National trends, safety, and effectiveness of minimally invasive concomitant chest wall resection for locally advanced lung cancer

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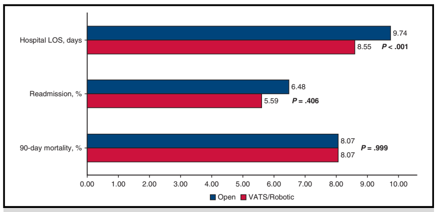
ABSTRACT

Objective: Concomitant chest wall resection for locally advanced lung cancer is traditionally performed via an open approach. The safety and effectiveness of minimally invasive approaches for chest wall resections are unknown.

Methods: We used the National Cancer Database to identify patients undergoing lobectomy/bi-lobectomy with concomitant chest wall resection from 2010 to 2020. We stratified patients into those undergoing a minimally invasive resection (video-assisted thoracoscopic surgery [VATS]/robotic) or open, while accounting for conversions. We also compared VATS with robotic approaches. The main outcomes were length of stay, mortality, readmissions, and overall survival. We used multivariable, Kaplan-Meier and Cox proportional models to identify associations.

Results: Of 2837 patients, 756 procedures (26.6%) were started minimally invasive, of which 23.1% were robotic. There were 237 (31.3%) conversions. Patients undergoing a minimally invasive operation were similar in terms of age (65.2 ± 9.8 years vs 66.0 ± 9.9 years), sex, race, tumor histology, and location (all $P > .05$) but had smaller cancers (5.4 ± 2.6 cm vs 6.2 ± 4.3 cm; $P < .001$) compared with those undergoing open. They also had shorter length of stay (8.6 ± 7.6 days vs 9.7 ± 9.3 days; $P < .001$) but similar unadjusted 90-day mortality (8.2% vs 8.0%; $P = .999$). Neoadjuvant therapy was associated with less minimally invasive approaches (adjusted odds ratio, 0.69; $P \leq .001$). Larger cancers were associated with less minimally invasive operations and greater rates of conversions. However, the robotic approach was associated with lower conversion rates than VATS across all tumor sizes. Overall survival was equivalent.

Conclusions: The use of minimally invasive approaches to concomitant chest wall resection is increasing. Although conversions to open are common, this approach is safe and is associated with shorter hospital stays. Overall survival is equivalent to the open approach. (JTCVS Open 2024;19:311-24)



Comparison of outcomes between open and VATS/robotic approaches.

CENTRAL MESSAGE

The minimally invasive approach to concomitant chest wall resection for locally advanced NSCLC is increasingly used, associated with shorter hospital stay, and has similar survival to open approaches.

PERSPECTIVE

In this first report on the national trends, safety, and effectiveness of minimally invasive concomitant chest wall resection for locally advanced lung cancer, we demonstrate the increasing use of this approach over time, the improved short-term outcomes, particularly with hospital length of stay, and the similar long-term oncologic outcomes compared with open thoracotomy.

Minimally invasive approaches, such as robotic or video-assisted thoracoscopic surgery (VATS), have been increasingly used as the preferred approach in the surgical therapy of non–small cell lung cancer (NSCLC).[1,2] Multiple studies have shown that these minimally invasive approaches to lung cancer are a safe and oncologically effective alternative to open thoracotomy[3,4] and may offer many perioperative advantages in terms of shorter hospital stay, postoperative pain, and perioperative morbidity. Most of these studies pertain to common extents of resection.

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Abbreviations and Acronyms

aHR = adjusted hazard ratio
AJCC = American Joint Committee on Cancer
aOR = adjusted odds ratio
CI = confidence interval
NCDB = National Cancer Data Base
NSCLC = non–small lung cell carcinoma
VATS = video-assisted thoracoscopic surgery

With increasing experience and improvements in multimodality therapy and operative techniques, minimally invasive lung cancer surgery can now encompass more complex and extended resections. One example of this would be a lobectomy with concomitant chest wall resection for a locally advanced NSCLC invading the chest wall. Traditionally, concomitant chest wall resection was performed with an open thoracotomy.

However, minimally invasive concomitant chest wall resection has been reported in isolated case reports and limited case series, demonstrating its feasibility and operative technique.[5-13] The first reported use of the minimally invasive approach was described by Widmann and colleagues.[11] in 2000, demonstrating that the VATS approach permitted accurate, controlled, and complete dissection and resection of lung and chest wall structures. The minimally invasive approach can facilitate chest wall resection from the inside of the chest cavity with direct visualization of ribs without dividing any overlying muscles or spreading ribs,[8] which is believed to result in less postoperative pain and shorter hospital length of stay.[8,14] However, there have not been any large observational studies clarifying the trends in the adoption of the minimally invasive approach to concomitant chest wall resection. In addition, its safety profile and long-term oncologic results are unknown.

In this context, we report the national trends in using minimally invasive approaches to lobectomy/bilobectomy with concomitant chest wall resection for locally advanced NSCLC from the National Cancer Database (NCDB). We examined the safety of this approach compared with traditional thoracotomy and assessed its oncologic effectiveness by examining overall survival. We hypothesized that the trends would show an increase in use, with similar, if not better, short- and long-term outcomes. The findings are important to thoracic surgeons as they continue to push the envelope by incorporating minimally invasive approaches to complex and extended resections and disease presentations.

METHODS

Data Source

We used hospital-based nationally representative data from the NCDB for this study. The NCDB is a prospective national cancer registry maintained by the American College of Surgeons and the American Cancer Society. It collects data from more than 1500 Commission on Cancer–accredited centers across the United States that capture approximately 70% of all newly diagnosed cases of cancer annually and contains more than 34 million patient records.[15] It includes data regarding patient demographics, diagnosis, tumor characteristics, staging, treatment strategy, and perioperative and long-term outcomes. The Loyola University Chicago Institutional Review Board reviewed and approved this research study's proposal deeming it exempt (217151, April 21, 2023).

Patient Population

We included all adult patients aged 18 years or older diagnosed with NSCLC between 2010 and 2020. The starting year for the study was 2010, as the NCDB only started collecting data on surgical approach 2010 onwards. Patients were identified using *International Classification of Disease – Oncology, Third Edition*, location codes for lung cancer (C34.0-34.9). We only included patients who had an extended lobectomy or bilobectomy with concomitant chest wall resection for their lung cancer based on the site-specific surgery code, "46." These patients were defined as having concomitant resection. It is plausible that some patients may have not undergone the resection in an en bloc fashion; we assume this not to be common practice.

Main Exposure and Outcome Variables

The approach of open thoracotomy versus minimally invasive concomitant chest wall resection at time of lobectomy/bilobectomy was the main exposure variable. We stratified patients into those undergoing a minimally invasive resection (VATS/robotic) and those undergoing an open approach. Moreover, we further stratified minimally invasive resection patients into those undergoing a VATS operation and those undergoing a robotic operation. To account for conversions, we analyzed the data using both intention-to-treat and as-treated classifiers. The NCDB does not collect data on the reason for conversion.

The main outcomes of interest were length of stay, 90-day mortality, readmissions, surgical margins, and overall survival. Surgical margins are defined on the final pathology report and collected by the NCDB. Overall survival is defined as the time from diagnosis to death from any cause.

Statistical Analysis

Patient clinical, demographic, and pathologic variables were compared between those who received an open lobectomy/bilobectomy with concomitant chest wall resection versus those who received minimally invasive concomitant chest wall resection using Student *t* tests for continuous variables and Pearson χ^2 for categorical variables as appropriate. We also compared those who underwent a VATS approach versus a robotic approach as above.

To identify associations with conversions, we used multivariable logistic regression modeling to predict the probability of conversions. The variables included in this model were age, sex, race, insurance, comorbidity index, neoadjuvant therapy, tumor size, histology, and American Joint Committee on Cancer (AJCC) analytic stage. We also specifically examined the association between VATS versus robotic approaches on the probability of a conversion over tumor size as a continuous variable. We then plotted the predicted marginal rate for a conversion at each tumor size stratified by the approach.

We next calculated risk-adjusted outcome rates for either approach (open vs minimally invasive) using multivariable logistic regression models for each short-term outcome of interest; namely, readmissions, 90-day mortality, and surgical margins. Hospital length of stay was modeled as a negative binomial regression. As such, there were 4 logistic regression models. All models adjusted for age, sex, race, insurance, comorbidity index, neoadjuvant therapy, tumor size, histology, and AJCC analytic stage. These variables were selected a priori. Each outcome's risk adjusted rate was calculated using the beta coefficients from the respective regression models while holding all other variables constant. To account for clustering within hospitals, we used robust standard errors.

To compare the robotic versus VATS approach, we also calculated risk-adjusted outcome rates using multivariable logistic regression models for each outcome of interest. For this comparison, we used similar models but excluded patients who had an open approach. Similar to the analytic approach used previously, each outcome's risk adjusted rate was calculated using the beta coefficients from the respective regression models while holding all other variables constant.

Finally, we used Kaplan-Meier and Cox proportional hazards survival analyses to estimate overall survival. The Cox model adjusted for minimally invasive approach, age, sex, race, Charlson comorbidity index, neoadjuvant therapy, tumor size, histology, and AJCC analytic stage. All data and statistical analyses were conducted using Stata, version 18.0SE (Stata Corp). All tests were 2-sided using a $P < .05$. Confidence intervals are reported to a 95% confidence level (95% CI).

RESULTS

Of 2837 patients with locally advanced lung cancer requiring a lobectomy/bilobectomy with concomitant chest wall resection, 756 (26.6%) were started minimally invasively. Of those, 23.1% were robotic. Year over year, the use of minimally invasive approaches increased from 13% in 2010 to 53% in 2020, as shown in Figure 1, *A*. Particularly, in more recent years, the rate at which concomitant resections were started and completed in a minimally invasive fashion without conversion had also increased from 8% in 2010 to 36% in 2020. Over time, the robotic approach increased from 7% in 2010 to 45% in 2020, with the rate of completing the operation robotically without conversion rising from 0% to 44% in the same time frame, as shown in Figure 1, *B*. In contrast, VATS use dropped from 93% in 2010 to 55% in 2020, with the rate of completion also dropping from 56% to 25%, as shown in Figure 1, *C*. It appears that the decrease in the open approach is a result of the increase in the robotic approach; while VATS has remained steady, as shown in Figure E1.

When we compared open and minimally invasive approaches, patients were similar in terms of age (65.2 ± 9.8 vs 66.0 ± 9.9), sex, race, insurance, tumor histology, location, and analytic stage. (all $P > .05$) as shown in Table 1. Patients undergoing an open approach had relatively lower Charlson comorbidity scores ($P = .035$). Patients undergoing a minimally invasive approach were more likely to have a smaller tumor (<5 cm) compared with those undergoing an open approach (35.0% vs 46.7%; $P < .001$) and were less likely to receive neoadjuvant therapy (21.9% vs 14.9%; $P < .001$) but slightly more likely to receive adjuvant therapy (37.8% vs 39.8%; $P < .001$).

Table E1 shows the baseline characteristics between VATS and robotic approaches. There were no differences in terms of age (65.8 ± 9.9 years vs 66.6 ± 9.6 years), sex, race, Charlson comorbidity index, insurance, tumor histology, location, stage, multimodal therapy, and surgical margins (all $P > .05$). However, patients in the VATS group were more likely to have larger cancers (≥5 cm) compared with those in the robotic group (55.4% vs 46.3%; $P = .034$).

Of those started minimally invasively, there were 237 (31.3%) conversions to open. Patients who were converted to open were similar in terms of age (65.8 ± 9.8 years vs 66.2 ± 10.0 years), sex, race, Charlson comorbidity score, insurance, tumor histology, location, multimodal therapy, and stage (all $P > .05$), as shown in Table 2. However, those with a large tumor size were more likely to have conversion to open (50.3% vs 59.9%; $P = .014$).

The multivariable logistic regression model predicting minimally invasive approach and adjusting for age, sex, race, Charlson comorbidity score, insurance, receiving neoadjuvant radiation, tumor size, histology, and stage is shown in Table 3. Patients who received neoadjuvant radiation (adjusted odds ratio [aOR], 0.69, 95% confidence interval [CI], 0.55-0.84; $P \leq .001$) or had larger tumors (aOR, 0.62; 95% CI, 0.52-0.75; $P \leq .001$) had lower adjusted odds of starting a procedure minimally invasive. In addition, those with stage II (aOR, 0.74; 95% CI, 0.55-0.99; $P = .040$) were less likely to have a minimally invasive operation. Age, sex, race, insurance, Charlson comorbidity index, and tumor histology were not associated with the approach.

On the multivariable model predicting conversion, only large tumor size (≥5 cm) was associated with conversion to open (aOR, 1.41; 95% CI, 1.01-1.98; $P = .043$) for the overall cohort as shown in Table 3. However, when stratifying by VATS versus robotic, the robotic approach was associated with lower probability of conversion over all tumor size in the unadjusted (Figure 2, *A*) and adjusted analyses (Figure 2, *B*). For example, at a tumor size of 50 mm, VATS was associated with a conversion probability of 38% compared with 18% for a robotic approach at the same tumor size.

On Cox proportional hazard analysis, increasing age (adjusted hazard ratio [aHR], 1.03; 95% CI, 1.02-1.04; $P < .001$), male sex (aHR, 1.20; 95% CI, 1.08-1.32; $P < .001$), a greater Charlson Comorbidity Index score (aHR, 1.26; 95% CI, 1.10-1.44; $P = .001$), increasing tumor size (aHR, 1.01; 95% CI, 1.00-1.00; $P < .001$), and squamous histology (aHR, 1.20; 95% CI, 1.07-1.34; $P = .002$) were associated with worse survival. The minimally invasive approach was not associated with survival when compared with open, as shown in Table E2. Neoadjuvant therapy was associated with improved survival (aHR, 0.75; 95% CI, 0.66-0.84; $P < .001$).

Patients in the minimally invasive group had shorter length of stay (8.6 ± 7.6 days vs 9.7 ± 9.3 days; $P < .001$), similar unadjusted 90-day mortality (8.2% vs 8.0%; $P = .999$), and unadjusted readmission rates (5.7% vs 6.4%; $P = .406$).

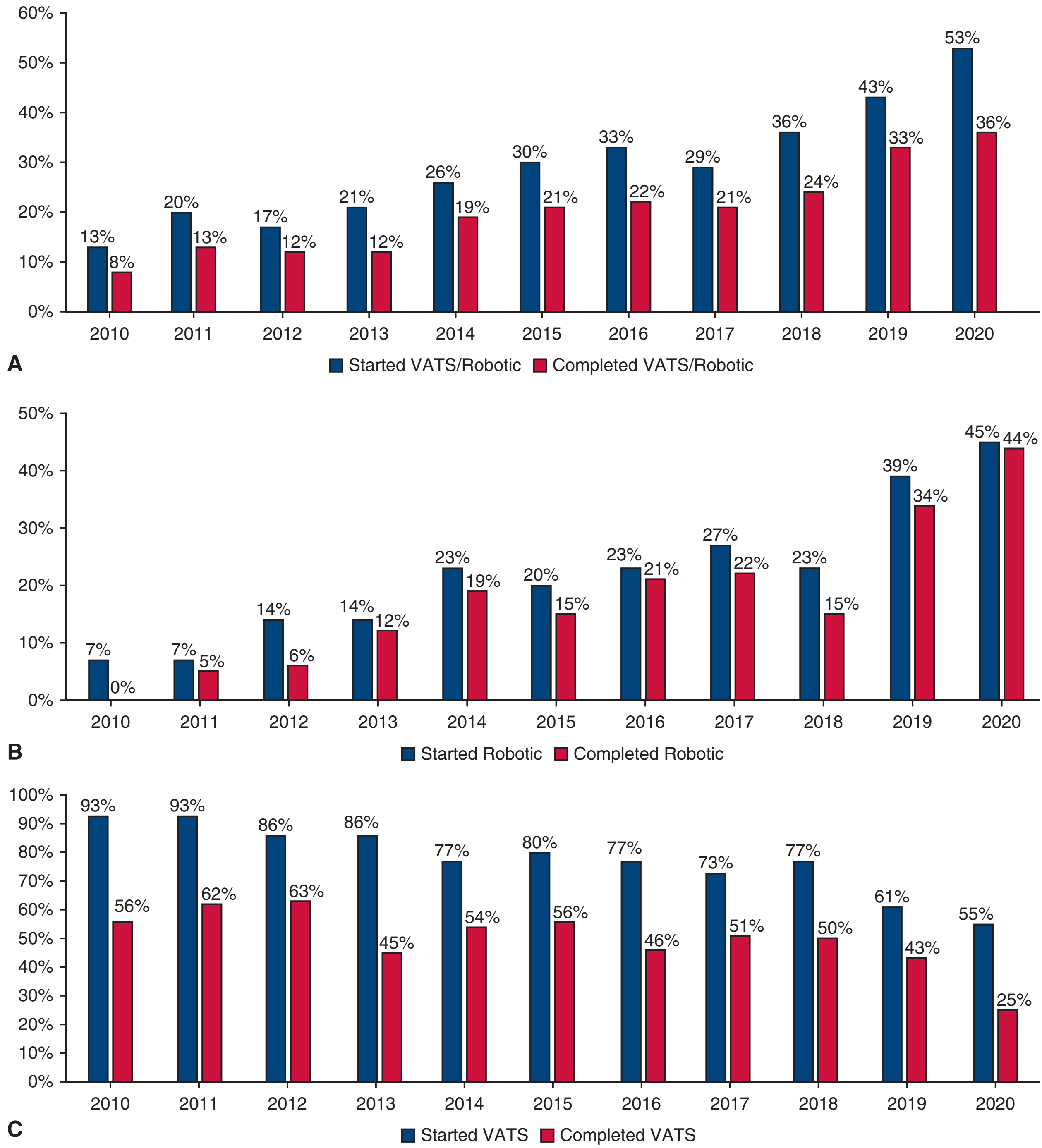

FIGURE 1. Percentage of cases started with a minimally invasive approach versus cases completed over time. A, Minimally invasive, (B) robotic, and (C) VATS. *VATS*, Video-assisted thoracoscopic surgery.

After risk-adjustment accounting for age, sex, race, insurance, comorbidity index, and neoadjuvant therapy, tumor size, histology, and stage, the minimally invasive approach to concomitant chest wall resection was still associated with shorter hospital length of stay (8.6 days vs 9.8 days; $P < .001$), similar readmission rates (5.6% vs 6.5%; $P = .406$), and similar 90-day mortality rates (8.1% vs 8.1%; $P = .999$) as shown in Figure 3.

Patients undergoing the robotic approach had lower unadjusted readmission rates (2.3% vs 6.7%; $P = .027$). Hospital stay (8.3 ± 7.8 days vs 8.7 ± 7.6 days; $P = .555$), mortality (8.6% vs 8.1%; $P = .839$), and negative margins

TABLE 1. Baseline clinical and demographic characteristics between patients who underwent a minimally invasive versus open concomitant chest wall resection

Characteristics	Open approach (n = 2081)	Minimally invasive (n = 756)	*P* value
Age, y	65.2 ± 9.8	66.0 ± 9.9	.088
Sex, n (%)			.810
Female	861 (41.4)	309 (40.9)	
Male	1220 (58.6)	447 (59.1)	
Race, n (%)			.789
White	1806 (86.8)	659 (87.2)	
Non-White	275 (13.2)	97 (12.8)	
Insurance, n (%)			.460
Uninsured	64 (3.1)	23 (3.0)	
Private	670 (32.2)	221 (29.2)	
Public	1324 (63.6)	505 (66.8)	
Unknown	23 (1.1)	7 (0.9)	
Charlson-Deyo score, n (%)			.035
0	1061 (51.0)	344 (45.5)	
1	672 (32.3)	273 (36.1)	
≥2	348 (16.7)	139 (18.4)	
Tumor size, n (%)			<.001
<5	728 (35.0)	353 (46.7)	
≥5	1353 (65.0)	403 (53.3)	
Tumor histology, n (%)			.625
Adenocarcinoma	735 (35.3)	274 (36.2)	
Squamous cell	977 (47.0)	340 (45.0)	
Other	369 (17.7)	142 (18.8)	
Location, n (%)			.248
Upper lobe	1646 (79.1)	579 (76.6)	
Middle lobe	19 (0.9)	12 (1.6)	
Lower lobe	321 (15.4)	123 (16.3)	
Overlapping/other	95 (4.6)	42 (5.5)	
TNM stage, n (%)			.022
Stage I	179 (8.6)	90 (11.9)	
Stage II	1235 (59.3)	414 (54.8)	
Stage III	563 (27.1)	219 (29.0)	
Stage IV	104 (5.0)	33 (4.4)	
Multimodal therapy, n (%)			<.001
None	626 (30.1)	277 (36.6)	
Neoadjuvant therapy	455 (21.9)	113 (14.9)	
Adjuvant therapy	787 (37.8)	301 (39.8)	
Perioperative therapy	109 (5.2)	28 (3.7)	
Unknown	104 (5.0)	37 (3.9)	
Surgical margins, n (%)			.001
Negative margins	1646 (79.1)	641 (84.8)	
Positive margins	435 (20.9)	115 (15.2)	

Percentages may not add to 100% due to rounding. *TNM*, Tumor-node-metastasis.

TABLE 2. Baseline clinical and demographic characteristics between patients who had no conversions to open versus those who converted to open from minimally invasive approach

Characteristics	No conversion (n = 519)	Conversion (n = 237)	*P* value
Age, y	65.8 ± 9.8	66.2 ± 10.0	.626
Sex, n (%)			.210
Female	220 (42.4)	89 (37.6)	
Male	299 (57.6)	148 (62.4)	
Race, n (%)			.301
White	448 (86.3)	211 (89.0)	
Non-White	71 (13.7)	26 (11.0)	
Insurance, n (%)			.453
Uninsured	17 (3.3)	6 (2.5)	
Private	160 (30.8)	61 (25.7)	
Public	337 (64.9)	168 (70.9)	
Unknown	5 (1.0)	2 (0.8)	
Charlson-Deyo score, n (%)			.900
0	239 (46.1)	105 (44.3)	
1	186 (35.8)	87 (36.7)	
≥2	94 (18.1)	45 (19.0)	
Tumor size, n (%)			.014
<5	258 (49.7)	95 (40.1)	
≥5	261 (50.3)	142 (59.9)	
Tumor histology, n (%)			.132
Adenocarcinoma	198 (38.2)	76 (32.1)	
Squamous cell	232 (44.7)	108 (45.6)	
Other	89 (17.1)	53 (22.4)	
Location, n (%)			.529
Upper lobe	404 (77.8)	175 (73.8)	
Middle lobe	8 (1.5)	4 (1.7)	
Lower lobe	82 (15.8)	41 (17.3)	
Overlapping/other	25 (4.8)	17 (7.2)	
TNM stage, n (%)			.467
Stage I	66 (12.7)	24 (10.1)	
Stage II	284 (54.7)	130 (54.8)	
Stage III	144 (27.8)	75 (31.7)	
Stage IV	25 (4.8)	8 (3.4)	
Multimodal therapy, n (%)			.764
None	185 (35.7)	92 (38.8)	
Neoadjuvant therapy	83 (16.0)	30 (12.7)	
Adjuvant therapy	205 (39.5)	96 (40.5)	
Perioperative therapy	20 (3.8)	8 (3.4)	
Unknown	26 (5.0)	11 (4.6)	
Surgical margins, n (%)			.270
Negative margins	435 (83.8)	206 (86.9)	
Positive margins	84 (16.2)	31 (13.1)	

Percentages may not add to 100% due to rounding. *TNM*, Tumor-node-metastasis.

rates (82.3% vs 85.5%; $P = .293$) were similar between VATS and robotic approach within the minimally invasive group.

After risk adjustment, the robotic approach to concomitant chest wall resection was still associated with lower readmission rates (2.3% vs 6.8%; $P = .011$); however, it had similar hospital length of stay (8.3 days vs 8.7 days; $P = .593$), 90-day mortality (8.5% vs 8.1%; $P = .899$), and negative margin rates (83.5% vs 85.0%; $P = .615$).

The 5-year overall survival between the minimally invasive and open approach was equivalent (log-rank $P = .358$),

TABLE 3. Multivariable models predicting a minimally invasive approach and predicting conversion

Characteristics	Minimally invasive approach aOR (95% CI)	Minimally invasive approach P value	Conversion aOR (95% CI)	Conversion P value
Age	1.00 (0.99-1.01)	.726	0.99 (0.97-1.01)	.340
Sex, male	1.06 (0.89-1.27)	.485	1.24 (0.90-1.72)	.185
Race, White	1.04 (0.81-1.34)	.775	1.31 (0.80-2.13)	.281
Insurance				
Uninsured		Reference		
Private	0.85 (0.51-1.42)	.543	1.26 (0.46-3.42)	.657
Public	0.92 (0.55-1.53)	.739	1.71 (0.63-4.67)	.294
Unknown	0.71 (0.27-1.91)	.502	1.64 (0.24-11.23)	.613
Charlson-Deyo score				
0		Reference		
1	1.20 (0.99-1.45)	.059	1.03 (0.72-1.46)	.884
≥2	1.17 (0.92-1.48)	.197	1.03 (0.67-1.59)	.899
Neoadjuvant therapy	0.69 (0.55-0.84)	<.001	0.72 (0.48-1.08)	.112
Tumor size				
<5		Reference		
≥5	0.62 (0.52-0.75)	<.001	1.41 (1.01-1.98)	.043
Tumor histology				
Adenocarcinoma		Reference		
Squamous cell	0.94 (0.78-1.14)	.545	1.04 (0.72-1.50)	.847
Other	1.08 (0.85-1.38)	.532	1.40 (0.89-2.18)	.145
TNM stage				
Stage I		Reference		
Stage II	0.74 (0.55-0.99)	.040	1.09 (0.64-1.86)	.755
Stage III	0.93 (0.68-1.27)	.633	1.21 (0.68-2.15)	.525
Stage IV	0.72 (0.45-1.16)	.175	0.76 (0.30-2.00)	.574

aOR, Adjusted odds ratio; *95% CI*, 95% confidence interval; *TNM*, tumor-node-metastasis.

as shown in Figure 4, *A*. Similarly, VATS had comparable overall survival when compared with a robotic approach (log rank $P = .809$), as shown in Figure 4, *B*.

DISCUSSION

In this first and largest national observational study on the use of minimally invasive (VATS and robotic) approaches to lobectomy/bilobectomy with concomitant chest wall resection for NSCLC, we found that (1) there is an increasing trend toward starting and completing these resections in a minimally invasive fashion, particularly robotically; (2) the minimally invasive approach is associated with shorter hospital lengths of stay; (3) the minimally invasive approach is associated with similar risk-adjusted mortality and readmission rates without jeopardizing oncologic outcomes; and (4) as tumor size increases, the probability of conversion to open increases, although the robotic approach is associated with lower conversion rates at all tumor sizes. The findings have important implications to practicing thoracic surgeons and allow for expanding the use of these minimally invasive approaches to this complex presentation by skilled surgeons. The demonstrated collective experience is useful to demonstrate the risks, benefits, and outcomes of this approach, and to ensure patient advocacy, health care quality, and patient safety as advanced techniques are adopted and continue to evolve (Figure 5).[16]

Fortunately for patients, concomitant chest wall resection for lung cancer is not a common presentation. In the time frame of this study, only 2837 patients were identified from the NCDB. A recent report from the Society of Thoracic Surgeons General Thoracic Database analyzed data from 306 patients undergoing concomitant chest wall resection.[17] Although that report was not focused on discussing the minimally invasive approach and its adoption, it does add additional context to the current study. First, the majority of chest wall resections in the Society of Thoracic Surgeons were also performed via thoracotomy (>67%) compared with 73.4% in this study. The findings presented herein demonstrate the increasing use of the minimally invasive approach. Year over year, the use of the minimally invasive approach for concomitant resection in the US increased over 3-fold, from 13% in 2010 to 53% in 2020. Extrapolating from business models, adoption of new technology follows an S curve with 4 stages: initial slow growth, rapid growth, late-stage slow growth, and stationary

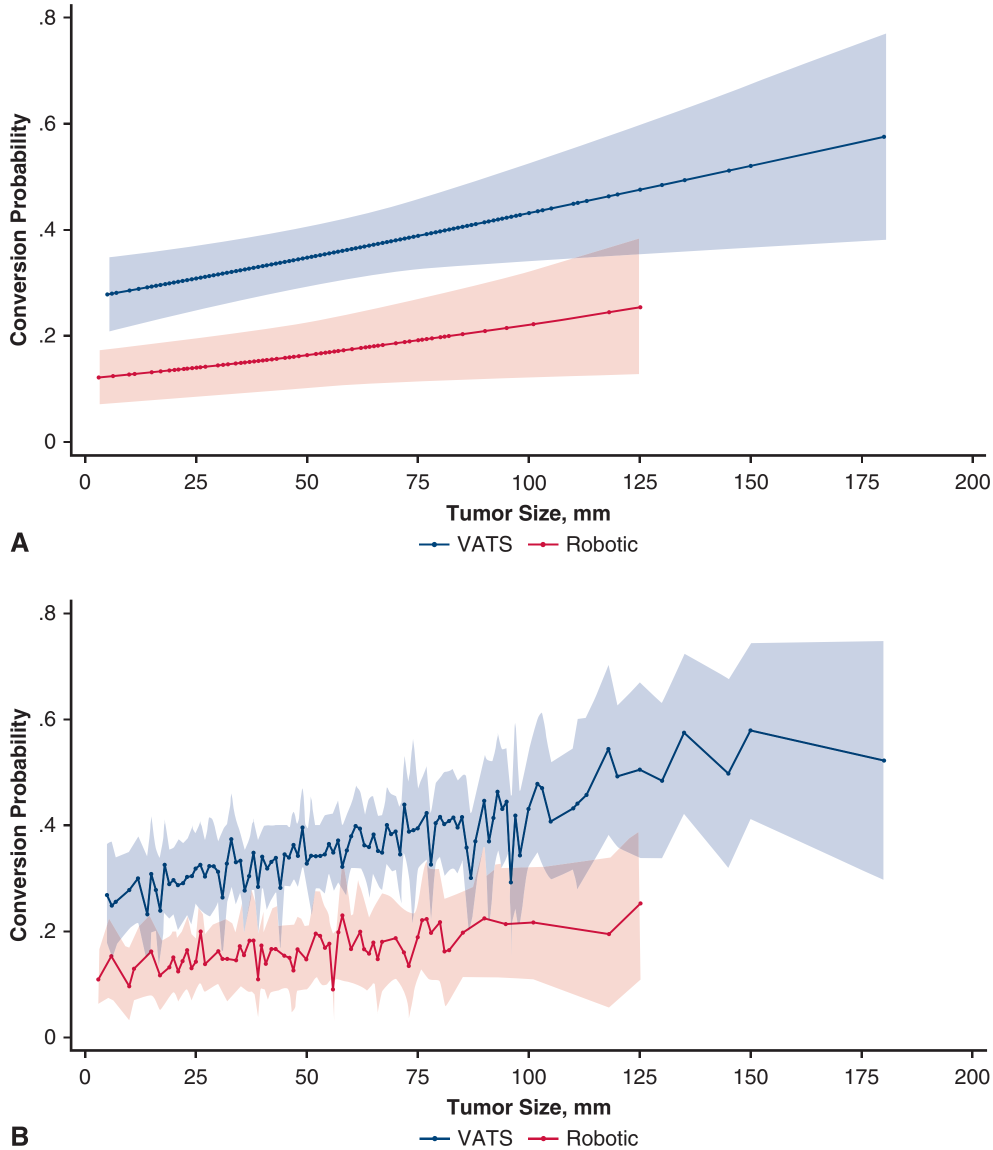

FIGURE 2. Conversion probability by approach and tumor size in the (A) unadjusted analysis and (B) adjusted analysis. Risk adjustment accounted for age, race, sex, neoadjuvant therapy, tumor histology, size, and analytic stage. 95% Confidence interval is shown. *VATS*, Video-assisted thoracoscopic surgery.

demand. Minimally invasive approaches are heading into the rapid growth phase; however, the maximal rate for adoption is still unclear. Certainly, there will be instances that a concomitant chest wall resection just cannot be performed in a minimally invasive fashion because of the tumor size, number of ribs required for resection, or extensive sternal involvement, and thus we cannot at this juncture aim for 100%. However, these instances may also benefit from starting the operation minimally invasively, addressing the hilum and fissure first, and then completing the chest wall resection with a more limited hybrid approach, than what would have been needed to address the lung and the chest wall via the same incision.

Conversely, the rate of conversion to thoracotomy has decreased over time, likely reflecting increased experience with this approach. It is possible that these conversions are rather a reflection of a hybrid resection than a true conversion; however, it is difficult to ascertain the reason of conversion from the NCDB. To combat this uncertainty, the analysis presented herein is rather strengthened by the ability to analyze these patients based on intent and based on as-treated methodology, factoring for conversions to an open approach.

Intuitively, tumor size was inversely and independently associated with the odds of a minimally invasive approach and was associated with conversions. In our analysis, we

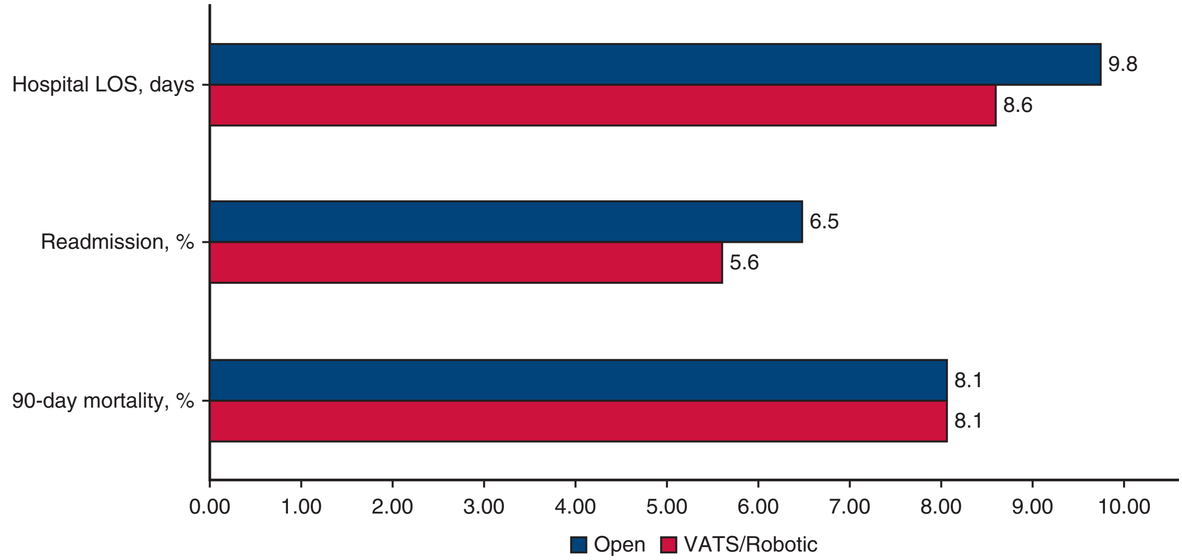

FIGURE 3. Comparison of outcomes between open versus minimally invasive approach. Hospital LOS was significantly decreased for VATS (8.6 days) compared with open (9.8 days), $P < .001$. There were not significant differences in readmissions rates or 90-mortality $P = .406$ and $P = .999$, respectively. *LOS*, Length of stay; *VATS*, video-assisted thoracoscopic surgery.

stratified tumor size to those less than 5 cm, and those at 5 cm or larger; subsequently, this showed that those with larger tumor size had decreased odds of starting the procedure in a minimally invasive fashion. We have previously published our experience with robotic approach to various chest wall resections for multiple pathologies and showed the feasibility of a minimally invasive approach to some tumors measuring 8 cm in maximal size.[18] It is worth mentioning that the robotic approach is increasing for chest wall resections. It also appears that the increase in robotic use was a result of less open operations rather than less VATS operations. A similar trend where the increase in robotic lobectomy was associated with a decrease in open lobectomy, and a steady VATS lobectomy rate has also been previously noted in the literature.[19-23] It remains difficult to ascertain if the increase in robotics is solely due to surgeons transitioning away from open resection. Ultimately, the surgeon would be the best predictor of which patients would benefit from a minimally invasive approach versus open, and VATS versus robotic, based on their skillset and preferences. The results presented herein support the equivalency of both VATS and robotic approaches.

Minimally invasive concomitant chest wall resection in this cohort was associated with nearly a 2-day reduction in hospital length of stay after risk adjustment. Although the NCDB does not have data on postoperative pain control, it is likely that this reduction in length of stay may be attributed to better pain control with the minimally invasive approach. Previously published reports of VATS resection for chest wall tumors and concomitant resections support this notion with reported less reliance on analgesics, chest tube drainage and less neurogenic complications than traditional open thoracotomy.[8] Although the actual resection specimen itself should virtually be similar whether the operation is performed minimally invasively or via thoracotomy, with the same number of divided ribs; it is believed that the culprit for pain is the use of a rib-spreader rather than the actual ribs divided. In addition, with the minimally invasive approach, the overlying musculature is largely left intact without disruption or dissection, as the chest wall resection is completed from the inside of the pleural space. It is likely that the combination of the above results in less pain, and in turn, shorter hospital length of stay.

Minimally invasive chest wall resection as presented in this study was associated with similar short-term mortality and readmission rates. The reported risk adjusted mortality in this study, is similar to a recent report from the Society of Thoracic Surgeons in which concomitant chest wall resections at time of lung cancer operations were associated with a 2.9% operative mortality rate.[17] Although this rate is generally greater than the mortality rate for less complex resections, it is important to note that these patients represent patients with locally advanced lung cancer, most of whom had received perioperative therapy, which may partly explain the increased mortality.[24] In the STS report, concomitant chest wall resection was associated with a 21% complication rate; however, the NCDB does not collect data on complications. The greater 90-day mortality in this cohort may also be due to complications and failure to rescue beyond the immediate postoperative period. All in all, the overall low and comparable 30-day readmission rates between the different approaches, 3.3% and 4.2% respectively, is reassuring.

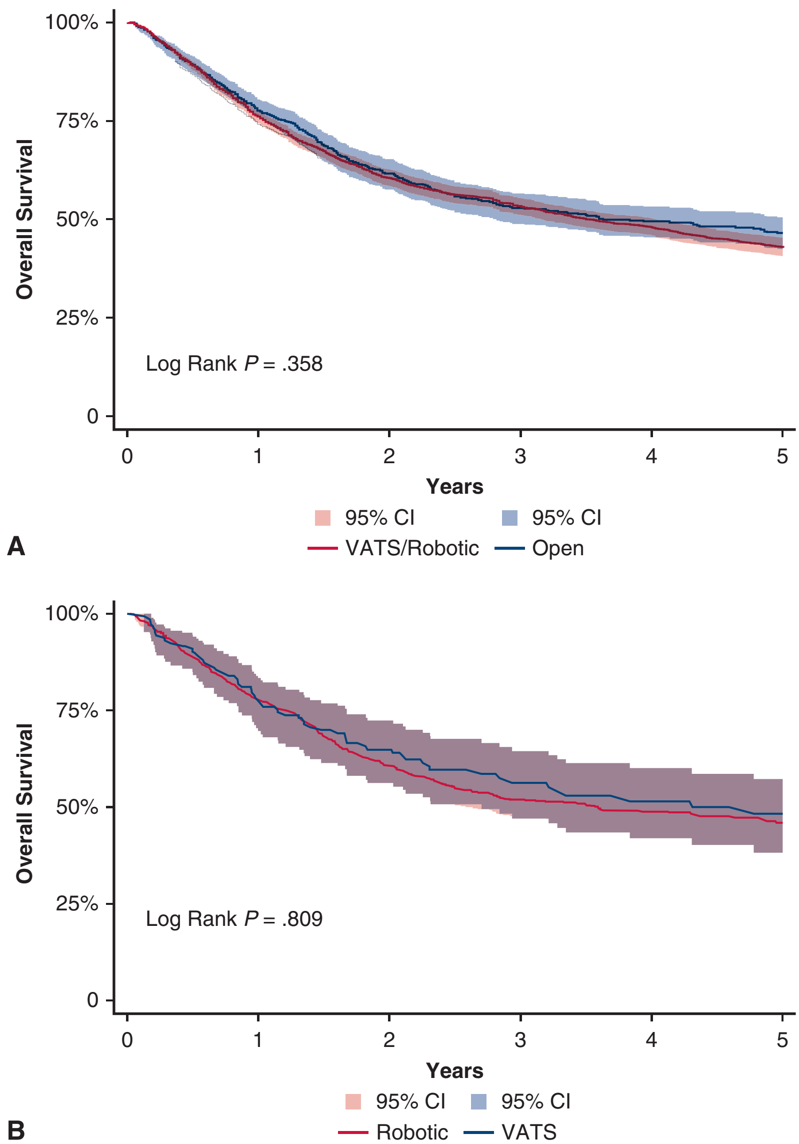

FIGURE 4. Overall survival by approach to lobectomy/bilobectomy with concomitant chest wall resection. A, Minimally invasive versus open, (B) VATS versus robotic. Both had equivalent 5-year overall survival. *CI*, Confidence interval; *VATS*, video-assisted thoracoscopic surgery.

One important finding from the results presented herein was that the robotic approach had a lower conversion rate even after accounting for tumor size and clinical characteristics. In 2020, almost 50% of procedures that started robotic were completed as such, whereas only 25% of those started VATS were completed as such. As mentioned previously, tumor size plays an independent part in conversion, but the robotic approach offers an advantage over VATS for large tumors, likely as the result of improved visualization, instrument dexterity, and maneuverability.[25] In our analysis, at a tumor size of 5 cm for example, VATS had nearly double the probability of open conversion than a robotic approach. This observation is true across all tumor sizes recorded in this study. The robotic and VATS approach had similar negative margin rates.

This study has several limitations. First and foremost, this is an observational study, which is subject to inherent selection and confounding bias. The exact reasoning why one patient received a minimally invasive lobectomy/bilobectomy with concomitant chest wall resection versus an open one is not documented, but it is likely because of surgeon discretion, which is unmeasurable. Although tumors were smaller in the minimally invasive group, those patients also tended to have more comorbid conditions. Yet, overall survival was similar. Second, the results may not be generalizable, as the NCDB only collects data from Commission on Cancer–accredited hospitals. That being said, these patients should arguably only be offered surgery at tertiary referral centers. In addition, the NCDB does not contain data on cancer recurrence; therefore, we are unable to draw conclusions

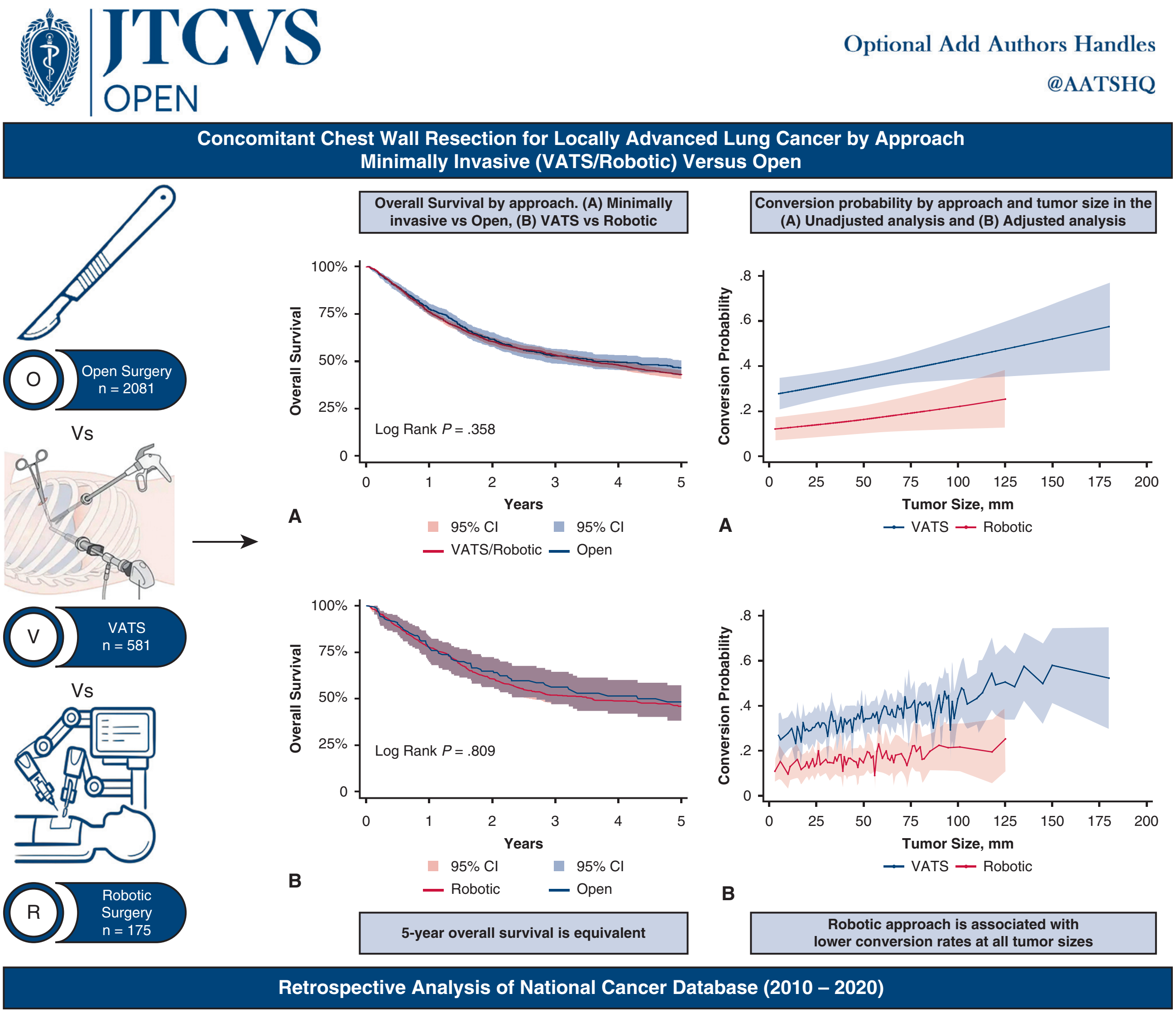

FIGURE 5. Graphical abstract highlighting the main results and findings when comparing VATS and robotic approaches for chest wall concomitant resection. *VATS*, Video-assisted thoracoscopic surgery; *CI*, confidence interval.

on disease-free survival. Also, the NCDB does not capture data on postoperative complications or health care–related quality of life. Without these data, we are unable to comment on the quality of life after either approach. Another limitation is that the NCDB does not report if the use of a thoracoscope to assess for pleural disease, extent of chest wall invasion in a planned thoracoscopic approach is counted as conversion per se. As a result, the number of what thoracic surgeons view as a conversion may not be accurately reported and the conversion rate reported here may therefore be inflated. Finally, we are also unable to distinguish between lobectomy or bilobectomy as the NCDB groups them together when a concomitant chest wall resection is performed. Notwithstanding these limitations, we believe our results are relevant to the practicing thoracic surgeons because they provide the largest snapshot of the safety profile of this approach and demonstrate its increasing adoption.

CONCLUSIONS

In this first national report on the use of minimally invasive approaches to lobectomy/bilobectomy with concomitant chest wall resection for locally advanced NSCLC, we found that the minimally invasive approach is being used more frequently with up to 1 in 5 concomitant chest wall resections being performed in a minimally invasive fashion in the United States. Although conversions to open are common, the minimally invasive approach is safe and is associated with shorter hospital stays. The minimally invasive approach, whether VATS or robotic, is also associated with equivalent overall survival when compared with the open approach.

Conflict of Interest Statement

The authors reported no conflicts of interest.

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

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Key Words: lung cancer, chest wall invasion, minimally invasive, concomitant resection

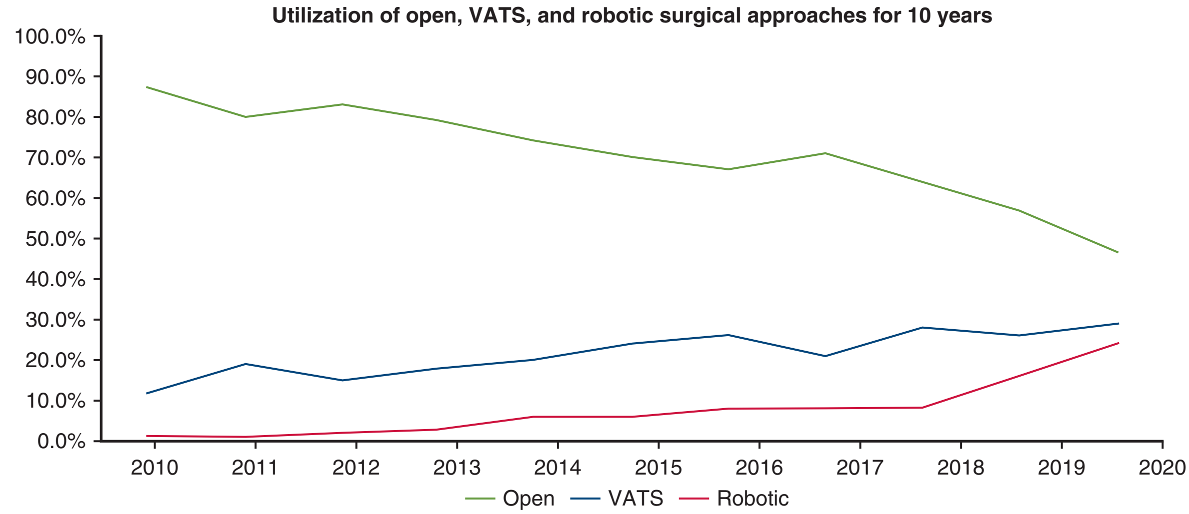

FIGURE E1. Use of open, VATS, and robotic surgical approaches over 10 years for lobectomy/bilobectomy with concomitant chest wall resections. *VATS*, Video-assisted thoracoscopic surgery.

TABLE E1. Baseline clinical and demographic characteristics between patients who underwent VATS versus robotic concomitant chest wall resection

Characteristics	VATS (n = 581)	Robotic (n = 175)	P value
Age, y	65.8 ± 9.9	66.6 ± 9.6	.311
Sex, n (%)			.256
Female	231 (39.8)	78 (44.6)	
Male	350 (60.2)	97 (55.4)	
Race, n (%)			.241
White	511 (88.0)	148 (84.6)	
Non-White	70 (12.0)	27 (15.4)	
Insurance, n (%)			.700
Uninsured	18 (3.1)	5 (2.8)	
Private	175 (30.1)	46 (26.3)	
Public	382 (65.8)	123 (70.3)	
Unknown	6 (1.0)	1 (0.6)	
Charlson-Deyo score, n (%)			.122
0	253 (43.6)	91 (52.0)	
1	215 (37.0)	58 (33.1)	
≥2	113 (19.4)	26 (14.9)	
Tumor size, n (%)			.034
<5	259 (44.6)	94 (53.7)	
≥5	322 (55.4)	81 (46.3)	
Tumor histology, n (%)			.203
Adenocarcinoma	217 (37.4)	57 (32.6)	
Squamous cell	251 (43.2)	89 (50.9)	
Other	113 (19.4)	29 (16.6)	
Location, n (%)			.329
Upper lobe	449 (77.3)	130 (74.3)	
Middle lobe	7 (1.2)	5 (2.9)	
Lower lobe	91 (15.7)	32 (18.3)	
Overlapping/other	34 (5.8)	8 (4.6)	
TNM stage, n (%)			.700
Stage I	67 (11.5)	23 (13.1)	
Stage II	321 (55.2)	93 (53.1)	
Stage III	170 (29.3)	49 (28.0)	
Stage IV	23 (4.0)	10 (5.7)	
Multimodal therapy, n (%)			.070
None	208 (35.8)	69 (39.4)	
Neoadjuvant therapy	96 (16.5)	17 (9.7)	
Adjuvant therapy	222 (38.2)	79 (45.1)	
Perioperative therapy	23 (4.0)	5 (2.9)	
Unknown	32 (5.5)	5 (2.9)	
Surgical margins, n (%)			.293
Negative margins	497 (85.5)	144 (82.3)	
Positive margins	84 (14.5)	31 (17.7)	

Percentages may not add to 100% due to rounding. *VATS*, Video-assisted thoracoscopic surgery; *TNM*, tumor-node-metastasis.

TABLE E2. Cox proportional hazards model predicting overall survival

Characteristics	Hazard ratio	95% Confidence interval	*P* value
Minimally invasive	0.95	0.84-1.06	.361
Age	1.03	1.02-1.04	<.001
Sex, male	1.20	1.08-1.32	<.001
Race, White	1.02	0.88-1.19	.795
Charlson-Deyo score			
0		Reference	
1	0.94	0.85-1.06	.325
≥2	1.26	1.10-1.44	.001
Neoadjuvant therapy	0.75	0.66-0.84	<.001
Tumor size	1.00	1.00-1.00	<.001
Tumor histology			
Adenocarcinoma		Reference	
Squamous cell	1.20	1.07-1.34	.002
Other	1.25	1.09-1.45	.002