. With regard to appropriate patient selection for VATS pneumonectomy, we performed a logistic regression to identify predictors of conversions and found that none of the included variables were associated with increased likelihood of converting from a VATS to open approach. Of note, in the present study, the majority of the VATS and open procedures (89%) were performed by the same surgeons, albeit during their learning curve. In general, the technical difficulty of a thoracoscopic approach alone does not determine the candidacy of the patient, because the comfort level of an individual surgeon changes over his or her learning curve. Skills learned in the VATS approach for central tumors that require lobectomy are transferrable to VATS pneumonectomy. Ongoing improvements in technology, specifically optics and tools that promote dissection, make more patients eligible for VATS pneumonectomy than before.

The patients who are not good candidates for VATS pneumonectomy are those in whom it is difficult to determine, by VATS, the technical feasibility of a sleeve/pulmonary arterioplasty. In addition, very large tumors that are central requiring thoracotomy for removal are also a relative contraindication. However, even in such cases, with experience, a VATS approach can be feasible. Exposure to the hilum can be enhanced by the use of a camera and can allow for central clamping and dissection, including stapling of the left main pulmonary artery at its origin, for a central left pneumonectomy. At the very least, an initial thoracoscopic approach may allow additional views of the hilum that are less obstructed by the tumor, thereby enhancing dissection.

In the present study, all cases were first assessed to discern whether a sleeve lobectomy would be feasible. Our approach is to prioritize parenchymal sparing procedures such as the sleeve lobectomy over a pneumonectomy in patients with central lung cancers (eg, we would readily perform an open sleeve lobectomy over a VATS pneumonectomy). Assessment for sleeve lobectomy by VATS was the same as by open approaches and involved the use of imaging analysis and intraoperative

TABLE 5. Patient and tumor characteristics after propensity-score matching

Characteristic	Open approach (n = 50)	VATS approach (n = 50)	P value
Female sex (n, %)	20 (40)	21 (42)	.84
Age (mean ± SD) (y)	61.3 ± 11.0	63.5 ± 10.5	.32
Ethnicity (n, %)			1.00
White	45 (90)	46 (92)	
Black	5 (10)	4 (8)	
FEV1 (mean ± SD) (% predicted)	73.9 ± 16.7	76.5 ± 19.3	.46
DLCO (mean ± SD) (% predicted)	71.8 ± 18.1	71.5 ± 20.1	.93
History of diabetes (n, %)	0 (0)	1 (2)	1.00
Hypertension (n, %)	20 (40)	25 (50)	.32
COPD (n, %)	13 (26)	16 (32)	.51
Clinical T status (n, %)			.87
1a	1 (2)	4 (8)	
1b	2 (4)	2 (4)	
2a	23 (46)	21 (42)	
2b	5 (10)	5 (10)	
3	14 (28)	14 (28)	
4	5 (10)	4 (8)	
Clinical N status (n, %)			.13
0	31 (62)	23 (46)	
1	10 (20)	19 (38)	
2	9 (18)	7 (14)	
3	0 (0)	1 (2)	
Clinical stage (n, %)			.96
IA	2 (4)	2 (4)	
IB	12 (24)	10 (20)	
IIA	10 (20)	8 (16)	
IIB	12 (24)	15 (30)	
IIIA	11 (22)	13 (26)	
IIIB	3 (6)	2 (4)	
Congestive heart failure (n, %)	0 (0)	0 (0)	1.00
Coronary artery disease (n, %)	7 (14)	12 (24)	.20
Pulmonary embolism (n, %)	0 (0)	0 (0)	1.00
History of smoking (n, %)	46 (92)	46 (92)	1.00
Smoking pack y (mean ± SD)	41.8 ± 32.6	42.4 ± 24.3	.73
Neoadjuvant chemotherapy (n, %)	14 (28)	17 (34)	.52
Neoadjuvant radiation (n, %)	6 (12)	6 (12)	1.00
Surgical laterality (n, %)			1.00
Left	18 (36)	18 (36)	
Right	32 (64)	32 (64)	
Operative year (n, %)			.70
1999-2003	10 (20)	8 (16)	
2003-2009	21 (42)	19 (38)	
2010-2016	19 (38)	23 (46)	
Pathologic T status (n, %)			.94
0	0 (0)	0 (0)	
1a	3 (6)	5 (10)	

(Continued)

TABLE 5. Continued

Characteristic	Open approach (n = 50)	VATS approach (n = 50)	P value
1b	1 (2)	2 (4)	
2a	25 (50)	26 (52)	
2b	4 (8)	4 (8)	
3	14 (28)	11 (22)	
4	3 (6)	2 (4)	
Pathologic N status (n, %)			.92
0	15 (30)	14 (28)	
1	27 (54)	29 (58)	
2	8 (16)	7 (14)	
Pathologic stage (n, %)			.91
0	0 (0)	0 (0)	
IA	2 (4)	2 (4)	
IB	6 (12)	10 (20)	
IIA	15 (30)	14 (28)	
IIB	11 (22)	8 (16)	
IIIA	15 (30)	15 (30)	
IIIB	1 (2)	1 (2)	
IV	0 (0)	0 (0)	
Tumor size (mean ± SD) (cm)	4.93 ± 2.64	4.77 ± 2.41	.91
Histology (n, %)			.83
Adenocarcinoma	18 (36)	20 (40)	
Squamous	22 (44)	22 (44)	
Large cell	4 (8)	2 (4)	
Carcinoid and neuroendocrine	2 (4)	4 (8)	
Poorly differentiated	2 (4)	1 (2)	
Other	2 (4)	1 (2)	

VATS, Video-assisted thoroscopic; SD, standard deviation; FEV1, forced expiratory volume in 1 second; DLCO, diffusing capacity of the lung for carbon monoxide; COPD, chronic obstructive pulmonary disease.

dissection of interlobar structures. With regard to the 19% of patients who underwent a conversion, these were all patients in whom it was thought that a pneumonectomy was necessary. One important limitation of this study is that we were not able to precisely capture the decision making process of sleeve versus pneumonectomy (eg, data on the patients in whom a conversion led to a sleeve lobectomy are unavailable).

Although several studies have shown that a VATS approach to lobectomy is associated with decreased pain¹⁶ and a decreased length of hospital stay,¹⁷ in the present study, no significant differences in perioperative mortality and length of hospital stay were found between the VATS and open pneumonectomy groups. This may be because compared with a lobectomy, the adverse physiologic impact of a pneumonectomy may affect certain outcomes (eg, perioperative mortality, length of stay) more significantly than the impact of the surgical approach. In this study, other important outcomes such as chronic pain scores, extent of narcotic use, length of time to return to work, inflammatory and immunologic responses, time to

TABLE 6. Perioperative outcomes after propensity-score matching

Characteristic	Open approach (n = 50)	VATS approach (n = 50)	P value
30-d mortality (n, %)	3 (6)	2 (4)	1.00
90-d mortality (n, %)	4 (8)	7 (14)	.53
Length of hospitalization, median (IQR), d	5 (4-6)	5 (4-6)	.10
Chest tube duration, median (IQR),* d	2 (1-2)	1 (1-2)	.04
Estimated blood loss (mean $\pm$ SD) (mL)†	378 $\pm$ 221	395 $\pm$ 408	.48
Length of surgery (mean $\pm$ SD) (min)‡	239 $\pm$ 92	272 $\pm$ 93	.14
Acute pain syndrome (n, %‡)	5 (10)	4 (8)	.75
Lymph nodes dissected (mean $\pm$ SD)	12.9 $\pm$ 9.8	20 $\pm$ 15.5	.01
Lymph node stations dissected (mean $\pm$ SD)	4.8 $\pm$ 2.3	4.9 $\pm$ 4.1	.56
N2 stations dissected (mean $\pm$ SD)	3.7 $\pm$ 1.6	4.9 $\pm$ 1.9	.001
Overall morbidity (n, %)	12 (24)	14 (28)	.65
Atrial fibrillation	10 (20)	11 (22)	.81
Bronchopleural fistula	1 (2)	1 (2)	1.00
Empyema	0 (0)	0 (0)	1.00
Pneumonia	3 (6)	4 (8)	1.00
Pericardial effusion	1 (2)	3 (6)	.62
Myocardial infarction	0 (0)	0 (0)	1.00

VATS, Video-assisted thoracoscopic; IQR, interquartile range; SD, standard deviation. *Data only available for 79 of 100 patients (open: n = 41, VATS: n = 38). †Data only available for 68 of 100 patients (open: n = 19, VATS: n = 49). ‡Data only available for 77 of 100 patients (open: n = 28, VATS: n = 49). §Data only available for 99 of 100 patients (open: n = 50, VATS: n = 99). ||Data only available for 90 of 100 patients (open: n = 44, VATS: n = 46).

administration of adjuvant chemotherapy, chemotherapy tolerance, and noncancer-specific mortality were not measured.

Of note, in prior single-center reports of VATS versus open pneumonectomy, a significantly greater percentage of patients in the VATS group had reduced acute pain (as measured by a visual analogue pain scale)⁴ or were pain free at 1 year when compared with the open group (53% vs 19%, $P = .03$).³ In the present study, we did not measure chronic pain, and although we did include acute pain as a variable, this outcome was determined from physician clinic notes and not by specific visual analogue scales and other instruments. We hypothesize that evaluation of other outcomes not included in this study may show differences between VATS and open approaches to pneumonectomy and that assessment of these outcomes will be important in future studies. Furthermore, because this report describes the early experience of VATS pneumonectomy, it may be reasonable to expect that outcomes will improve with experience and enhancements that reliably occur with greater adoption.

Study Strengths and Limitations

The strength of this study is its multi-institutional design, with a large cohort of more than 400 patients that allowed for evaluation of short- and long-term outcomes of VATS versus open pneumonectomy using multivariable and propensity score-matched analysis. The study does have several limitations. First, it is a retrospective study, and

although multivariable adjustment and propensity matching were used to decrease the potential effects of selection bias, unobserved confounding could still be present. Second, the power of the propensity analysis was limited because there were only 50 patients in each arm of the propensity-matched analysis; thus, the study may have been underpowered to detect small but meaningful differences. Third, the findings from this study are from 3 institutions that perform a high volume of VATS pneumonectomies and may be limited in its generalizability. Fourth, there has been an evolution in practice over the past 16 years, which may have affected our outcomes, although we did try to account for differences in treatment “eras” by including the operative year in multivariable and propensity score-matched analysis. Fifth, the learning curve of VATS pneumonectomy was not formally assessed. Sixth, we did not have data on the exact location of the tumor (eg, peripheral vs central) and the percentage of intrapericardial pneumonectomy in the VATS and open groups. Qualitatively, an intrapericardial approach did not deter the conduct of a VATS pneumonectomy. From early in our experience of both lobectomies and pneumonectomies, opening the pericardium thoracoscopically to achieve fresh tissue planes to avoid tedious vascular VATS dissection in an amalgamated hilum was a useful maneuver for all central, postinduction cases. Thus, we do not expect that the open approach to pneumonectomy would have been associated with a higher rate of intrapericardial pneumonectomies when compared with a VATS pneumonectomy. Seventh, data on clinical stage were not

FIGURE 2. Overall and recurrence-free survival for patients undergoing VATS versus open pneumonectomy for NSCLC: propensity score-matched analysis. A, Overall survival. This figure depicts the Kaplan–Meier overall survival estimates of the open (*solid line*) versus VATS group (*dashed line*) for patients included in the propensity score-matched analysis. B, Recurrence-free survival. This figure depicts the Kaplan–Meier recurrence-free survival estimates of the open (*solid line*) versus VATS group (*dashed line*) for patients included in the propensity score-matched analysis. Tick marks represent censored subjects. VATS, Video-assisted thoracoscopic.

available for some patients and cancer-specific survival was not available for any of the patients. Eighth, although we do have lymph node data that were presented in this study, the data are limited by the fact that these data can have inconsistencies, given that protocols from pathologists across institutions were not uniform and details regarding how pathologists counted individual nodes are unavailable. Finally, the follow-up time for patients was relatively short, and longer follow-up time would strengthen findings.

CONCLUSIONS

In this multi-institutional study, VATS pneumonectomy for NSCLC was found to be feasible and effective. When compared with an open approach, the VATS approach to pneumonectomy was found to be associated with a similar perioperative complication rate and similar overall survival and does not appear to compromise oncologic outcomes. On the basis of these results, we conclude that surgeons with experience in using VATS for locally advanced lung

cancer may consider the thorascopic approach for patients with NSCLC who require pneumonectomy.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://aats.blob.core.windows.net/media/18Apr30/25ABC%202.General%20Thoracic%20SS/S72%20-%20Part%20/S72_2_webcast_041336881.mp4.

Long-term Survival Following Open versus VATS Pneumonectomy for Non-small-cell Lung Cancer: A Multi-Center Study

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Conflict of Interest Statement

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Key Words: lung cancer, minimally invasive surgery, thoracic surgery

Discussion

Dr James D. Luketich (*Pittsburgh, Pa*). You, Dr D'Amico, and the other co-authors are to be congratulated on this important contribution. I do have some comments and observations and a few questions.

It looks like this would have boiled down to approximately 8 pneumonectomies per year per institution total, so that means, if I divide that, maybe a handful of VATS pneumonectomies per year per institution, maybe more recently because it seemed like the VATS became common, but nevertheless, a fairly small number. I wonder how many surgeons at each institution were performing VATS pneumonectomies and did you have criteria to limit it to only a few surgeons?

Dr Chi-Fu Jeffrey Yang (*Durham, NC*). Thank you, Dr Luketich. In our series, Dr D'Amico and Dr Demmy accounted for about 50% of the VATS pneumonectomies. Dr McKenna did 26 of these cases, or about 17%, and Dr Nwogu did 19, or 12%, of these cases. In total, eleven surgeons

contributed to this data.

Dr Luketich. One thing I have observed over the years as we take on more complex minimally invasive cases is the number we do per year and what is the likelihood of getting good at it. Were you able to assess that just looking at the outcomes? Do you think there was a minimum number on this learning curve toward feeling comfortable with VATS pneumonectomy? Did you come up with a number at all or any sense of what that might be for the audience?

Dr Yang. That is one of the key limitations of this study; we were not able to formally assess the learning curve. However, all of the surgeons who contributed data were very comfortable with VATS lobectomies, VATS sleeves, and complex hilar dissection with the VATS approach.

Dr Luketich. The second question, first, I want to comment about it. One of my general concerns is that the

pneumonectomy rate at any given institution may vary, and I think most of us in academic centers like to think, and there are some data to show, that the rate of pneumonectomy in an academic center is far less than, say, in a community center.

Having said that, do you think that the decision to make that conversion from an open or to a VATS lobe and when to proceed, in other words, the learning curve for the dissection and understanding when you can actually avoid a pneumonectomy by VATS, that seems to be what concerns me the most, which is that while I am doing a dissection open, many times I can figure out a way to save the other lobe. Do you think that that's possible with all VATS and that what accounted for a significant number of the conversions was trying to basically figure out that you can do it? Were there some patients not included in this study who were converted from VATS to open but you avoided pneumonectomy? Do you know that number?

Dr Yang. In terms of the number of patients who underwent conversion that led to a sleeve lobectomy, we do not have that data and that is a limitation. However, to your point, the learning curve for complex VATS procedures is based on the experience of the specific surgeon, and we do think that as surgeons become more experienced with complex VATS cases, especially VATS sleeve lobectomies, complex hilar dissections, they should have the technical skills to feel comfortable performing a VATS pneumonectomy. At our institution and the other 2 institutions, the priority was for a parenchymal-sparing lung procedure. So the priority would always be VATS sleeve, open sleeve, over a VATS pneumonectomy.

Dr Luketich. Were you able to look at the final gross pathology of the VATS pneumonectomies to determine if there were any that came out that you subsequently said, hey, we might have dropped the ball on this one; maybe if we would have opened we would have saved the pneumonectomy? Was that possible based on the final path or the gross path?

Dr Yang. We currently don't have those data, but that's something certainly we can look at.

Dr Luketich. My last comment is about the number of N2 patients. We are always concerned to have intraoperative N2 found, even at lobectomy. It seemed like the rate of N2 was a little on the high side for patients subsequently receiving a pneumonectomy. I didn't see exactly how many patients had a mead beforehand, but do you think that number is high on the total number of pneumonectomies that actually had N2 at final path, and in reviewing your data on that, did some of those patients have a negative mead or were those the ones that maybe should have had a mead?

Dr Robert J. Cerfolio (*New York, NY*). Or endobronchial ultrasound (EBUS).

Dr Yang. To your point, we don't have that current data, but at our institution our common practice is for patients to get a positron emission tomography (PET) scan followed by EBUS; if there is N2 disease, they are then to get induction chemotherapy followed by repeat restaging with mediastinoscopy followed by resection.

Alternatively, patients may get a PET followed by EBUS followed by induction chemotherapy, then VATS restaging and followed by resection, if considered operable candidates.

Now, there were definitely patients with N2 disease that were excluded from this study. Overall, of the cohort that you mentioned, 12% of VATS patients did have pathologic N2 and 20% in the open group had pathologic N2. Half of those were actually unsuspected N2s, so they were clinical N0, N1, and then on final path were found to have pathologic N2.

Dr Cerfolio. Single station?

Dr Yang. Likely single station.

Dr Cerfolio. Okay, so microscopic single station.

Dr Yang. We don't have that level of detail with regard to the data, but we suspect that the patients who had clinical N2 and then on final pathology had pathologic N2 were probably patients who received induction chemotherapy and on restaging did not have any evidence of N2 disease, who then underwent their resection, and then on final path had microscopic N2 disease.

Dr Luketich. My last question is on blood loss. Many times we point to one of the advantages of minimally invasive surgery is that we lower the blood loss consistently. It didn't seem like that was the case here. Do you have an explanation for why the blood loss was not less in the VATS group?

Dr Yang. Again, to your point, the learning curve was something we didn't formally assess. Preliminarily, in our discussions with all 3 institutions, it does look like as surgeons became more familiar and comfortable with this technique they tackled more difficult cases, which may in part explain why we did not see any significant difference in blood loss between surgical approaches.

Dr Scott Swanson (*Boston, Mass*).

Excellent study and presentation. To my knowledge, this is the first example where a minimally invasive operation was no better than an open operation, and I assume that's because physiology trumps exposure, but I would have thought with pain-related issues you would still see a benefit, but maybe the magnitude of the

pneumonectomy overwhelmed that. Do you have any comment on that? I am kind of surprised. I also think the mortality was a little higher than I would have expected. Do you have any sense of that or is that just what you think it ought to be?

Dr Yang. Thank you, Dr Swanson. With regard to your first question, after multivariable analysis and in propensity score-matched analysis, there actually were no differences in survival between the 2 groups, although the curves do show quite a bit of a difference, but that's probably due to different factors that we didn't control for in our analysis.

One thing that we didn't do that we can do in the future is perform a competing risks analysis and look at what the contribution is of noncancer specific mortality to survival. The Memorial group recently published in the *Annals of Surgery* a study showing that minimally invasive surgery lobectomy was associated with decreased, noncancer-specific mortality after doing a competing risks analysis.

Finally, with regard to the perioperative mortality rate, in going over the literature, we think it's probably around where you might expect it to be. We looked at about 15 different studies evaluating pneumonectomy after induction therapy and their perioperative mortality rates. The rate in our study is within the range of where we would expect it to be.

Dr Swanson. That's great. My first question was really about the perioperative outcomes, length of stay, readmission rates, things like that. You usually see a significant benefit with VATS over open, and they were identical, so I assume because the physiology of taking a whole lung out creates its own issues whether you do it minimally invasive or not. Do you have any thoughts about why you didn't see a benefit early on with length of stay, pain-related issues, morbidity in that group?

Dr Yang. Compared with a lobectomy, the adverse physiologic impact of a pneumonectomy may affect certain outcomes such as perioperative morbidity and length of stay more significantly than the impact of the surgical approach. In this study, we did not look at other important outcomes such as chronic pain scores, extent of narcotic use, length of time to return to work, and it will be important to look at these other measures in future studies.

Dr Joseph B. Shrager (*Stanford, Calif*). I am going to pile on a bit on something that Jim started to allude to. It's avoiding the pneumonectomy that you can do open that most of us would have a hard time doing VATS. When you look at your data, you have on univariate analysis a better survival for those undergoing VATS than open, and that's because you are operating in patients who basically have a lower stage or lower tumor size or something along those lines, who, open, would not have had a pneumonectomy. So I

think your data bear out that concern, unless you have some other way to explain that finding.

So, for example, a tumor that's nearly inseparable from the pulmonary artery that if you get proximal and distal control open, which all of us can do open, you can often get that tumor off the pulmonary artery and avoid a pneumonectomy. You can't do that dissection thoracoscopically. Maybe there are 2 people in the world who can, but it's very difficult. Similarly, sleeve lobectomies, yes, there are some people who have done some sleeves by VATS, but it's not going to happen in 99% of places, and so you are going to have patients receiving pneumonectomies who didn't need a pneumonectomy.

Dr Cerfolio. Okay, so I am going to disagree with you so Tommy gets a chance.

Dr Shrager. Obviously there are people in this room who disagree with me, but that's why we are here.

Dr Cerfolio. But you can get proximal control with VATS and the robot; you can do a vascular bronchial sleeve.

Dr Shrager. You can, but when you are in the midst of doing a difficult operation, 99% of people are going to take the lung out in the middle of trying to do that.

Dr Cerfolio. We shouldn't be taking the lung out.

Dr Thomas A. D'Amico (*Durham, NC*). I would say that you can get proximal control of the artery and you can assess whether it's a sleeve or not. Over the period of time, I personally did more sleeves than pneumonectomies, and I don't remember taking a specimen out and saying, damn, I could have done a sleeve on this. So that's just my response.

You're right, it's not easy, but it can be done. And I worked a long time before I did my first pneumonectomy to do all the dissection and then opening and determining did I do enough dissection to say this is a pneumonectomy or not. Todd was doing them many years before I said okay, but I learned how to do it by doing all the dissection and then opening and feeling and saying, yes, it's a pneumonectomy.

Dr Cerfolio. I think we are concluded. The point is, do what you need to do *not* to do a pneumonectomy. If you can't do it thoracoscopically, do it open. I think the robot makes it easier. There is an innovation technique with VATS you can do with the robot to put a tourniquet on the main pulmonary artery, it's incredibly safe, proximally and distally. All of us in this room can do bronchovascular, bronchus and vascular, sleeves in a minimally invasive platform. If you can't, you open, because the worst thing in the world is to do a pneumonectomy.

Thank you. Tell us when you come back what it is in a year, you will see an advantage to VATS, and look at right versus left, which you didn't show us.

FIGURE E1. This bar graph demonstrates the conversion rate over 3 time periods contained in the study: 2000 to 2005, 2006 to 2010, and 2011 to 2016. VATS, Video-assisted thoracoscopic surgery.

TABLE E1. Characteristics of patients converted from video-assisted thoracoscopic surgery to open

Characteristic	Patients (n = 23)
Female sex (n, %)	9 (39)
Age (mean ± SD) (y)	65.6 ± 9.7
Ethnicity (n, %)	
White	16 (70)
Black	1 (4)
Hispanic	0 (0)
Native American	0 (0)
Asian	1 (4)
Middle Eastern	1 (4)
Unknown	4 (17)
FEV1 (mean ± SD) (% predicted)*	78.7 ± 25.7
DLCO (mean ± SD) (% predicted)†	79.2 ± 20.7
History of diabetes (n, %)	2 (9)
Hypertension (n, %)	10 (43)
COPD (n, %)	6 (26)
Congestive heart failure (n, %)	0 (0)
Coronary artery disease (n, %)	4 (17)
Stroke (n, %)	0 (0)
Pulmonary embolism (n, %)	0 (0)
History of smoking (n, %)	22 (96)
Smoking pack y (mean ± SD)	48.2 ± 31.1
Neoadjuvant chemotherapy (n, %)	8 (35)
Neoadjuvant radiation (n, %)	4 (17)
Surgical laterality (n, %)	
Left	7 (30)
Right	14 (61)
Unknown	2 (9)
Operative year (n, %)	
2000-2005	7 (30)
2006-2010	11 (48)
2011-2016	5 (22)

SD, Standard deviation; FEV1, forced expiratory volume in 1 second; DLCO, diffusing capacity of the lung for carbon monoxide; COPD, chronic obstructive pulmonary disease. *Data only available for 22 of 23 patients. †Data only available for 21 of 23 patients.

TABLE E2. Multivariable logistic regression analysis of predictors of conversion from video-assisted thoracoscopic surgery to open pneumonectomy

Characteristic	Odds ratio (95% CI)	<i>P</i> value
Tumor size	1.00 (0.77-1.29)	.98
Pathologic N stage		
0	Ref (Ref)	Ref
1	1.18 (0.26-5.31)	.83
2	5.32 (0.88-32.03)	.07
Laterality		
Left	Ref (Ref)	Ref
Right	3.18 (0.88-11.59)	.08
Induction therapy	0.78 (0.18-3.36)	.74

CI, Confidence interval.