Thoracoscopic lobectomy is associated with lower morbidity than open lobectomy: A propensity-matched analysis from the STS database

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Background: Several single-institution series have demonstrated that compared with open thoracotomy, video-assisted thoracoscopic lobectomy may be associated with fewer postoperative complications. In the absence of randomized trials, we queried the Society of Thoracic Surgeons database to compare postoperative mortality and morbidity following open and video-assisted thoracoscopic lobectomy. A propensity-matched analysis using a large national database may enable a more comprehensive comparison of postoperative outcomes.

Methods: All patients having lobectomy as the primary procedure via thoracoscopy or thoracotomy were identified in the Society of Thoracic Surgeons database from 2002 to 2007. After exclusions, 6323 patients were identified: 5042 having thoracotomy, 1281 having thoracoscopy. A propensity analysis was performed, incorporating preoperative variables, and the incidence of postoperative complications was compared.

Results: Matching based on propensity scores produced 1281 patients in each group for analysis of postoperative outcomes. After video-assisted thoracoscopic lobectomy, 945 patients (73.8%) had no complications, compared with 847 patients (65.3%) who had lobectomy via thoracotomy ($P < .0001$). Compared with open lobectomy, video-assisted thoracoscopic lobectomy was associated with a lower incidence of arrhythmias [n = 93 (7.3%) vs 147 (11.5%); $P = .0004$], reintubation [n = 18 (1.4%) vs 40 (3.1%); $P = .0046$], and blood transfusion [n = 31 (2.4%) vs n = 60 (4.7%); $P = .0028$], as well as a shorter length of stay (4.0 vs 6.0 days; $P < .0001$) and chest tube duration (3.0 vs 4.0 days; $P < .0001$). There was no difference in operative mortality between the 2 groups.

Conclusions: Video-assisted thoracoscopic lobectomy is associated with a lower incidence of complications compared with lobectomy via thoracotomy. For appropriate candidates, video-assisted thoracoscopic lobectomy may be the preferred strategy for appropriately selected patients with lung cancer. (J Thorac Cardiovasc Surg 2010;139:366-78)

Thoracoscopic lobectomy, also referred to as video-assisted thoracoscopic surgery (VATS) lobectomy, is associated with many outcome advantages compared with lobectomy by thoracotomy.[1-11] Recently, it has been proposed that surgical outcomes are superior with thoracoscopic lobectomy, based on analysis of postoperative complications in single institutional series.[12-14] However, to date there is no large randomized trial comparing VATS lobectomy to lobectomy by thoracotomy.

In the absence of robust data from phase III trials, we queried the Society of Thoracic Surgeons (STS) General Thoracic Database (STS-GTD) to compare the postoperative mortality and morbidity following open and thoracoscopic lobectomy. A propensity-matched analysis using a large national database may enable a more powerful and comprehensive comparison of postoperative outcomes.

PATIENTS AND METHODS

Data Source

The STS has maintained a prospective database of patients having cardiothoracic surgery in the United States since 1987 with the database expanded in 1999 to include general thoracic surgery operations. At the time of the latest report, there were more than 80 participating sites (hospitals, group practices, or individual surgeons). Harvested data are maintained and analyzed by the Duke Clinical Research Institute in compliance with the Health Insurance Portability and Accountability Act of 1996. Variables are collected on a standardized data form that includes information about patient demographics, medical history, surgical procedures, cancer staging, and outcome (http://www.ctsnet.org/file/ThoracicDCFV2_07_Nonannotated.pdf). Institutional Review Boards of each participating site approved the use of this database for quality improvement research. The collection and maintenance of the general thoracic surgery portion of the database has been described elsewhere.[15,16]

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Abbreviations and Acronyms

STS = Society of Thoracic Surgeons
STS-GTD = Society of Thoracic Surgeons General Thoracic Database
VATS = video-assisted thoracoscopic surgery

Patient Population

The study population consists of patients having lobectomy as the primary procedure at STS-participating hospitals between January 1, 2002, and December 31, 2007. All data were collected using STS-GTSD 1.30, 1.31, 2.06, 2.061, and 2.07 data collection forms. Patients were excluded from the study if they had prior thoracic surgery, a pulmonary procedure other than lobectomy, an approach other than thoracoscopy and thoracotomy was listed, if both thoracoscopy and thoracotomy were listed as the approach, and if data were missing on age (6 patients, 0.13% excluded from analysis) and gender (17 patients, 0.27% excluded from analysis). Six thousand three hundred twenty-three patients were identified (5042 having thoracotomy, 1281 having thoracoscopy; Appendix Table 1). The distribution of techniques used for lobectomies performed during that time interval is shown in Figure 1.

Data Collection and Statistical Model

Data collected for each patient included continuous variables [age at time of surgery, body mass index with missing values (9.2% missing) entered according to gender-specific median values, forced vital capacity as a percent of predicted with missing values (27.11% missing) entered according to median values, forced expiratory volume in 1 second as a percent of predicted with missing values (22.81% missing) entered according to median values, carbon monoxide diffusing capacity as a percent of predicted with missing values (42.15% missing) entered according to median values]; binary variables (0% missing) with all missing values defaulted to ''no'' per the STS database [hypertension, preoperative thoracic radiation therapy, congestive heart failure, coronary artery disease, peripheral vascular disease, preoperative steroid use steroid, current smoker (patient smokes or quit less than 1 month), cerebrovascular disease, diabetes, and renal insufficiency (dialysis or creatinine level greater than 2)]; and categorical variables [Zubrod score (5.05% missing), American Society of Anesthesiologists Risk Scale (7.92% missing), status (clinical status of the patient at the time of the primary surgical procedure; 3.67% missing), and clinical (43% missing) and pathologic cancer stage (23% missing)]. Clinical stage was not included in the model due to the significant amount of missing data. Missing data variables were treated as above to limit the introduction of bias by their exclusion.

Propensity scores were estimated using a logistic model including the following variables: age, gender, Zubrod score, American Society of Anesthesiologists Risk Scale, body mass index, hypertension, coronary artery disease, congestive heart failure, renal insufficiency, diabetes, current smoker, preoperative chemotherapy or radiotherapy, cerebrovascular disease, steroid use, clinical status, forced vital capacity as a percent of predicted, forced expiratory volume in 1 second as a percent of predicted, and carbon monoxide diffusing capacity as a percent of predicted. Patients were then matched using a Greedy 5 to 1 digit matching algorithm.[17] Missing values in Zubrod score, American Society of Anesthesiologists Risk Scale, and clinical status were kept as separate levels. Standardized difference $[(X_2 - X_1)/((S_2^2 + S_1^2)/2)^{1/2}$, where X_1 and X_2 are samples means in the thoracotomy and groups, respectively, and $S_2^2 + S_1^2$ are the sample standard deviations] was used to assess significance in differences of preoperative variables as well as clinical and pathologic staging between the 2 groups (>20 and <−20 being significantly different). Standardize difference was used rather than *P* value as it has been shown by others to not be sensitive to sample size, as *P* value is, and hence better for propensity matching.[18] Matching based on propensity scores produced 1281 patients in each group for analysis of postoperative outcomes (Table 1). Postoperative outcomes analyzed for each group were assessed for significance (*P* values) based on McNemar tests (matched comparison) or Pearson chi-square (unmatched comparison) for categorical outcomes and Wilcoxon signed–rank tests for continuous outcomes with significance adjusted for Bonferroni correction where needed (Table 2). Postoperative outcomes as well as clinical and pathologic staging of the unmatched cohort of 6323 patients can be found in the appendix for comparison (Appendix Tables 2–5). Analysis was performed using S-Plus 6 (Insightful Corp, Seattle, WA) and SAS 9.1 (SAS Institute, Cary, NC).

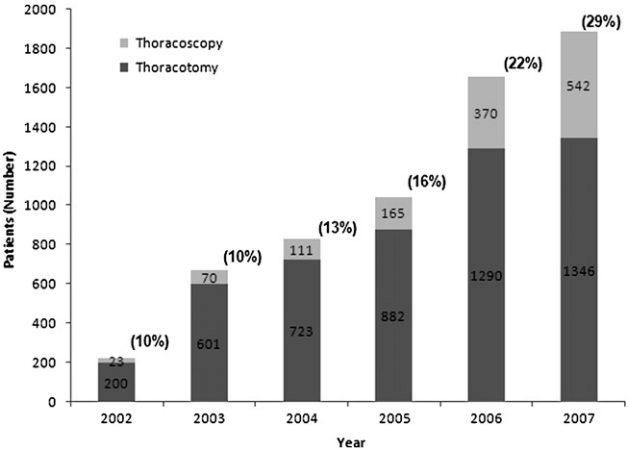

FIGURE 1. Lobectomy by thoracotomy or thoracoscopy by year in Society of Thoracic Surgeons (STS) general thoracic database.

RESULTS

Patient Characteristics

The baseline characteristics of the 1281 patients in each group who were derived by propensity matching from the initial cohort of 6323 patients are shown in Table 1. A total of 83 centers participating in the STS-GTD contributed patients to these matched groups (70 having VATS, 83 having thoracotomy). The contribution from each center can be found in Appendix Table 2. As designed, the baseline characteristics of the 2 cohorts are statistically similar for the preoperative variables used for propensity matching.

The clinical and pathologic stages for the matched cohorts are shown in Table 2. Clinical staging information was missing in a large number of patients in both groups including 430 patients (33.6%) who had VATS lobectomy and 591 patients (46.1%) who had an open lobectomy. There was no statistically significant difference in the pathologic stage distribution between the 2 groups, with the majority of lobectomies performed for pathologic stage I disease. Thus, although clinical and pathologic stages were not included in the propensity matching analysis, the final pathologic stage distribution in the 2 groups is similar.

Perioperative Mortality and Morbidity

Analysis of the propensity-matched groups for postoperative outcomes demonstrated that VATS lobectomy was associated with significantly lower morbidity: 945 patients

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TABLE 1. Characteristics of patients having lobectomy (matched)

	Thoracotomy (n = 1281)	Thoracoscopy (n = 1281)	Standardized difference*
Demographics			
Age			
Median	66.00	66.00	2.26
25th	57.00	58.00	
75th	74.00	74.00	
Mean ± SD	64.83 ± 12.1	65.10 ± –12.1	
Gender			
Male	549 (42.86%)	540 (42.15%)	
Female	732 (57.14%)	741 (57.85%)	1.42
Preoperative risk factors			
Zubrod Score			
0	595 (46.45%)	576 (44.96%)	–2.98
1	534 (41.69%)	562 (43.87%)	4.42
2	76 (5.93%)	75 (5.85%)	–0.33
3	32 (2.50%)	29 (2.26%)	–1.53
4	4 (0.31%)	5 (0.39%)	1.32
Missing	40 (3.12%)	34 (2.65%)	–2.80
ASA risk class			
I	59 (4.61%)	49 (3.83%)	–3.88
II	360 (28.10%)	341 (26.62%)	–3.33
III	723 (56.44%)	749 (58.47%)	4.10
IV	41 (3.20%)	47 (3.67%)	2.57
V	2 (0.16%)	1 (0.08%)	–2.28
Missing	96 (7.49%)	94 (7.34%)	–0.60
BMI (kg/m^2)			
Median	25.82	25.69	0.26
25th	23.03	22.97	
75th	29.38	29.30	
Mean ± SD	26.55 ± 5.33	26.56 ± 5.33	
Hypertension			
No	681 (53.16%)	661 (51.60%)	
Yes	600 (46.84%)	620 (48.40%)	3.13
Coronary artery disease			
No	1109 (86.57%)	1097 (85.64%)	
Yes	172 (13.43%)	184 (14.36%)	2.71
Congestive heart failure			
No	1248 (97.42%)	1254 (97.89%)	
Yes	33 (2.58%)	27 (2.11%)	–3.10
Renal insufficiency			
No	1265 (98.75%)	1268 (98.99%)	
Patient has any history of diabetes			
No	1164 (90.87%)	1140 (88.99%)	
Yes	117 (9.13%)	141 (11.01%)	6.23
Current smoker or quit <1 mo Preoperatively			
No	969 (75.64%)	956 (74.63%)	
Yes	312 (24.36%)	325 (25.37%)	2.35
Preoperative chemotherapy			
No	1166 (91.02%)	1164 (90.87%)	
Preoperative x-ray therapy			
No	1212 (94.61%)	1213 (94.69%)	
Yes	69 (5.39%)	68 (5.31%)	–0.35
Peripheral vascular disease			
No	1202 (93.83%)	1204 (93.99%)	
Yes	79 (6.17%)	77 (6.01%)	–0.65
Cerebrovascular history			
No	1178 (91.96%)	1160 (90.55%)	
Yes	103 (8.04%)	121 (9.45%)	4.97
Steroids			
No	1235 (96.41%)	1234 (96.33%)	
Yes	46 (3.59%)	47 (3.67%)	0.42
Clinical status at time of surgery			
Emergent	2 (0.16%)	5 (0.39%)	4.49
Urgent	21 (1.64%)	15 (1.17%)	–3.97
Elective	1241 (96.88%)	1248 (97.42%)	3.28
Missing	17 (1.33%)	13 (1.01%)	–2.90
Pulmonary function tests			
FVC predicted			
Median	89.00	89.00	–1.96
25th	84.00	82.00	
75th	98.00	100.00	
Mean ± SD	90.37 ± 17.0	90.02 ± 18.6	
FEV predicted			
Median	81.00	81.00	–3.31
25th	77.00	73.00	
75th	94.00	97.00	
Mean ± SD	83.88 ± 19.6	83.20 ± 21.5	
DLCO predicted			
Median	73.00	73.00	–1.93
25th	73.00	69.00	
75th	79.00	83.00	
Mean ± SD	75.94 ± 18.7	75.58 ± 18.6	

ASA, American Society of Anesthesiologists Risk Scale; *BMI,* body mass index; *DLCO predicted,* carbon monoxide diffusing capacity as a percent of predicted; *FEV predicted,* forced expiratory volume in 1 second as a percent of predicted; *FVC predicted,* forced vital capacity as a percent of predicted; *SD,* standard deviation. *Standardized difference $= 100(X_2 - X_1)/((S_2^2 + S_1^2)/2)^{1/2}$, X_1 and X_2 are samples means in the thoracotomy and thoracoscopy groups respectively, and $S_2^2 + S_1^2$ are the sample standard deviations. Differences less than –20 and greater than 20 are significant (at least $P < .05$).

(73.8%) of patients who had thoracoscopic lobectomy had no complications, compared with 837 patients (65.3%) of those who had lobectomy by thoracotomy ($P < .0001$). There was no difference in operative mortality (Table 3).

Specific postoperative complications included in the STS-GTSD are also compared in the 2 matched groups (Table 3). Compared with lobectomy via thoracotomy, VATS lobectomy was associated with a lower incidence of overall

TABLE 2. Clinical and pathologic staging of patients having lobectomy (matched)

	Thoracotomy (n = 1281)	Thoracoscopy (n = 1281)	Standardized difference*
Clinical cancer stage			
Missing	591 (46.14%)	430 (33.57%)	–25.87
Stage I A/B	470 (36.69%)	700 (54.64%)	36.63
Stage II A/B	80 (6.25%)	46 (3.59%)	–12.29
Stage III A	44 (3.43%)	28 (2.19%)	–7.56
Stage III B	9 (0.70%)	15 (1.17%)	4.86
Stage IV	15 (1.17%)	17 (1.33%)	1.41
Occult	1 (0.08%)	2 (0.16%)	2.28
Undefined	71 (5.54%)	43 (3.36%)	–10.61
Pathologic cancer stage			
Missing	279 (21.78%)	267 (20.84%)	–2.29
Stage 0	1 (0.08%)	0 (0%)	–3.95
Stage I A/B	676 (52.77%)	783 (61.12%)	16.92
Stage II A/B	162 (12.65%)	106 (8.27%)	–14.32
Stage III A	89 (6.95%)	70 (5.46%)	–6.15
Stage III B	36 (2.81%)	30 (2.34%)	–2.96
Stage IV	21 (1.64%)	14 (1.09%)	–4.71
Undefined	17 (1.33%)	11 (0.86%)	–4.50

*Standardized difference $= 100(X_2 - X_1)/((S_2^2 + S_1^2)/2)^{1/2}$, X_1 and X_2 are samples means in the thoracotomy and thoracoscopy groups, respectively, and $S_2^2 + S_1^2$ are the sample standard deviations. Differences less than –20 and greater than 20 are significant (at least $P < .05$).

pulmonary complications (7.6% vs 12.2%; $P = .0001$). Specific subgroup analysis showed that patients who had VATS lobectomy had significantly fewer reintubations postoperatively compared with those who had lobectomy via thoracotomy.

Similarly, overall cardiovascular morbidity was significantly lower in the VATS lobectomy group (8.3% vs 13.0%, $P = .0002$), with a significant reduction noted in atrial arrhythmias requiring treatment [93 patients (7.3%) vs 147 patients (11.5%), $P = 0.0004$]. There was no difference detected among other cardiovascular complications.

The frequency of blood transfusions was also significantly lower following VATS lobectomy (2.4% vs 4.7%, $P = .0028$). Although the frequency of overall infectious complications was lower after lobectomy, the difference did not achieve statistical significance after Bonferroni adjustment for multiple comparisons.

Operative Time, Chest Tube Duration, and Length of Stay

Operative time, measured from the time of skin incision, was higher for VATS lobectomy, with a median increase in operative time of 30 minutes (median 173 vs 143 minutes, $P < .0001$). Although the frequency of prolonged air leaks (>5 days) were similar for both cohorts (7.57% vs 8.67%, $P = .3531$), VATS lobectomy was associated with earlier chest tube removal (median 3 days vs 4 days, $P < .0001$; Table 4). Length of stay was also shorter by a median of 2 days for those having VATS lobectomy (median 4 days vs 6 days, $P < .0001$).

DISCUSSION

In this study, analyzing the incidence of postoperative complications using a propensity-matched analysis of patients in the STS-GTD, VATS lobectomy is associated with lower postoperative morbidity compared with thoracotomy, with a lower overall complication rate and lower rates of several individual complications, including atrial fibrillation. Although the results of this study do not rise to the level 1 evidence obtained from randomized trials, the propensity-matching analysis used in the current analysis reduces many of the biases inherent in retrospective single-institution case series.

This study suggests that VATS lobectomy should be performed in appropriately selected patients with lung cancer. Notwithstanding a phase II trial conducted by the Cancer and Leukemia Group B (CALGB 39802) demonstrating the safety and feasibility of lobectomy,[19] the acceptance of VATS lobectomy into the national general thoracic practice remains limited. In 2007, nearly 70% of all lobectomies reported to the STS-GTD were still performed via open thoracotomy (Figure 1).[15] The lack of wider national and international application of VATS lobectomy may be due to the relatively steep learning curve required for the procedure, the fact that most practicing surgeons did not learn the procedure in training (including general surgeons who still perform lobectomy),[20] and concerns regarding oncologic efficacy. However, experience with this procedure has demonstrated that it can be taught and practiced safely[2,3,21] and that the operation is at least as oncologically effective.[2,3,22]

The concept that thoracoscopic lobectomy may have a lower complication profile has recently been analyzed in single-institution series including patients having VATS lobectomy and patients having open lobectomy. In 1 study, 122 patients having VATS lobectomy and 122 patients having lobectomy by thoracotomy were compared.[12] Overall, the incidence of postoperative complications was lower in the VATS group (17.2% vs 27.9%, $P = .046$); however, these patients were matched for age and sex only, and there was no significant difference in the incidence of any of the specific complications reported. In another study, limited to the analysis of elderly patients, VATS lobectomy resulted in a significantly lower rate of complications compared with thoracotomy (28% vs 45%, $P = 0.04$).[13] However, this series was limited to patients with clinical stage I non–small-cell lung cancer, and the incidence of several specific complications analyzed individually was not significantly different between the 2 groups. A propensity analysis of a larger group of patients from these series demonstrated a numerical, but not statistically significant, improvement in survival.[23]

In a larger study comparing outcomes of VATS lobectomy compared with thoracotomy, a propensity-matched analysis based on preoperative variables and stage as

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TABLE 3. Postoperative outcomes of patients having lobectomy (matched)

Postoperative outcomes	Thoracotomy (n = 1281)	Thoracoscopy (n = 1281)	*P* value*
Any complication			
No	837 (65.34%)	945 (73.77%)	<.0001†
Yes	444 (34.66%)	336 (26.23%)	
Death (discharge or 30-d)			
No	1268 (98.99%)	1269 (99.06%)	1.0000
Yes	13 (1.01%)	12 (0.94%)	
Pulmonary complications			
Any pulmonary complication			
No	1125 (87.82%)	1184 (92.43%)	.0001†
Yes	156 (12.18%)	97 (7.57%)	
Air leak duration > 5 d			
No	1170 (91.33%)	1184 (92.43%)	.3531
Yes	111 (8.67%)	97 (7.57%)	
Atelectasis requiring bronchoscopy			
No	1239 (96.72%)	1254 (97.89%)	.0722
Yes	42 (3.28%)	27 (2.11%)	
Pneumonia			
No	1225 (95.63%)	1243 (97.03%)	.0758
Yes	56 (4.37%)	38 (2.97%)	
Evidence of adult respiratory distress syndrome			
No	1271 (99.22%)	1272 (99.30%)	1.0000
Yes	10 (0.78%)	9 (0.70%)	
Bronchopleural fistula			
No	1279 (99.84%)	1278 (99.77%)	1.0000
Yes	2 (0.16%)	3 (0.23%)	
Pulmonary embolus			
No	1278 (99.77%)	1278 (99.77%)	1.0000
Yes	3 (0.23%)	3 (0.23%)	
Initial ventilatory support > 48 h			
No	1274 (99.45%)	1275 (99.53%)	1.0000
Yes	7 (0.55%)	6 (0.47%)	
Reintubation			
No	1241 (96.88%)	1263 (98.59%)	.0046†
Yes	40 (3.12%)	18 (1.41%)	
Tracheostomy			
No	1268 (98.99%)	1270 (99.14%)	.8388
Yes	13 (1.01%)	11 (0.86%)	
Other pulmonary event			
No	1221 (95.32%)	1249 (97.50%)	.0042†
Yes	60 (4.68%)	32 (2.50%)	
Cardiovascular complications			
Any cardiovascular complication			
No	1114 (86.96%)	1175 (91.73%)	.0002†
Yes	167 (13.04%)	106 (8.27%)	
Atrial arrhythmia requiring treatment			
No	1134 (88.52%)	1188 (92.74%)	.0004†
Yes	147 (11.48%)	93 (7.26%)	
Ventricular arrhythmia requiring treatment			
No	1274 (99.45%)	1275 (99.53%)	1.0000
Yes	7 (0.55%)	6 (0.47%)	
Myocardial infarct			
No	1280 (99.92%)	1280 (99.92%)	1.0000
Yes	1 (0.08%)	1 (0.08%)	
DVT requiring treatment			
No	1277 (99.69%)	1279 (99.84%)	.6875
Yes	4 (0.31%)	2 (0.16%)	
Other cardiovascular event			
No	1263 (98.59%)	1271 (99.22%)	.1849
Yes	18 (1.41%)	10 (0.78%)	
Hematologic complications			
Any hematologic complication			
No	1213 (94.69%)	1239 (96.72%)	.0158†
Yes	68 (5.31%)	42 (3.28%)	
Bleeding requiring reoperation			
No	1274 (99.45%)	1265 (98.75%)	.0931
Yes	7 (0.55%)	16 (1.25%)	
Postoperative blood transfusion			
No	1221 (95.32%)	1250 (97.58%)	.0028†
Yes	60 (4.68%)	31 (2.42%)	
Other hematology or bleeding requiring therapy			
No	1278 (99.77%)	1279 (99.84%)	1.0000
Yes	3 (0.23%)	2 (0.16%)	
Infection			
Any infection			
No	1233 (96.25%)	1255 (97.97%)	.0141
Yes	48 (3.75%)	26 (2.03%)	
Urinary tract infection			
No	1251 (97.66%)	1265 (98.75%)	.0541
Yes	30 (2.34%)	16 (1.25%)	
Patient experienced empyema requiring therapy			
No	1273 (99.38%)	1280 (99.92%)	.0391
Yes	8 (0.62%)	1 (0.08%)	
Wound infection			
No	1278 (99.77%)	1278 (99.77%)	1.0000
Yes	3 (0.23%)	3 (0.23%)	
Sepsis			
No	1273 (99.38%)	1275 (99.53%)	.7905
Yes	8 (0.62%)	6 (0.47%)	
Other complications			
Any gastrointestinal complication			
No	1256 (98.05%)	1264 (98.67%)	.2800

TABLE 3. Continued

Postoperative outcomes	Thoracotomy (n = 1281)	Thoracoscopy (n = 1281)	*P* value*
Yes	25 (1.95%)	17 (1.33%)	
Any neurologic complication			
No	1272 (99.30%)	1262 (98.52%)	.0755
Yes	9 (0.70%)	19 (1.48%)	
Any miscellaneous complication			
No	1219 (95.16%)	1228 (95.86%)	.4519
Yes	62 (4.84%)	53 (4.14%)	

DVT, Deep vein thrombosis. **P* values are based on McNemar tests. †Significant after Bonferroni adjustment.

performed, comparing 284 patients in each group.[14] In this study, 69% of those who had VATS lobectomy had no complications, versus 51% who had thoracotomy ($P = .0001$). In addition, VATS lobectomy was associated with a lower incidence of atrial fibrillation (13% vs 21%; $P = .01$), less atelectasis (5% vs 12%; $P = .006$), fewer prolonged air leaks (13% vs 19%; $P = .05$), fewer transfusions (4% vs 13%; $P = .002$), less pneumonia (5% vs 10%; $P = .05$), less renal failure (1.4% vs 5%; $P = .02$), shorter chest tube duration (median 3 vs 4 days; $P < .0001$), and shorter length of hospital stay (median 4 vs 5 days; $P < .0001$).[14]

In this study, VATS lobectomy was associated with fewer overall complications, as well as with specific complications that are recognized to have an important impact on cost and outcome. The frequency of postoperative atrial arrhythmias has now been demonstrated to be significantly lower after thoracoscopic lobectomy. Atrial fibrillation is a significant source of morbidity after cardiothoracic surgery and often prolongs hospital stay by requiring the need for extended telemetry monitoring, anticoagulation, or pharmacologic cardioversion.[24,25] The lower incidence of atrial arrhythmias after VATS lobectomy may be due to decreased levels of cytokines and other inflammatory immunodulators released after thoracoscopic techniques compared with thoracotomy.[26]

The results of the current analysis also demonstrate that the incidence of postoperative pulmonary complications were significantly lower after VATS lobectomy (7.6% vs 12.2%). In particular, the need for reintubation was less frequent after lobectomy compared with lobectomy by thoracotomy, but the incidence of other complications was not statistically different in the 2 groups. Although the reason for this reduction is unclear, it may be due to optimal postoperative pain control in the VATS lobectomy group, which has been demonstrated in numerous studies.[4,5,8,9] As the use of epidural anesthesia and postoperative pain scores were not recorded in the STS-GTD, this cannot be confirmed by this study. In addition, thoracoscopic lobectomy is associated with a lower transfusion rate, a lower postoperative infection rate, shorter chest tube duration, and shorter length of stay, compared with thoracotomy by lobectomy.

TABLE 4. Operative time, chest tube duration, and length of stay for patients having lobectomy (matched)

	Thoracotomy (n = 1281)	Thoracoscopy (n = 1281)	*P* value*
Duration from skin incision (min)*			
Median	143.00	173.00	<.0001
Mean ± SD	158.63 ± 73.7	179.53 ± 75.3	
Missing (%)	6.25	5.15	
Chest tube duration (d)			
Median	4.00	3.00	<.0001
Mean ± SD	4.76 ± 3.93	3.65 ± 3.09	
Missing (%)	3.28	8.67	
Postoperative length of stay (d)*			
Median	6.00	4.00	<.0001
Mean ± SD	7.16 ± 7.08	5.31 ± 5.95	
Missing (%)	1.09	3.59	

SD, Standard deviation. **P* values are based on McNemar tests for categorical outcomes and Wilcoxon signed–rank tests for continuous outcomes; significant after Bonferroni adjustment.

The impact of VATS lobectomy on postoperative morbidity in our cohort of 2562 patients may have been underestimated by the relatively young age and the lack of major cardiopulmonary comorbidity in patients in both cohorts. The majority of patients were free of coronary artery disease (>85%), congestive heart failure (>95%), and renal insufficiency (>98%), and both groups had relatively well-preserved pulmonary function. A recent analysis of the Surveillance, Epidemiology, and End-Results (SEER)–Medicare database from 1992 to 2002, showed that patients with resectable lung cancer are now older (median age: 67 years) and more frequently present with significant comorbidities.[26,27] Given these trends, VATS lobectomy may be of even greater benefit in a population that is typically older and with more comorbidities than our study population.[4,28]

The demonstration of reduced complications after VATS lobectomy should have important ramifications in the care of patients after lobectomy. VATS lobectomy is associated with a lower overall incidence of complications, as well as a reduction of several specific complications, suggesting that VATS lobectomy may actually be a safer operation in appropriately selected patients. In addition, the minimally invasive approach should offer important economic advantages, as the management of postoperative complications will significantly increase the cost of surgical management. Furthermore, considering that VATS lobectomy is also associated with a shorter length of stay, the apparent comparative effectiveness of VATS lobectomy is further magnified.

We recognize that there are important limitations to this analysis. Although propensity matching reduces the bias

inherent in a comparison of 2 surgical techniques, it is not equivalent to a prospective, randomized trial. In this voluntary data set, over 10% of patients had missing entry of preoperative variables, including demographics, pulmonary function tests, and clinical stage. In general, patients with missing data were not excluded from analysis to prevent the introduction of an unknown confounder. Clinical stage was not used in the matching process as a significant portion of these data were also missing in both groups, as shown in Table 2. Although there was a statistically higher portion of clinical stage I patients in the VATS group, the proportion of clinical stage I and II patients were statistically similar between the 2 groups, which is the cohort of patients in which VATS lobectomy are typically performed. Although not used in the matching algorithm, there was no difference in overall pathologic stage distribution between the 2 groups. Of note, 2 separate propensity scoring models incorporating clinical and pathologic stage as well as another model excluding patients with missing clinical stage data yielded similar results (data not shown).

Other limitations in our analysis result from weaknesses inherent in any large national database. This includes the inability to discern within the STS-GTD which patients in the thoracoscopy group were converted to thoracotomy intraoperatively. Hence, an intention-to-treat analysis cannot be performed. Our 2 groups to the best of our knowledge represent a cohort that had either VATS or thoracotomy for lobectomy. It is unclear if the 17 patients excluded from the analysis for being listed as both thoracoscopy and thoracotomy represent this group of patients who had intraoperative conversion, as operative notes are not available. If it indeed does, the rate of conversion would be exceedingly low and not consistent with the literature. An additional limitation results that the STS database does not mandate technique and hence variances in VATS techniques such as number and sites of ports, the use of rib spreader, and the extent of mediastinal lymphadenectomy performed cannot be controlled at each participating center. However, no one center contributed disproportionately to the 1281 matched group of patients (Appendix Table 1), with no center contributing more than 99 patients to the VATS group or 131 patients to the thoracotomy group. Hence, the results are not skewed by the results of one center exceptionally facile with VATS techniques. A separate analysis examining risks factors for complications after VATS lobectomy will further assess these factors (hospital type and volume) in VATS outcomes.

Furthermore, as complications are self-reported in the STS database, they may be underreported and hence skew our results. As the trend toward VATS lobectomy is a self-directed effort by surgeons to improve outcomes, an inherent bias may be to minimize complications, facilitate chest tube removal, and hence discharge. Additionally, our analysis also does not include long-term outcomes, as the STS-GTD does not maintain these data. Thus, the long-term effect of the improved postoperative outcomes cannot be determined.

In conclusion, this propensity-matched study of patients in the STS-GTSD found VATS lobectomy to be associated with a lower incidence of multiple postoperative complications compared with lobectomy by thoracotomy, as well as decreased chest tube duration and length of stay. In lieu of a randomized control trial comparing thoracotomy and thoracoscopy for lobectomy, this study provides the best available evidence regarding outcomes after VATs lobectomy. VATs lobectomy may be the preferred strategy for appropriately selected patients with lung cancer.

References

1. Onaitis M, D'Amico TA. Minimally invasive management of lung cancer, *Sabiston and Spencer's Surgery of the Chest.*. Philadelphia: Elsevier Science; 2004.
2. McKenna RJ Jr, Houck W, Fuller CB. Video-assisted thoracic surgery lobectomy: experience with 1,100 cases. *Ann Thorac Surg*. 2006;81:421-5; discussion 425-6.
3. Onaitis MW, Petersen RP, Balderson SS, et al. Thoracoscopic lobectomy is a safe and versatile procedure: experience with 500 consecutive patients. *Ann Surg*. 2006;244:420-5.
4. Demmy TL, Curtis JJ. Minimally invasive lobectomy directed toward frail and high-risk patients: a case control study. *Ann Thorac Surg*. 1999;68: 194-200.
5. Nagahiro I, Andou A, Aoe M, et al. Pulmonary function, postoperative pain, and serum cytokine level after lobectomy: a comparison of VATS and conventional procedure. *Ann Thorac Surg*. 2001;72:362-5.
6. Petersen RP, Pham D, Burfeind WR, et al. Thoracoscopic lobectomy facilitates the delivery of chemotherapy after resection for lung cancer. *Ann Thorac Surg*. 2007;83:1245-9; discussion 1250.
7. Nicastri DG, Wisnivesky JP, Litle VR, et al. Thoracoscopic lobectomy: report on safety, discharge independence, pain, and chemotherapy tolerance. *J Thorac Cardiovasc Surg*. 2008;135:642-7.
8. Whitson BA, Andrade RS, Boettcher A, et al. Video-assisted thoracoscopic surgery is more favorable than thoracotomy for resection of clinical stage I non-small cell lung cancer. *Ann Thorac Surg*. 2007;83:1965-70.
9. Whitson BA, Groth SS, Duval SJ, Swanson SJ, Maddaus MA. Surgery for early-stage non-small cell lung cancer: a systematic review of the video-assisted thoracoscopic surgery versus thoracotomy approaches to lobectomy. *Ann Thorac Surg*. 2008;86:2008-18.
10. Yan TD, Black D, Bannon PG, McCaughan BC. Systematic review and meta-analysis of randomized and nonrandomized trials on safety and efficacy of video-assisted thoracic surgery lobectomy for early-stage non-small-cell lung cancer. *J Clin Oncol*. 2009 [Epub ahead of print].
11. Ohbuchi T, Morikawa T, Takeuchi E, Kato H. Lobectomy: video-assisted thoracic surgery versus posterolateral thoracotomy. *Jpn J Thorac Cardiovasc Surg*. 1998; 46:519-22.
12. Park BJ, Zhang H, Rusch VW, Amar D. Video-assisted thoracic surgery does not reduce the incidence of postoperative atrial fibrillation after pulmonary lobectomy. *J Thorac Cardiovasc Surg*. 2007;133:775-9.
13. Cattaneo SM, Park BJ, Wilton AS, Seshan VE, et al. Use of video-assisted thoracic surgery for lobectomy in the elderly results in fewer complications. *Ann Thorac Surg*. 2008;85:231-6.
14. Villamizar NR, Darrabie MD, Burfeind WR, et al. Thoracoscopic lobectomy is associated with lower morbidity compared to thoracotomy. *J Thorac Cardiovasc Surg*. 2009;138:419-25.
15. Boffa DJ, Allen MS, Grab JD, Gaissert HA, Harpole DH, Wright CD. Data from The Society of Thoracic Surgeons General Thoracic Surgery database: the surgical management of primary lung tumors. *J Thorac Cardiovasc Surg*. 2008;135: 247-54.
16. Wright CD, Gaissert HA, Grab JD, O'Brien SM, Peterson ED, Allen MS. Predictors of prolonged length of stay after lobectomy for lung cancer: a Society of

Thoracic Surgeons General Thoracic Surgery Database risk-adjustment model. *Ann Thorac Surg*. 2008;85:1857-65.
17. Parson LS. Reducing bias in a propensity score matched-pair sample using greedy matching techniques. Proceedings of the Twenty-sixth Annual SAS® Users Group International Conference, Long Beach, CA, 2001.
18. Austin PC. A critical appraisal of propensity-score matching in the medical literature between 1996 and 2003. *Stat Med*. 2007;27:2037-49.
19. Swanson SJ, Herndon JE 2nd, D'Amico TA, et al. Video-assisted thoracic surgery lobectomy: report of CALGB 39802—a prospective, multi-institution feasibility study. *J Clin Oncol*. 2007;25:4993-7.
20. Farjah F, Flum DR, Varghese TK Jr, Symons RG, Wood DE. Surgeon specialty and long-term survival after pulmonary resection for lung cancer. *Ann Thorac Surg*. 2009;87:995-1004; discussion 1005-6.
21. Seder CW, Hanna K, Lucia V, Boura J, et al. The safe transition from open to thoracoscopic lobectomy: a 5-year experience. *Ann Thorac Surg*. 2009;88: 216-25.
22. D'Amico TA. Long-term outcomes after thoracoscopic lobectomy. *Thorac Surg Clin*. 2008;18:259-62.
23. Flores RM, et al. Lobectomy by video-assisted thoracic surgery (VATS) versus thoracotomy for lung cancer. *J Thorac Cardiovasc Surg*. 2009;138:11-8.
24. Mayson SE, Greenspon AJ, Adams S, et al. The changing face of postoperative atrial fibrillation prevention: a review of current medical therapy. *Cardiol Rev*. 2007;15:231-41.
25. Amar D, Zhang H, Park B, Heerdt PM, Fleisher M, Thaler HT. Inflammation and outcome after general thoracic surgery. *Eur J Cardiothorac Surg*. 2007;32:431-4.
26. Whitson BA, D'Cunha J, Andrade RS, et al. Thoracoscopic versus thoracotomy approaches to lobectomy: differential impairment of cellular immunity. *Ann Thorac Surg*. 2008;86:1735-44.
27. Chang MY, Mentzer SJ, Colson YL, Linden PA, Jaklitsch MT, Lipsitz SR, et al. Factors predicting poor survival after resection of stage IA non–small cell lung cancer. *J Thorac Cardiovasc Surg*. 2007;134:850-85.
28. Berry M, Hanna J, Tong BC, Burfeind WR, Harpole DH, D'Amico TA, Onaitis MW. Risk factors for morbidity after lobectomy for lung cancer in elderly patients. *Ann Thorac Surg*. 2009;88:1093-9.

Discussion

Dr Neil Christie *(Pittsburgh, Pa).* I have no conflicts to disclose.

Earlier studies in thoracoscopic lobectomy focused on feasibility and technique. That having been established, there is now an interest to determine if it is superior to the open thoracotomy technique and, as such, should become the standard of care. This paper has demonstrated a significant decrease in perioperative complications and a shortened length of stay with the thoracoscopic approach to lobectomy.

I would now like to ask a few questions. First, all thoracoscopic lobectomy series have a subset of patients in whom conversion to thoracotomy is required, occasionally due to intraoperative complications such as bleeding. In your analysis, it would seem that these conversion cases are not included in the thoracoscopic group, potentially biasing your study in favor of thoracoscopy. Could you please comment on this?

Dr Subroto Paul *(New York, NY).* Excellent question. There were patients who were excluded, 17 patients in total, who had VATS lobectomy as well as thoracotomy listed as a procedure performed. Looking at the STS database, it is difficult to ascertain which patients were conversion cases and trying to keep them as an intent-to-treat analysis. So we did exclude those patients, and these are a pure group of patients who just had completed a VATS lobectomy versus an open thoracotomy lobectomy. It does introduce bias and, hence, why this trial is not the equivalent of a randomized trial with an intention-to-treat analysis.

Dr Christie. My second question is, some authors recommend thoracoscopic lobectomy only for stage I node-negative cancers due to the potential of increased difficulty of resection with enlarged lymph nodes. Your study included patients with stage II and stage III cancer. Were you able to do a subset analysis of outcomes with clinical stage II and stage III lung cancers, and would you recommend the thoracoscopic approach as being optimal in these patients?

Dr Paul. A separate analysis was performed using clinical stage as a preoperative variable and including only clinical stage I and stage II patients, and the outcomes were very similar, with the same rates of lower atrial fibrillation, reintubation.

In terms of the second question, could you elaborate a little bit more?

Dr Christie. In that subset of patients who had more advanced disease and clinical nodal disease, do you think the complication rates would still be lower than that seen with thoracotomy?

Dr Paul. It seems from our data that if you had a VATS lobectomy, even for a higher-stage disease, your complication rates are lower, and that is supported by several other single-institution studies. Further analysis of the data would be needed just to look at that subset.

Dr Christie. My final question is, acknowledging the potential selection bias in your study, would you and your colleagues recommend that a prospective randomized study be undertaken of thoracoscopic lobectomy versus open thoracotomy?

Dr Paul. Well, the gold standard would be to have a randomized trial, but the number of patients that would need to be recruited would be in excess of probably 1000 in each arm to show some of these complications, so it would be difficult to perform and conduct. I don't think it will ever be done, but it probably should be done.

Thank you.

Dr David Cooke *(Sacramento, Calif).* Very good presentation, Subroto.

I have a couple questions. One, did you match the thoracoscopic group and the open lobectomy group with patients having mediastinal lymph node sampling or dissections? The assumption is that most of these patients probably did have mediastinal lymph node sampling or dissection, but from previous studies, it's not 100%. In fact, there is a good percentage of patients who do not have sampling or dissection. That might affect possibly the length of chest tube duration, among other outcomes.

Dr Paul. Excellent question. We are kind of limited by the database, which does not include dissection versus sampling within the study, so that is not included as part of the matching process, and that may have affected the results. I think that is one of the questions that we're trying to get at through indirect means through the STS database.

Dr Cooke. The second question is, did you look at differences in terms of intensive care unit admissions and hospital readmissions between the 2 groups?

Dr Paul. That is also another excellent question. Those are parameters that are not included in the STS database, so we could not look at them.

Dr Raja Flores *(New York, NY).* Nice study, Subroto. I have a word of caution, though. I think when one looks at conversion, it seems as if the ascertainment of the data for the STS

database may be a bit skewed with regard to patients who were converted. If you look at the data, you had 17 patients who had both thoracoscopy and thoracotomy out of 1300. Potentially those are conversions. It's not known for sure. If those are conversions, that number is very small. If you look at the prospective study, the CALGB trial, of surgeons who are technically very facile in doing VATS lobectomy, their conversion rate was 14%. So for the database, I think that's low. And whenever you have a group of patients who are converted, the proper analysis is not to exclude them but to include them in the VATS lobectomy group so as to minimize any bias in favor of VATS. Overall, I think it was an excellent study based on the data available, but I think there are some major limitations with the ascertainment of the data for the database that limit the conclusions of this study.

Dr Paul. I agree with your point. There are some things that were limited by the database in terms of what information we can get out of it.

APPENDIX TABLE 1. Characteristics of patients having lobectomy (unmatched)

	Thoracotomy (n = 5042)	Thoracoscopy (n = 1281)	Standardized difference*
Demographics			
Age			
Median	67.00	66.00	0.93
25th	58.00	58.00	
75th	74.00	74.00	
Mean ± SD	64.99 ± 12.1	65.10 ± 12.1	
Gender			
Male	2439 (48.37%)	540 (42.15%)	
Female	2603 (51.63%)	741 (57.85%)	1.42
Preoperative risk factors			
Zubrod score			
0	2131 (42.26%)	576 (44.96%)	5.45
1	2234 (44.31%)	562 (43.87%)	–0.88
2	274 (5.43%)	75 (5.85%)	1.82
3	91 (1.80%)	29 (2.26%)	3.25
4	22 (0.44%)	5 (0.39%)	–0.72
5	5 (0.10%)	0 (0%)	–4.46
Missing	285 (5.65%)	34 (2.65%)	–15.07
ASA risk class			
I	100 (1.98%)	49 (3.83%)	10.98
II	1237 (24.53%)	341 (26.62%)	4.78
III	2799 (55.51%)	749 (58.47%)	5.97
IV	492 (9.76%)	47 (3.67%)	–24.51
V	7 (0.14%)	1 (0.08%)	–1.85
Missing	407 (8.07%)	94 (7.34%)	–2.75
BMI (kg/m^2)			
Median	26.40	25.69	–10.85
25th	23.59	22.97	
75th	29.80	29.30	
Mean ± SD	27.17 ± 5.84	26.56 ± 5.33	
Hypertension			
No	2418 (47.96%)	661 (51.60%)	
Yes	2624 (52.04%)	620 (48.40%)	–7.29
Coronary artery disease			
No	4211 (83.52%)	1097 (85.64%)	
Yes	831 (16.48%)	184 (14.36%)	–5.86
Congestive heart failure			
No	4920 (97.58%)	1254 (97.89%)	
Yes	122 (2.42%)	27 (2.11%)	–2.10
Renal insufficiency			
No	4918 (97.54%)	1268 (98.99%)	
Yes	124 (2.46%)	13 (1.01%)	–11.07
Patient has any history of diabetes			
No	4380 (86.87%)	1140 (88.99%)	
Yes	662 (13.13%)	141 (11.01%)	–6.52
Current smoker or quit <1 mo preoperatively			
No	3600 (71.40%)	956 (74.63%)	
Yes	1442 (28.60%)	325 (25.37%)	–7.28
Preoperative chemotherapy			
No	4382 (86.91%)	1164 (90.87%)	
Yes	660 (13.09%)	117 (9.13%)	–12.61
Preoperative x-ray therapy			
No	4382 (86.91%)	1213 (94.69%)	
Yes	443 (8.79%)	68 (5.31%)	–13.62
Peripheral vascular disease			
No	4614 (91.51%)	1204 (93.99%)	
Yes	428 (8.49%)	77 (6.01%)	–9.56
Cerebrovascular history			
No	4593 (91.09%)	1160 (90.55%)	
Yes	449 (8.91%)	121 (9.45%)	1.87
Steroids			
No	4860 (96.39%)	1234 (96.33%)	
Yes	182 (3.61%)	47 (3.67%)	0.32
Clinical status at time of surgery			
Emergency	28 (0.56%)	5 (0.39%)	–2.41
Urgent	311 (6.17%)	15 (1.17%)	–26.81
Elective	4484 (88.93%)	1248 (97.42%)	34.16
Missing	219 (4.34%)	13 (1.01%)	–20.72
Pulmonary function tests			
FVC predicted			
Median	89.00	89.00	8.94
25th	81.00	82.00	
75th	95.00	100.00	
Mean ± SD	88.13 ± 16.6	90.02 ± 18.6	
FEV_1 predicted			
Median	81.00	81.00	11.40
25th	72.00	73.00	
75th	90.00	97.00	
Mean ± SD	80.44 ± 18.9	83.20 ± 21.5	
DLCO predicted			
Median	73.00	73.00	11.90
25th	70.00	69.00	
75th	75.00	83.00	
Mean ± SD	72.86 ± 18.7	75.58 ± 18.6	

ASA, American Society of Anesthesiologists Risk Scale; *BMI,* body mass index; *FVC predicted,* forced vital capacity as a percent of predicted; *FEV_1 predicted,* forced expiratory volume in 1 second as a percent of predicted; *DLCO predicted,* carbon monoxide diffusing capacity as a percent of predicted; *SD,* standard deviation. *Standardized difference $= 100(X_2 - X_1)/((S_2^2 + S_1^2)/2)^{1/2}$, X_1 and $X2$ are samples means in the thoracotomy and thoracoscopy groups, respectively, and $S_2^2 + S_1^2$ are the sample standard deviations. Differences less than –20 and greater than 20 are significant (at least $P < .05$).

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APPENDIX TABLE 2. Distribution of lobectomies performed by participating STS center

Center	Thoracotomy (n = 1281)	Thoracoscopy (n = 1281)
1	0	99
2	10	93
3	131	92
4	4	81
5	77	80
6	19	62
7	13	55
8	8	51
9	20	49
10	14	46
11	14	46
12	5	35
13	1	35
14	30	31
15	7	30
16	8	27
17	33	26
18	13	25
19	1	25
20	15	21
21	11	21
22	39	15
23	91	14
24	9	14
25	0	14
26	2	13
27	1	13
28	26	12
29	22	12
30	4	11
31	1	10
32	26	8
33	14	8
34	11	8
35	0	8
36	50	6
37	2	6
38	38	5
39	15	5
40	10	5
41	5	5
42	3	5
43	2	5
44	3	4
45	2	4
46	31	3
47	19	3
48	8	3
49	2	3
50	1	3
51	48	2
52	47	2
53	22	2
54	9	2
55	8	2
56	2	2
57	30	1
58	20	1
59	14	1
60	12	1
61	11	1
62	10	1
63	8	1
64	5	1
65	4	1
66	4	1
67	3	1
68	3	1
69	1	1
70	0	1
71	17	0
72	17	0
73	16	0
74	16	0
75	15	0
76	13	0
77	13	0
78	9	0
79	7	0
80	6	0
81	5	0
82	5	0
83	3	0
84	2	0
85	2	0
86	2	0
87	1	0

STS, Society of Thoracic Surgeons.

APPENDIX TABLE 3. Clinical and pathologic staging of patients having lobectomy (unmatched)

	Thoracotomy (n = 5042)	Thoracoscopy (n = 1281)	Standardized difference*
Clinical cancer stage			
Missing	2261 (44.84%)	430 (33.57%)	–23.25
Stage I A/B	1823 (36.16%)	700 (54.64%)	37.78
Stage II A/B	327 (6.49%)	46 (3.59%)	–13.26
Stage III A	221 (4.38%)	28 (2.19%)	–12.35
Stage III B	64 (1.27%)	15 (1.17%)	–0.90
Stage IV	79 (1.57%)	17 (1.33%)	–2.01
Occult	3 (0.08%)	2 (0.16%)	2.94
Undefined	264 (5.24%)	43 (3.36%)	–9.28
Pathologic cancer stage			
Missing	1196 (23.72%)	267 (20.84%)	–6.92
Stage 0	2 (0.04%)	0 (0%)	–2.82
Stage I A/B	2524 (50.06%)	783 (61.12%)	22.40
Stage II A/B	645 (12.79%)	106 (8.27%)	–14.75
Stage III A	375 (7.44%)	70 (5.46%)	–8.04
Stage III B	127 (2.52%)	30 (2.34%)	–1.15
Stage IV	96 (1.90%)	14 (1.09%)	–6.68
Occult	7 (0.14%)	0 (0%)	–5.27
Undefined	17 (1.39%)	11 (0.86%)	–5.03

*Standardized difference $= 100(X_2 - X_1)/((S_2^2 + S_1^2)/2)^{1/2}$, X_1 and X_2 are samples means in the thoracotomy and thoracoscopy groups, respectively, and $S_2^2 + S_1^2$ are the sample standard deviations. Differences less than –20 and greater than 20 are significant (at least $P < .05$).

APPENDIX TABLE 4. Postoperative outcomes of patients having lobectomy (unmatched)

Postoperative outcomes	Thoracotomy (n = 5042)	Thoracoscopy (n = 1281)	*P* value*
Any complication occurred?			
No	3254 (64.54%)	945 (73.77%)	<.0001†
Yes	1788 (35.46%)	336 (26.23%)	
Death (discharge or 30-d)			
No	4973 (98.63%)	1269 (99.06%)	.2199
Yes	69 (1.37%)	12 (0.94%)	
Pulmonary complications			
Any pulmonary complication occurred?			
No	4438 (88.02%)	1184 (92.43%)	.0001†
Yes	604 (11.98%)	97 (7.57%)	
Air leak duration > 5 d			
No	4573 (90.70%)	1184 (92.43%)	.0528
Yes	469 (9.30%)	97 (7.57%)	
Atelectasis requiring bronchoscopy			
No	4860 (96.39%)	1254 (97.89%)	.0073
Yes	182 (3.61%)	27 (2.11%)	
Pneumonia			
No	4824 (95.68%)	1243 (97.03%)	.0278
Yes	218 (4.32%)	38 (2.97%)	
Evidence of adult respiratory distress syndrome			
No	4991 (98.99%)	1272 (99.30%)	.3085
Yes	50 (1.01%)	9 (0.70%)	
Bronchopleural fistula			
No	5026 (99.68%)	1278 (99.77%)	.6274
Yes	16 (0.32%)	3 (0.23%)	
Pulmonary embolus			
No	5019 (99.54%)	1278 (99.77%)	.2676
Yes	23 (0.46%)	3 (0.23%)	
Initial ventilatory support > 48 h			
No	5002 (99.21%)	1275 (99.53%)	.2217
Yes	40 (0.79%)	6 (0.47%)	
Reintubation			
No	4880 (96.79%)	1263 (98.59%)	.0005†
Yes	162 (3.21%)	18 (1.41%)	
Tracheostomy			
No	4975 (98.67%)	1270 (99.14%)	.1735
Yes	67 (1.33%)	11 (0.86%)	
Other pulmonary event			
No	4848 (85.72%)	1249 (97.50%)	.0202
Yes	720 (14.28%)	32 (2.50%)	
CV complications			
Any CV complication occurred?			
No	4322 (85.72%)	1175 (91.73%)	<.0001†
Yes	720 (14.28%)	106 (8.27%)	

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APPENDIX TABLE 4. Continued

Postoperative outcomes	Thoracotomy (n = 5042)	Thoracoscopy (n = 1281)	*P* value*
Atrial arrhythmia requiring treatment			
No	4426 (87.78%)	1188 (92.74%)	<.0001†
Yes	616 (12.22%)	93 (7.26%)	
Ventricular arrhythmia requiring treatment			
No	5003 (99.23%)	1275 (99.53%)	.2461
Yes	39 (0.77%)	6 (0.47%)	
Myocardial infarct			
No	5028 (99.72%)	1280 (99.92%)	.1898
Yes	14 (0.28%)	1 (0.08%)	
DVT requiring treatment			
No	5016 (99.48%)	1279 (99.84%)	.0835
Yes	26 (0.52%)	2 (0.16%)	
Other cardiovascular event			
No	4961 (98.39%)	1271 (99.22%)	.0267
Yes	81 (1.61%)	10 (0.78%)	
Hematologic complications			
Any hematologic complication			
No	4726 (98.39%)	1239 (96.72%)	<.0001†
Yes	81 (1.61%)	42 (3.28%)	
Bleeding requiring reoperation			
No	5008 (99.33%)	1265 (98.75%)	.0381
Yes	34 (0.67%)	16 (1.25%)	
Postoperative blood transfusion			
No	4759 (94.39%)	1250 (97.58%)	<.0001†
Yes	283 (5.61%)	31 (2.42%)	
Other hematology or bleeding requiring therapy			
No	5023 (99.62%)	1279 (99.84%)	.2202
Yes	19 (0.38%)	2 (0.16%)	
Infection			
Any infection			
No	4886 (96.91%)	1255 (97.97%)	.0419
Yes	156 (3.09%)	26 (2.03%)	
Urinary tract infection			
No	4957 (98.31%)	1265 (98.75%)	.2655
Yes	85 (1.69%)	16 (1.25%)	
Patient experienced empyema requiring therapy			
No	5017 (99.50%)	1280 (99.92%)	.0369
Yes	25 (0.50%)	1 (0.08%)	
Wound infection			
No	5023 (99.62%)	1278 (99.77%)	.4388
Yes	19 (0.38%)	3 (0.23%)	
Sepsis			
No	4999 (99.15%)	1275 (99.53%)	.1612
Yes	43 (0.85%)	6 (0.47%)	
Other complications			
Any gastrointestinal complication			
No	4925 (97.68%)	1264 (98.67%)	.0275
Yes	117 (2.32%)	17 (1.33%)	
Any neurologic complication			
No	4943 (98.04%)	1262 (98.52%)	.2567
Yes	99 (1.96%)	19 (1.48%)	
Any miscellaneous complication			
No	4699 (93.20%)	1228 (95.86%)	.0004†
Yes	343 (6.80%)	53 (4.14%)	

CV, Cerebrovascular; *DVT*, deep vein thrombosis. **P* values are based on Pearson chi-square tests. †Significant after Bonferroni adjustment.

APPENDIX TABLE 5. Operative time, chest tube duration, and length of stay for patients having lobectomy (unmatched)

	Thoracotomy (n = 5042)	Thoracoscopy (n = 1281)	*P* value*
Duration of skin incision (min)*			
Median	144.00	173.00	<.0001
Mean ± SD	159.10 ± 74.5	179.53 ± 75.3	
Missing (%)	9.94	5.15	
Chest tube duration (d)			
Median	4.00	3.00	<.0001
Mean ± SD	4.61 ± 4.01	3.65 ± 3.09	
Missing (%)	5.31	8.67	
Postoperative length of stay (d)*			
Median	6.00	4.00	<.0001
Mean ± SD	7.44 ± 7.12	5.31 ± 5.95	
Missing (%)	1.59	3.59	

SD, Standard deviation. *P values are based on Pearson chi-square tests for categorical outcomes and Wilcoxon signed–rank tests for continuous outcomes; significant after Bonferroni adjustment.