Video-Assisted Thoracoscopic Lobectomy for Lung Cancer: Current Practice Patterns and Predictors of Adoption

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Background. **Video-assisted thoracoscopic surgery (VATS) lobectomy has been shown to be a safe, minimally invasive approach for the surgical management of lung cancer. Despite evidence supporting oncologic efficacy, recent reports indicate that less than half of lobectomies are performed by VATS. We examined nationwide lobectomy practice patterns to identify specific predictors for VATS adoption.**

Methods. **Premier hospital data (2010 to 2014) were used to identify open and VATS lobectomy procedures performed for the treatment of primary lung cancer. Propensity score method was used to match VATS and open operations (1:1) on clinical characteristics. Variables associated with VATS lobectomy were assessed by logistic regression to evaluate independent predictors. Secondary outcomes included postoperative complications, readmission, and mortality.**

Results. **Patients with primary lung cancer (n = 17,304) that underwent VATS (n = 6,670, 38.5%) or open (n = 10,634, 61.5%) lobectomy were identified; 6,670 patients in each group were matched for analysis. VATS performance increased significantly from 2010 to 2014, (39.6% versus 43.8%, p = 0.0004), particularly for thoracic surgeons (50.3% versus 54.7%, $p < 0.0001$), those performing 15 or more lobectomies per year (53.6% versus 59.8%, $p < 0.0001$), and for surgeons practicing in the Northeast (54.8% versus 59.9%, p = 0.0001). Independent predictors of VATS utilization included surgeon volume and specialty training, hospital type and size, and region. Multivariate analysis demonstrated a significant association between VATS and surgeon volume, independent of specialty.**

Conclusions. **National rates of VATS lobectomy continue to increase, particularly for thoracic surgeons, high-volume surgeons, and surgeons in the Northeast. Surgeon volume and specialty are strong independent predictors of VATS lobectomy. Efforts that support centralization of care may improve VATS lobectomy rates and decrease the regional variability identified in this analysis.**

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Over the past two decades, video-assisted thoracoscopic surgery (VATS) lobectomy has slowly gained acceptance as a viable surgical approach for lung cancer treatment. During this period, numerous studies have demonstrated that VATS is associated with reduced morbidity and improved quality of life compared with open operation, particularly for early-stage disease and older patients with comorbidities [1–6]. In addition, VATS has been strongly associated with improved postoperative pain control and faster recovery, resulting in shorter hospital lengths of stay compared than traditional thoracotomy [6–8].

Secondary data analyses from The Society of Thoracic Surgery (STS) General Thoracic Surgery Database (GTSD) have demonstrated that the proportion of lobectomies performed by VATS has increased over time, from 8% in 2003 to 44.7% by 2010 [7]. However, recent single-institution case series and a large national database analysis suggest that the rate of VATS adoption for lobectomy may have slowed, with national performance remaining less than 50% [9, 10]. Various patient and tumor-specific characteristics, such as chest wall invasion or superior sulcus tumors, clearly influence a surgeon's decision to perform VATS lobectomy. However, patient selection based on these nonmodifiable factors likely does not account for the slowing rate of VATS utilization demonstrated in recent years. Identification of potentially modifiable factors associated with lower VATS lobectomy rates may help guide efforts to increase VATS adoption.

In the present study, we sought to understand current trends in the performance of lobectomy and to identify specific predictors of VATS utilization. We hypothesize that regional and institutional practice patterns vary widely, and that surgeon-specific factors, such as volume and specialty training, are associated with differing rates of VATS adoption.

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Material and Methods

Data Source

To evaluate our hypothesis, the Premier Perspective Database was queried and analyzed. This nationally representative database contains de-identified clinical and utilization claims from 670 participating hospitals, capturing patient billing records, costs, and coding histories. Premier records represent one of every five discharges in the United States. In total, approximately 36 million inpatient and 250 million outpatient claims have been collected over the past 15 years. The database is maintained by Premier, Inc. (Washington, DC), a national health care performance improvement alliance.

Premier Perspective includes hospital submissions (patient demographic characteristics), hospital characteristics, surgeon characteristics, payer information, Diagnosis Related Groups (DRGs), primary and secondary International Classification of Diseases, Ninth Edition (ICD-9) diagnosis and procedure codes, current procedural terminology codes, and resource utilization (hospital length of stay [LOS] and department-specific billing). Information from the data set is extracted using de-identified Universal Billing forms. Inpatient discharge claims contain a weighted variable that enables records to be adjusted to represent hospital characteristics, geographic region and setting, size, and teaching status. Postoperative complications are identified from ICD-9 diagnosis and procedures codes on inpatient claims.

Variable Definitions

Premier defines surgeon specialty by board certification. Thoracic or cardiothoracic surgeons certified by the American Board of Thoracic Surgery (ABTS) are identified as thoracic. Board-eligible cardiothoracic or American Board of Surgery-accredited general surgeons are categorized as nonthoracic. Each claim contains a single surgeon designation: double-certified cardiothoracic surgeons are identified as thoracic. Urban or rural setting is assigned by census data (2010), with categories defined by population greater than or less than 50,000 people.

Patient Selection

All inpatient discharges between 2010 and 2014 with a primary ICD-9 procedure code for lobectomy of the lung (32.41, 32.49) and a DRG code for major chest procedures (163, 164, 165) were identified. Patient selection was restricted to claims with a primary ICD-9 diagnosis code of lung cancer (162) who underwent elective operation. VATS and open operations were identified using ICD-9 procedure codes 32.41 and 32.49, respectively. Robotic-assisted operations, pneumonectomy, sublobar resection, and chest wall resections were excluded. Surgeon volume (lobectomies /year) was categorized into quartiles based on the median value and interquartile range (<5, 5 to 8, 9 to 15, >15) calculated from the primary study group.

Statistical Analysis of Outcomes Measures

Temporal trends (2010 to 2014) in VATS performance by region, specialty, and surgeon volume were evaluated using a χ^2 test. Propensity score matching (1:1) using patient characteristics (age, sex, race, Charlson Comorbidity Index [CCI] score, payer type) was performed. All Patient-Refined (APR) DRGs severity of illness scale values (minor, moderate, major, and extreme) were included as patient matching variables. APR-DRG is an index of comorbidity unique to the Premier database and is used to account for differences related to an individual's severity of illness or risk of mortality. APR-DRG and CCI both account for patients with congestive heart failure, peripheral vascular disease, cerebrovascular disease, dementia, and liver disease. Generalized Estimating Equation models were used to measure the impact of surgical technique on outcomes, including LOS, readmission, and complications.

Univariate analysis was performed with a *t* test for continuous variables and χ^2 test for categorical variables to evaluate the association of surgeon training and volume, discharge year, individual comorbidities, and hospital characteristics (region, teaching status, urban or rural setting, bed size) on the performance of VATS lobectomy. Explanatory variables that were significant from the univariate analysis were placed in propensity-adjusted multivariate logistic regression models to estimate their association with VATS. Statistical significance was defined as p less than 0.05. Statistical analysis was performed using SAS software version 9.4 (SAS Institute, Cary, NC).

This study protocol was submitted to our institutional review board, and exemption was obtained.

Results

Of the 23,317 lobectomies identified in the database, 20,071 patients had a primary diagnosis of lung cancer. Excluding nonelective procedures (1,262 patients, 5.4% of operations) and robotic operations (1,505 lobectomies, 6.5% of operations), the primary study group consisted of 17,304 patients (6,670 VATS and 10,634 open) (Fig 1). Demographic baseline characteristics are shown in Table 1.

Trends in VATS lobectomy were assessed by region, surgeon specialty, and surgeon volume (Fig 2). During the study period, there was a significant increase in the national rate of VATS lobectomy (39.6% versus 43.8%, $p = 0.0004$). Adoption of VATS increased most dramatically in the Northeast (54.8% versus 59.9%, $p = 0.0001$) compared with other regions, significantly outpacing the national average. Growth in the South mirrored national trends (39.3% versus 43.6%, $p = 0.003$). However, VATS lobectomy rates remained unchanged in the West and Midwest (Fig 2A). Stratified by specialty, thoracic surgeons significantly increased their utilization of VATS for lobectomy (50.3% versus 54.70%, $p < 0.0001$), with essentially no change noted for nonthoracic surgeons (28.3% versus 28.4%, $p = 0.645$) (Fig 2B). In addition, VATS lobectomy rates increased for surgeons performing more than 15 lobectomies per year (53.6% versus 59.8%, $p < 0.0001$) and decreased for surgeons performing fewer than five lobectomies per year (26.3% versus 23.10%,

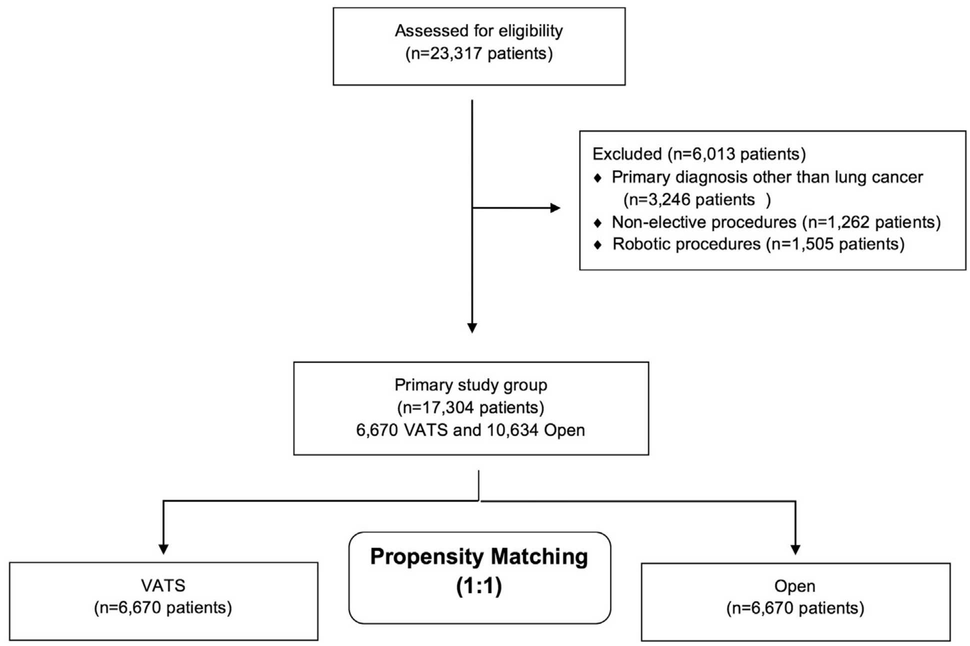


Fig 1. Study patient selection. (VATS = video-assisted thoracoscopic surgery.)

$p = 0.002$). Increased VATS adoption was also noted in the quartile of 9 to 15 lobectomies per year (36.4% versus 38.4%; $p = 0.01$) (Fig 2C).

To identify independent variables that might predict performance of VATS lobectomy, 13,340 patients were matched (1:1, 6,670 in each group) using propensity score methods. No significant differences were noted in patient demographic characteristics after matching (Table 2). Secondary outcome measures were evaluated in the matched cohorts (Table 3). Fewer patients experienced postoperative morbidity in the VATS group (20.69% versus 24.22%, $p = 0.0001$), and no difference in mortality was noted (1.11% versus 1.47%, $p = 0.066$). Postoperative complications occurred less frequently in the VATS group, including pneumonia (4.98% versus 5.97%, $p = 0.012$), wound complications (1.14% versus 1.66%, $p = 0.009$), air leak (14.28% versus 17.90%, $p < 0.0001$), or need for blood product transfusion (1.14% versus 2.77%, $p < 0.0001$). A shorter median LOS was noted after VATS lobectomy (6.0 days versus 7.4 days, $p < 0.001$).

An analysis on temporal trends for VATS lobectomy by region, surgeon specialty, and surgeon volume was repeated in the matched cohort and was noted to be similar to the primary study group. The Northeast consistently demonstrated the highest rate of VATS adoption (49.20% increased to 61.90%, $p < 0.0001$), outpacing national and regional rates. In subgroup analysis, 74.8% of lobectomies in academic Northeast institutions were by VATS.

Multivariate modeling identified a number of independent predictors for VATS lobectomy (Tables 4 and 5). Lobectomies performed in 2014 were 44% more likely to be done by VATS than in 2010 (odds ratio [OR] 1.44, 95% confidence interval [CI]: 1.28 to 1.62, $p < 0.0001$). Resections performed in urban hospitals (OR 2.04, 95% CI: 1.78 to 2.33, $p < 0.0001$) and academic institutions (OR 1.31, 95% CI: 1.20 to 1.43, $p < 0.0001$) were also significantly more likely to be done by VATS. Surgeons performing lobectomies in the Northeast were twice as likely to use a VATS approach than in the South (OR 2.29, 95% CI: 2.06 to 2.57, $p < 0.0001$) and 50% less likely if in the Midwest (OR 0.50, 95% CI: 0.45 to 0.56, $p < 0.0001$) (Table 5).

In addition, thoracic surgeons were 33% more likely to perform lobectomy by VATS than nonthoracic surgeons (OR 1.33, 95% CI: 1.23 to 1.44, $p < 0.0001$). By volume, surgeons performing more than 15 lobectomies per year (n = 185) were nearly four times more likely to use VATS than surgeons performing fewer than five lobectomies per year (n = 1,518; OR 3.78, 95% CI: 3.38 to 4.42, $p < 0.0001$; Table 5). In subgroup analysis, thoracic surgeons performing 9 to 15 lobectomies per year (n = 211; OR 1.28, 95% CI: 1.15 to 1.57, $p = 0.23$) or more than 15 lobectomies per year (n = 140; OR 4.16, 95% CI: 3.61 to 4.79, $p < 0.0001$) were more likely to use VATS than the lowest volume group (<5 lobectomies/year, n = 848). This trend was also identified in the nonthoracic group, with an increased likelihood of VATS lobectomy for nonthoracic surgeons performing 9 to 15 lobectomies per year (n = 97; OR 1.81, 95% CI: 1.59 to 1.97, $p < 0.001$) and more than 15 lobectomies per year (n = 45; OR 3.42, 95% CI: 2.81 to 4.18, $p < 0.0001$) compared with the lowest volume group (n = 670). Although the threshold for high volume was determined by quartiles, we independently evaluated the top 5% highest volume surgeons (>30 lobectomies/year), which as expected, mirrored the trends demonstrated by the high-volume (>15) cohort. Surgeons performing more than 30 lobectomies per year (n = 47) were more than four times more likely to use VATS than surgeons performing fewer than five lobectomies per year

Table 1. Patient Demographic and Hospital Characteristics Before Propensity Score Matching

Patient and Provider Characteristics	Open (n = 10,634)	VATS (n = 6,670)	p Value
Age, mean ± SD, y	67.1 ± 9.4	67.3 ± 9.2	0.019
CCI score, mean ± SD	4.36 ± 2.6	3.84 ± 2.3	<0.0001
Age categories			0.774
<65 years	35.62%	35.43%	
≥65 years	64.41%	64.65%	
Race			0.0001
White	76.11%	77.94%	
Black	7.62%	8.35%	
Hispanic	0.52%	0.22%	
Female sex	49.95%	54.80%	<0.0001
APR severity of illness			<0.0001
Mild	15.25%	21.89%	
Moderate	54.87%	56.67%	
Severe	23.43%	17.60%	
Extreme	6.44%	3.84%	
Insurance			0.408
Medicare	65.22%	64.54%	
Medicaid	5.42%	5.35%	
Managed care	25.17%	26.36%	
Teaching hospital	41.18%	55.53%	<0.0001
Urban setting	88.41%	94.52%	<0.0001
Bed size			<0.0001
≤250	15.71%	12.45%	
250–500	48.68%	35.85%	
>500	35.74%	52.21%	
Provider region			<0.0001
South	45.15%	42.11%	
Northeast	10.87%	27.29%	
Midwest	25.71%	15.18%	
West	18.32%	16.23%	
Physician specialty			<0.0001
Thoracic surgeon	67.45%	72.13%	
Other	32.49%	27.70%	
Comorbidities			
Congestive heart failure	4.71%	4.10%	0.059
COPD	56.12%	48.24%	<0.0001
Diabetes	19.23%	18.95%	0.639
Hypertension	64.72%	100.00%	<0.001
Myocardial infarction	7.45%	7.32%	0.797
Vascular disease	10.92%	10.47%	0.306
Dementia	2.83%	3.25%	0.139
Obesity	10.42%	10.00%	0.397

APR = All Patient-Refined; CCI = Charlson Comorbidity Index; COPD = chronic obstructive pulmonary disease; VATS = video-assisted thoracoscopic surgery.

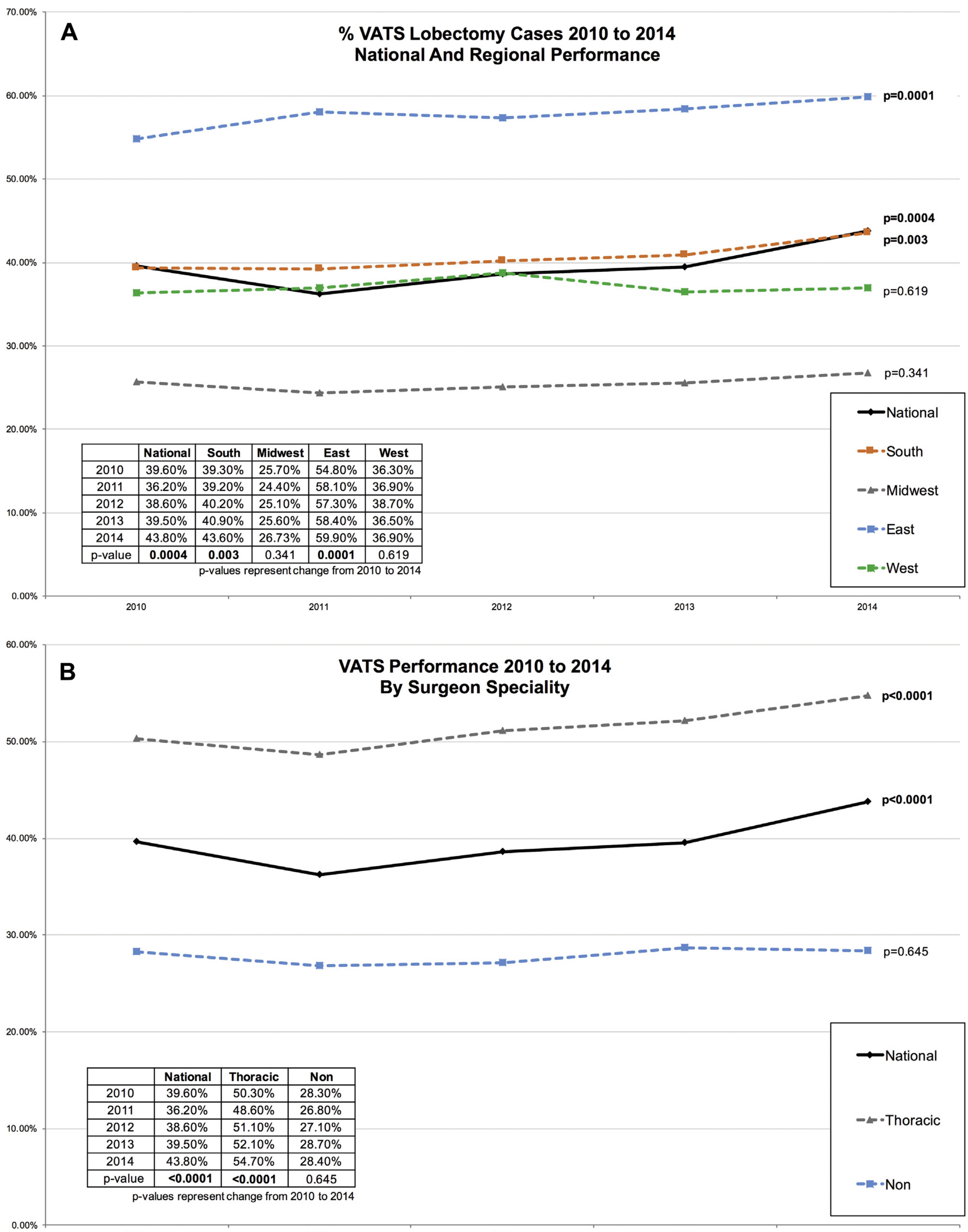
(OR 4.32, 95% CI: 3.71 to 4.97, $p < 0.0001$). Thoracic surgeons performing more than 30 lobectomies per year (n = 32) were even more likely to use VATS (OR 4.76, 95% CI: 3.98 to 5.12, $p < 0.0001$), with a total of 77.39% of operations performed as minimally invasive. In total, the highest volume thoracic and nonthoracic surgeons (n = 185) performed 39.4% of all VATS lobectomies in the matched analysis, with VATS utilization rates of 73.9% and 62.8%, respectively (Table 6).

Comment

Prospective randomized studies that directly compare open and VATS lobectomy are lacking. However, evidence from large case series, database analyses, and meta-analyses have demonstrated favorable short-term outcomes for VATS lobectomy [7, 9–13]. In addition, concerns about the oncologic efficacy of VATS have largely subsided now that long-term data have become available, demonstrating overall and disease-free survival that is comparable with open lobectomy [9]. Similar to reports from The STS GTSD, this study demonstrates continued improvement in the national rate of VATS lobectomy [7]. However, VATS adoption appears to have slowed in specific regions of the country, where VATS lobectomy rates remain less than 40%. In this study, we sought to understand these trends by identifying predictors of VATS utilization. Interestingly, regional disparities and differential practice patterns were uniquely identifiable by surgeon and hospital characteristics.

Surgeon specialty and volume were strongly associated with VATS utilization for lobectomy in our analysis. VATS adoption by thoracic surgeons increased significantly during the study period (50.3% to 54.7%, $p = 0.001$); however, no change was identified for nonthoracic surgeons. Higher volume surgeons also demonstrated a significant increase in VATS adoption (9 to 15 lobectomies/year: 36.4% to 38.4%, >15 lobectomies/year: 53.6% to 59.8%). When stratified by volume and specialty, we found that the highest volume surgeons were the greatest adopters of VATS, regardless of specialty (>15 lobectomies/year; nonthoracic surgeon: 60%, thoracic surgeon: 75%). This trend was even more significant for the top 5% by volume (>30 lobectomies/year), with VATS adoption rates greater than 77%, particularly for thoracic surgeons. In contrast, lower volume surgeons (<9 lobectomies/year) had the lowest VATS utilization rates in 2010 (<5 lobectomies/year: 26.3%; 5 to 8 lobectomies/year: 24.7%) and demonstrated no increase during the study period. These lower volume surgeons performed a significant portion of lobectomies in the primary study group (<5 lobectomies/year: 25% of total volume, <9 lobectomies/year: 47% of total volume), perhaps best explaining the slowed national rate of VATS adoption and failure to surpass the 50% mark in recent years.

A number of hospital characteristics were also found to be strongly associated with performance of VATS lobectomy, including teaching or academic designation, urban location, and hospital size. Interestingly, significant regional disparities were identified, including increased rates of VATS lobectomy in the South and Northeast, without any change noted in the Midwest and West. Although population density, access to academic and larger hospitals, and the number of high-volume and thoracic surgeons varied significantly, region remained an independent predictor of VATS after adjusting for other hospital and surgeon characteristics.



	National	South	Midwest	East	West
2010	39.60%	39.30%	25.70%	54.80%	36.30%
2011	36.20%	39.20%	24.40%	58.10%	36.90%
2012	38.60%	40.20%	25.10%	57.30%	38.70%
2013	39.50%	40.90%	25.60%	58.40%	36.50%
2014	43.80%	43.60%	26.73%	59.90%	36.90%
p-value	**0.0004**	**0.003**	0.341	**0.0001**	0.619

p-values represent change from 2010 to 2014

	National	Thoracic	Non
2010	39.60%	50.30%	28.30%
2011	36.20%	48.60%	26.80%
2012	38.60%	51.10%	27.10%
2013	39.50%	52.10%	28.70%
2014	43.80%	54.70%	28.40%
p-value	**<0.0001**	**<0.0001**	0.645

p-values represent change from 2010 to 2014

Fig 2. Video-assisted thoracoscopic surgery (VATS) performance 2010 to 2014, by (A) national and regional trends, (B) surgeon specialty, and (C) surgeon volume (quartiles).

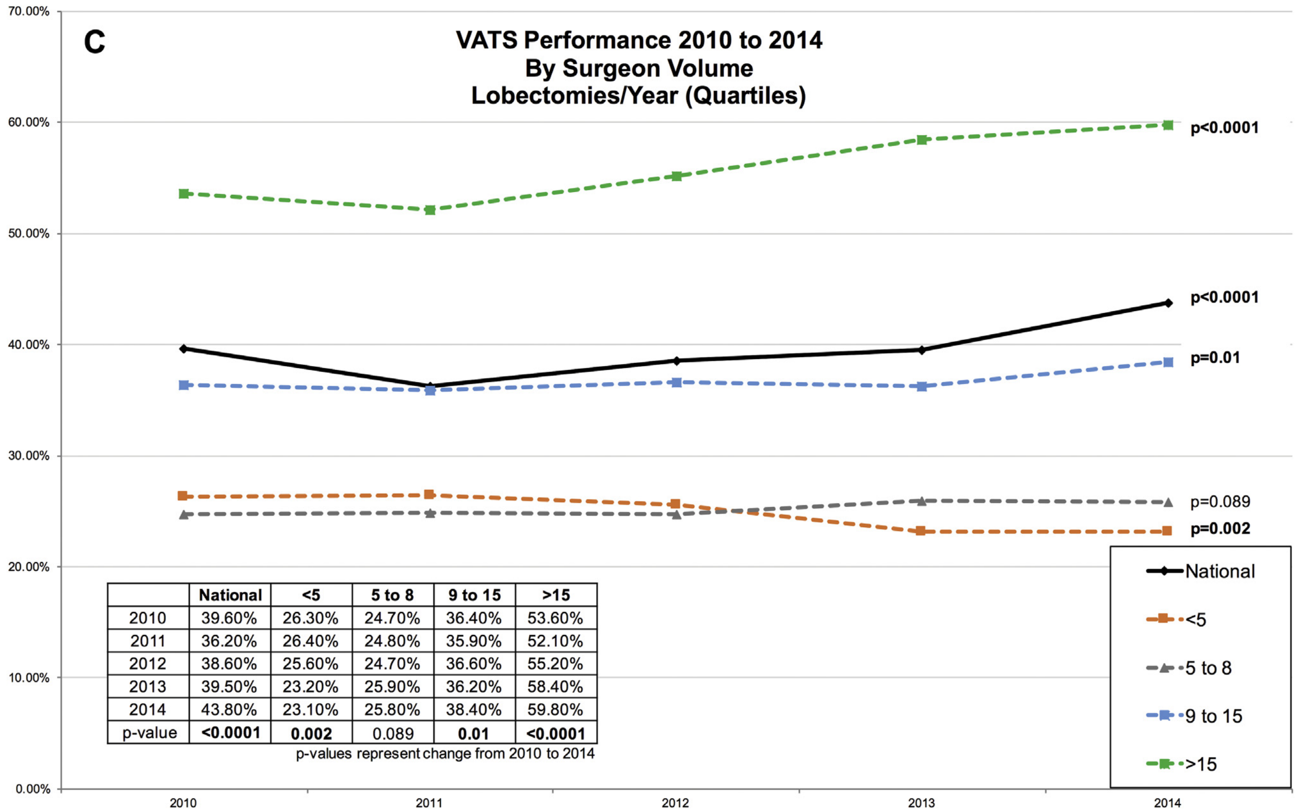


Fig 2. (Continued).

Centralization of care has been proposed as a means to improve patient results in numerous malignancies, based on data identifying superior short-term outcome metrics in higher volume centers and for surgeons who perform complex procedures [14, 15]. Similar improvements have been reported for VATS lung resections, with studies

Table 2. Propensity Matching Based on Clinical Characteristics

Patient and Provider Characteristics	Unmatched			Matched		
	Open (n = 10,634)	VATS (n = 6,670)	*p* Value	Open (n = 6,670)	VATS (n = 6,670)	*p* Value
CCI score, mean ± SD	4.36 ± 2.6	3.84 ± 2.3	<0.0001	3.84 ± 2.2	3.83 ± 2.3	0.673
Age categories			0.774			0.526
<65 years	35.65%	35.47%		34.86%	35.40%	
≥65 years	64.40%	64.66%		65.14%	64.60%	
Race			0.0001			0.990
White	76.12%	77.91%		79.16%	77.96%	
Black	7.62%	8.35%		7.48%	8.35%	
Hispanic	0.52%	0.22%		0.35%	0.40%	
Female sex	49.95%	54.80%	<0.0001	54.42%	54.82%	0.189
APR severity of illness			<0.0001			0.519
Mild	15.25%	21.89%		21.17%	21.89%	
Moderate	54.87%	56.67%		57.21%	56.67%	
Severe	23.43%	17.60%		17.96%	17.60%	
Extreme	6.44%	3.84%		3.66%	3.84%	
Insurance			0.408			0.716
Medicare	65.22%	64.54%		65.41%	64.54%	
Medicaid	5.42%	5.35%		4.93%	5.35%	
Managed care	25.1%	26.3%		25.92%	26.25%	

APR = All Patient-Refined; CCI = Charlson Comorbidity Index; VATS = video-assisted thoracoscopic surgery.

Table 3. Secondary End Points Open Versus VATS

End Point	Open (n = 6,670)	VATS (n = 6,670)	*p* Value
Mortality, 30 days	98 (1.47)	74 (1.11)	0.066
Readmission, 30 days	561 (8.41)	546 (8.18)	0.638
Any postoperative complications	1614 (24.22)	1380 (20.69)	0.0001
Complications			
Acute respiratory failure	428 (6.42)	418 (6.27)	0.722
Pneumonia	398 (5.97)	332 (4.98)	0.012
Wound complications	111 (1.66)	76 (1.14)	0.009
Air leak/pneumothorax	1194 (17.90)	952 (14.28)	<0.0001
Surgical site infection	63 (0.94)	56 (0.83)	0.519
Transfusion requirement	185 (2.77)	76 (1.14)	<0.0001
Myocardial infarction	159 (2.39)	142 (2.13)	0.322
Atelectasis/pulmonary collapse	889 (13.33)	962 (14.42)	0.068
Empyema	148 (2.22)	134 (2.01)	0.399
Bronchopleural fistula	31 (0.46)	19 (0.28)	0.089
Length of stay, days	7.4 ± 4.5	6.0 ± 4.2	<0.001
Operative times, minutes	243 ± 211	246 ± 91	0.312

Data are expressed as mean ± SD or n (%) unless otherwise indicated.

VATS = video-assisted thoracoscopic surgery.

demonstrating decreased perioperative mortality, lower risk of locoregional recurrence, and improved long-term survival comparing high- with low-volume surgeons [16–18]. Centralization could explain some of the regional differences observed in VATS adoption between 2010 and 2014, particularly if the volume of lobectomy operations shifted from low-volume and nonthoracic surgeons to high-volume and thoracic surgeons. Given that surgeon volume was a strong predictor of VATS, we performed a post hoc analysis to determine whether centralization of care, defined by shifts in surgeon volume at both the national and regional levels, was occurring during this study period. We identified that within the primary study group, the number of surgeons in the low-volume quartile decreased from 2010 to 2014, with a reciprocal increase in the number of surgeons within the two highest volume groups. Stratified by region, this trend was consistent in the Northeast and South, with a pronounced shift in the number of lobectomies performed by high-volume surgeons. However, centralization trends by surgeon volume were not identified in the Midwest and West.

Although large academic urban hospitals in the Midwest and West perform VATS lobectomy at rates that are comparable with Northeast hospitals, overall VATS adoption remained stagnant in these regions. Nonthoracic surgeons, often in small community hospitals, perform a considerable proportion of operations in rural communities where patients tend to prefer local care [14, 15]. In addition, access to large, urban, academic hospitals where higher volume thoracic surgeons tend to practice is limited in the Midwest and West compared with the Northeast. Therefore, we postulate that variability in VATS lobectomy may not be due to concerns for

Table 4. Univariate Predictors VATS

Patient and Provider Characteristics	Open (n = 6,670)	VATS (n = 6,670)	*p* Value
Discharge year			<0.0001
2010	21.56%	20.04%	
2011	21.86%	19.04%	
2012	20.39%	20.84%	
2013	19.64%	20.82%	
2014	16.55%	19.25%	
Hospital type			<0.0001
Academic hospital	40.64%	55.80%	
Nonteaching hospital	59.36%	44.20%	
Hospital setting			<0.0001
Urban	86.63%	93.85%	
Rural	13.37%	6.15%	
Bed size			<0.0001
≤250	14.18%	12.64%	
250–500	49.79%	37.30%	
>500	36.03%	50.06%	
Provider region			<0.0001
South	49.69%	46.00%	
Northeast	11.11%	26.58%	
Midwest	23.76%	12.86%	
West	15.44%	14.56%	
Comorbidities			
COPD	50.88%	51.20%	0.799
Congestive heart failure	3.51%	4.08%	0.096
Diabetes	18.11%	19.22%	0.105
Hypertension	64.21%	63.06%	0.171
Myocardial infarction	6.82%	7.41%	0.201
Peripheral vascular disease	7.45%	7.56%	0.818
Dementia	3.00%	6.00%	0.414
Obesity	9.37%	10.18%	0.115
Surgeon specialty			<0.001
Thoracic	60.13%	67.95%	
Nonthoracic	39.87%	32.05%	
Surgeon volume			<0.0001
<4	27.83%	17.69%	
5–8	25.71%	17.83%	
9–15	30.66%	24.71%	
>15	15.80%	39.78%	

COPD = chronic obstructive pulmonary disease; VATS = video-assisted thoracoscopic surgery.

oncologic equivalence or perceived hospital cost, but rather regional surgeon and patient preferences, as well as access to care [19, 20]. Implementation of centralized care may, in theory, be an effective strategy to increase VATS adoption. However, patients are often unwilling or unable to travel outside of their local community to regional surgeons or institutions. Insurance coverage may also be a considerable limitation when seeking out of network care. Therefore, educational efforts directed at lower volume nonthoracic surgeons in rural communities may be needed if increased VATS utilization is expected in these lower performing regions.

Table 5. Multivariate Predictors of VATS

Predictor	Odds Ratio (95% CI)	*p* Value
Discharge year		
2011 vs. 2010	0.94 (0.84–1.05)	0.279
2012 vs. 2010	1.16 (1.04–1.31)	0.009
2013 vs. 2010	1.23 (1.09–1.38)	0.000
2014 vs. 2010	1.44 (1.28–1.62)	<0.0001
Region		
Midwest vs. South	0.50 (0.45–0.56)	<0.0001
Northeast vs. South	2.29 (2.06–2.57)	<0.0001
West vs. South	1.05 (0.94–1.16)	0.366
Hospital characteristics		
Teaching vs. non-teaching	1.31 (1.20–1.43)	<0.0001
Urban vs. rural	2.04 (1.78–2.33)	<0.0001
<250 vs. 250–500 beds	0.59 (0.53–0.66)	<0.0001
<250 vs. >500 beds	0.61 (0.54–0.69)	<0.0001
Surgeon characteristics		
Thoracic vs. nonthoracic	1.33 (1.23–1.44)	<0.0001
Surgeon volume		
4–8 vs. <4	0.97 (0.87–1.08)	0.999
8–15 vs. <4	2.11 (1.93–3.12)	<0.001
>15 vs. <4	3.78 (3.38–4.42)	<0.0001

CI = confidence intervals; COPD = chronic obstructive pulmonary disease; VATS = video-assisted thoracoscopic surgery.

Limitations of the present study are similar to other retrospective reports using large data sets and those derived from hospital administrative data. Coding and documentation errors are possible, although likely equally represented in both cohorts. There is the potential for selection bias due to a lack of random assignment, which we anticipate is reduced by the large sample size. Although this is a large data set with increased statistical power to make conclusions, some important variables that may influence the decision to perform VATS, such as specific patient and tumor characteristics, are not reported and therefore cannot be included in the analysis. We also recognize that surgeon-specific preferences and level of expertise may affect which patients are appropriate candidates for VATS, which cannot be assessed from a retrospective data set. Finally, fellowship-trained thoracic surgeons who perform VATS lobectomy, but are not yet ABTS certified, are included in the nonthoracic group. These surgeons likely represent only a small portion of the nonthoracic group with little impact on these conclusions, given that nonthoracic trends remained stagnant during the study period. However, they may be causally associated with the centralization trends we have identified, as lower volume non–ABTS-certified thoracic surgeons increase their volume and become board certified, the number of surgeons in the higher volume thoracic surgeon quartile will predictably increase, as will rates of VATS lobectomy. Given the lack of considerable improvement in VATS adoption on a national level, we believe that this migration is not an important contributor to the overall trends we have identified and that the concept of centralized care holds true. Important strengths of this database include its large and nationally representative sample of patients with varying patient-, hospital-, and surgeon-specific characteristics.

In conclusion, this study represents the most up-to-date and expansive analysis of VATS lobectomy practice patterns in the United States, with the following three important findings: (1) national rates of VATS lobectomy continue to increase, particularly for thoracic surgeons, high-volume surgeons, and surgeons in the Northeast; (2) surgeon volume is a strong predictor of VATS lobectomy, independent of specialty, and appears to be the predominant driver for increased VATS adoption demonstrated in this study; and (3) shifts in the performance of

Table 6. Multivariate Analysis Open versus VATS Performance by Surgeon Volume (Quartiles), Stratified by Specialty

Surgeon Volume (Lobectomy/Year)	Operations, n (% Total)		OR (95% CI)	*p* Value
	Open	VATS		
All				
≤4	1856 (61.15)	1179 (38.85)	1	…
5–8	1729 (59.54)	1175 (40.46)	0.97 (0.87–1.08)	0.999
9–15	2020 (54.70)	1673 (45.30)	2.11 (1.93–3.12)	<0.001
>15	1065 (28.72)	2643 (71.28)	3.78 (3.38–4.42)	<0.0001
Thoracic				
≤4	997 (58.82)	698 (41.18)	1	
5–8	933 (61.87)	575 (38.13)	0.83 (0.77–1.96)	0.012
9–15	1336 (52.75)	1196 (47.25)	1.28 (1.15–1.57)	0.023
>15	731 (26.02)	2078 (73.98)	4.16 (3.61–4.79)	<0.0001
Nonthoracic				
≤4	859 (64.06)	481 (35.94)	1	
5–8	796 (57.02)	600 (42.98)	1.17 (0.99–1.37)	0.063
9–15	684 (58.91)	477 (41.09)	1.81 (1.59–1.97)	<0.001
>15	334 (37.15)	565 (62.85)	3.42 (2.81–4.18)	<0.0001

CI = confidence interval; OR = odds ratio; VATS = video-assisted thoracoscopic surgery.

lobectomy from low- to high-volume surgeons has resulted in a considerable increase in VATS lobectomy, particularly for the highest performing subgroups. This may be the result of a larger percentage of operations being performed by high-volume VATS surgeon, or because of surgeon shifts from low- to high-volume categories. These findings may be specifically applied to educational efforts targeted at improving national VATS lobectomy rates. Futures studies may expand on this work by evaluating shifts in practice patterns associated with centralization of thoracic cancer care, particularly for lower volume and open surgeons, that may enhance patient access to minimally invasive lung resection.

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