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Pre-COVID-19 National Mortality Trends in Open and Video-Assisted Lobectomy for Non-Small Cell Lung Cancer

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ABSTRACT

Introduction: In the current era of episode-based hospital reimbursements, it is important to determine the impact of hospital size on contemporary national trends in surgical technique and outcomes of lobectomy. Methods: Patients aged >18 y undergoing open and video-assisted thoracoscopic surgery (VATS) lobectomy from 2008 to 2014 were identified using insurance claims data from the National Inpatient Sample. The impact of hospital size on surgical approach and outcomes for both open and VATS lobectomy were analyzed. Results: Over the 7-y period, 202,668 lobectomies were performed nationally, including 71,638 VATS and 131,030 open. Although the overall number of lobectomies decreased (30,058 in 2008 versus 27,340 in 2014, P < 0.01), the proportion of VATS lobectomies increased (24.0% versus 46.9%), and open lobectomies decreased (76.0% versus 53.0%, all P < 0.01). When stratified by hospital size, small hospitals had a significant increase in the proportion of open lobectomies (6.4%-12.2%; P = 0.01) and trend toward increased number of VATS lobectomies (2.7%-12.2%). Annual mortality rates for VATS (range: 1.0%-1.9%) and open (range: 1.9%-2.4%) lobectomy did not significantly differ over time (all P > 0.05) but did decrease among small hospitals (4.1%-1.3% and 5.1%-1.1% for VATS and open, respectively; both P < 0.05). After adjusting for confounders, hospital bed size was not a predictor of in-hospital mortality. Conclusions: Utilization of VATS lobectomies has increased over time, more so among small hospitals. Mortality rates for open lobectomy remain consistently higher than VATS lo-
Introduction

Lung cancer is the number one cause of cancer-related mortality in the United States and worldwide, with an estimated 228,150 new cases in the United States in 2019 and 2.09 million new cases and 1.76 million deaths worldwide, despite a declining incidence over the last 2 decades from 70.2 cases per 100,000 people in 1999 to 55.2 per 100,000 people in 2017 within the United States. To date, lobectomy remains the gold standard for the management of early stage non–small cell lung cancer (NSCLC). Over the last decade, there has been a substantial growth in the use of video-assisted thoracoscopic surgery (VATS) in the management of patients, albeit with varying levels of uptake across different institutions. Recent studies have confirmed that VATS lobectomy is a safe and effective alternative to traditional lobectomy.

In the contemporary era, there is growing literature demonstrating the impact of operative volume and/or hospital size on overall patient outcomes. These studies have shown a strong correlation between lobectomy volume and patient outcomes, especially in patients treated at high-volume surgery centers. Although these findings are encouraging, volume alone has been shown to be an inadequate proxy of quality assessment after lobectomy. To address these inadequacies, the Society of Thoracic Surgeon’s recently used the General Thoracic Surgery Database (GTSD) to develop a composite quality measure scores for measuring performance of hospitals performing lobectomy, which does not include hospital size. Although the utility and reliability of GTSD have been validated previously, the composite scores were not generalizable (as they only included voluntary institutions participating in the database) and were also prone to selection bias, leaving the question of how to predict and judge surgical quality for lobectomy patients at institutions with different characteristics.

To our knowledge, there exists no study that has specially examined the impact of overall hospital size as a function of open or VATS lobectomies and outcomes (morbidity and mortality). We hypothesized that hospital size may play a significant role in terms of outcomes, in addition to known factors such as surgeon and hospital operative volume. This research may provide useful benchmarking data to guide resource utilization and provide a framework to improve quality and transparency at a national level. Thus, in this study, we sought to (1) describe contemporary national trends in open and VATS surgery volume and mortality, (2) examine the impact of hospital size on patient outcomes, and (3) develop a predictive model for in-hospital mortality after open and VATS surgery.

Methods

Data source

The National Inpatient Sample (NIS) is the largest publicly available all-payer database of hospitalized patients in the United States and is sponsored by the Agency for Healthcare Research and Quality (AHRQ) as a part of the Healthcare Cost and Utilization Project (HCUP). It is composed of more than 45 state databases and includes anonymized data on discharge diagnoses and procedures on about eight million hospitalizations from about 1000 hospitals sampled annually. Although the NIS dataset constitutes a 20% stratified sample of US hospitals, it provides reliable sampling weights to calculate robust national estimates that represent more than 95% of the US population.

This study adhered to best practices required by AHRQ for design and conduct of research using the NIS and followed recommendations for reporting statistics that are based on HCUP data. This study was considered exempt from institutional review board approval.

Study outcomes

Our primary outcomes of interest were national trends in procedures and all-cause, in-hospital mortality. Secondary outcomes of interest included specific adverse events such as acute myocardial infarction (MI), stroke, major bleed, acute kidney injury (AKI), hospital length of stay (LOS), inpatient cost, discharge disposition following surgery, and predictors of in-hospital outcomes. A list of ICD-9-CM codes used to define in-hospital complications is also included in Table e1 in the Data supplement.

Statistical analysis

Cochran-Armitage test for trend was conducted to determine significant differences in open and VATS volume and mortality
over time. Open and VATS surgeries were then stratified by hospital bed size (small, medium, and large) as defined by the NIS. Briefly, bed size categories were based on the number of hospital beds and were specific to the hospital’s region (Northeast, Midwest, South, and West) and teaching status (teaching versus nonteaching), as the NIS uses different cutoff points for rural, urban nonteaching, and urban teaching hospitals by region (see Data Supplement Table e2). Patient demographic information, clinically relevant diagnoses, surgical and in-hospital outcomes, hospital LOS and costs, and discharge disposition were extracted and compared by bed size. AHRQ comorbidities were used both as single categories and as Charlson comorbidity index to serve indirectly as an indicator for frailty. In addition to bed size, hospital location and teaching status were also examined.

Normally distributed continuous variables were expressed as a mean with standard deviation and compared using one-way analysis of variance tests. Categorical variables were presented as number and percentages and compared using \( \chi^2 \) tests. We then adjusted outcomes for the small-sized hospitals using multivariable logistic and linear regression to control for patient demographics, comorbidities, admission, and hospital-level factors. Independent predictors for in-hospital mortality were determined by including all preoperative variables in a backward selection, parsimonious multivariable logistic regression model with \( P < 0.05 \) as the threshold for inclusion. The final model contained preoperative variables that met the threshold for inclusion along with hospital bed size. This second logistic regression model was performed similarly to the previous model with \( 0.05 \) as the threshold criterion for statistical significance for all tests and models. Analysis was conducted using STATA version 13.1 (StataCorp LP, College Station, TX).

**Results**

**Overall patient sample**

Over the 7-y period, 202,668 lobectomies were recorded nationally in the NIS, with 131,030 done open (65%) and 71,638 (35%) done via VATS. Overall number of annual lobectomies decreased from 30,058 in 2008 to 27,340 in 2014 \( (P < 0.01; \text{Fig. 1}) \). At the same time, the proportion of VATS lobectomies increased from 24% to 47%; meanwhile, open lobectomies decreased from 76% of all cases to 53% \( (P < 0.01) \). Furthermore, no statistical difference in overall in-hospital mortality for either VATS or open lobectomy was observed for all cases during the study period; however, mortality for VATS lobectomy remained consistently lower than open lobectomy \( (\text{range 0.41% in 2010 to 1.42% in 2012; Fig. 2}) \).

**Open lobectomy**

Table 1 describes rates and demographics of patients undergoing open lobectomy. In terms of open lobectomy, rates were highest at small hospitals. Although the median age was statistically different, it was clinically similar \( (68 [IQR 10.2] \text{ versus 67 [IQR 9.9] versus 67 [IQR 9.8] y for small, medium, and large hospitals, respectively; } P < 0.01) \). Patients at large hospitals had higher Charlson comorbidity indices, rates of metastatic cancer, and MI history but lower rates of chronic obstructive pulmonary disease (COPD) compared with smaller hospitals. No differences were found between hospital size with observed rates of in-hospital outcomes (AKI, MI, major bleeding, pulmonary embolism, stroke, and death) except for LOS \( (\text{median 8.3 versus 8.6 versus 8.6 d for small, medium, and large hospitals, respectively; } P < 0.01) \). Overall, patients at larger hospitals had more costly stays \( ($33,813 versus$33,538 versus $34,839 for small, medium, and large hospitals, respectively; \ P < 0.01) \). However, patients at large hospitals were less likely to be discharged to a nonhome facility \( (P < 0.01; \text{Table 2}) \). Although annual mortality rates for open procedures did not statistically vary over time \( (1.9\% - 2.4\% \text{), a significant improvement in mortality for small hospitals did occur (} P < 0.01; \text{Fig. 2A}) \).

In multivariate analysis, hospital size was not a predictor of in-hospital mortality after open lobectomy \( (\text{Table e3}) \). Acute

![Fig. 1 – Temporal trend in open versus VATS lobectomy from 2008 to 2014 within the National Inpatient Sample. Figure 1 demonstrates decreased performance of overall lobectomies performed by open technique \( (n = 22,843 \text{ between 2008 and 2009 to } n = 15,000 \text{ in 2013-2014}) \) with a statistically significant increased utilization of video-assisted thoracoscopic lobectomy \( (n = 7215 \text{ in 2008-2009 to 12,015 in 2013-2014}) \) over the same period from 2008 to 2014 (both \( P < 0.01) \).]
MI, AIDS, congestive heart failure, COPD, coagulopathy, liver disease, fluid and electrolyte disorders, metastatic cancer, weight loss, and history of paralysis were associated with increased odds of in-hospital mortality, whereas female gender, Medicaid or private insurance, drug abuse, dyslipidemia, hypertension (HTN), hypothyroidism, smoking, and obesity were protective (all $P < 0.05$).

**VATS lobectomy**

Regarding VATS lobectomy, comorbidities between hospital sizes differed in terms of age, history of COPD, chronic deficiency anemias, psychoses, pulmonary circulation disorders, HTN, MI, All Patient Refined Diagnosis-Related Group risk mortality and severity, Charlson Comorbidity Index, and Sum of Elixhauser Comorbidities (all $P < 0.05$). However, clinically, these differences were minor apart from a 6% higher rate of MI history at medium hospitals compared with small hospitals. Small hospitals were more commonly located in the Northeast compared with the South for medium and large hospitals ($P = 0.04$) and were least likely to be nonprofit ($P = 0.04$) and most likely to be urban teaching hospitals despite their size ($P < 0.01$; Table 3). Smaller hospitals compared with medium or large hospitals were associated with higher rates of major bleeding (3.6% versus 3.4% versus 2.6% respectively; $P = 0.03$), pulmonary embolism (0.9% versus 0.2% versus 0.5% respectively; $P = 0.01$), and death (2.1% versus 1.4% vs. 1.3% respectively; $P < 0.01$) but shorter LOS (6 versus 6.4 versus 6.2 d, respectively; $P < 0.01$) and increased overall and adjusted inflated costs (net difference $8122 between small and large hospitals for adjusted cost; $P < 0.01$) than in larger hospitals ($P < 0.05$; Table 4). In-hospital mortality rates remained stable for medium and large hospitals. However, again, a statistical improvement in mortality over time was observed for VATS lobectomy at small hospitals (Fig. 3B). In multivariate analysis, hospital size was not a predictor of in-hospital mortality after VATS (Table e4). Female gender, those with dyslipidemia, obesity, and smoking history were protective against in-hospital mortality (all adjusted $P$ value $< 0.05$), whereas fluid or electrolyte disorders, acute MI, AKI, cardiac arrest, development of major bleed, heart block, or stroke were associated with increased odds of in-hospital mortality (all adjusted $P$ value $< 0.05$).

**Discussion**

This study takes an in-depth look at the impact of hospital size on national trends and in-hospital outcomes for open and VATS lobectomy in the United States. It serves as a snapshot from 2008 to 2014, a time of increasing expansion of VATS techniques into community hospitals. CALGB 39802, a prospective trial that established the safety and feasibility of VATS lobectomy, was published in 2007.22 Furthermore, the National Lung Screening Trial was published in 201123 and began to influence the willingness to obtain chest computed tomography scans as well as led to increased nodule identification and a stage shift with diagnosis of earlier stage lung cancer.

This study had several important findings: First, it demonstrated a decreased volume of lobectomies being performed in the United States by $\sim 10\%$, which we hypothesize may be because of rise in sublobar resection over the same period,24,25 which has been shown in other national databases such as that of the Society of Thoracic Surgeons,26 as well as lower incidence of new lung cancers27 and/or in use of radiation therapy.27 Next, we identified an approximately twofold increase in the utilization of VATS for lobectomy (24%-47%) with a drop-in rate of open lobectomies (76%-53%). VATS lobectomy was most commonly performed in the Northeast and...
Table 1 – Demographics, comorbidities, and hospital factors by hospital size for patients undergoing open lobectomy from 2008 to 2014 in the National Inpatient Sample.

| Variable | Small (n = 11,162) | Medium (n = 27,461) | Large (n = 92,407) | P value |
|----------|--------------------|---------------------|---------------------|---------|
| **Demographics, n (%)** | | | | |
| Age (y), median (IQR) | 68 (10.2) | 67 (9.9) | 67 (9.8) | <0.01 |
| Female | 5769 (51.7) | 13,824 (50.4) | 45,886 (49.7) | 0.20 |
| Race | | | | 0.77 |
| White | 7924 (83.7) | 20,402 (84.3) | 67,472 (84.2) | |
| Black | 786 (8.3) | 1891 (7.8) | 6314 (7.9) | |
| Hispanic | 334 (3.5) | 785 (3.2) | 3017 (3.8) | |
| Asian or Pacific Islander | 197 (2.1) | 550 (2.3) | 1733 (2.2) | |
| **Payer** | | | | 0.07 |
| Medicare | 7069 (63.6) | 17,044 (62.2) | 57,620 (62.4) | |
| Medicaid | 658 (5.9) | 1503 (5.5) | 5036 (5.5) | |
| Private | 3161 (28.4) | 7916 (28.9) | 26,161 (28.3) | |
| Self-pay | 115 (1.0) | 336 (1.2) | 1481 (1.6) | |
| Median household income quartile per ZIP code | | | | 0.04 |
| 1 | 2386 (21.7) | 7198 (26.8) | 23,742 (26.2) | |
| 2 | 3470 (31.6) | 7584 (28.2) | 24,471 (27.0) | |
| 3 | 2827 (25.7) | 6551 (24.3) | 22,334 (24.7) | |
| 4 | 2308 (21.0) | 5576 (20.7) | 19,946 (22.0) | |
| **Comorbidities, n (%)** | | | | |
| Alcohol abuse | 450 (4.0) | 966 (3.5) | 2853 (3.1) | 0.03 |
| Atrial fibrillation | 2157 (19.3) | 4971 (18.1) | 17,707 (19.2) | 0.22 |
| Deficiency anemias | 1476 (13.2) | 3916 (14.3) | 11,878 (12.9) | 0.12 |
| Congestive heart failure | 598 (5.4) | 1283 (4.7) | 4063 (4.4) | 0.13 |
| Chronic pulmonary disease | 5891 (52.8) | 14,804 (53.9) | 46,836 (50.7) | <0.01 |
| Coagulopathy | 282 (2.5) | 956 (3.5) | 2575 (2.8) | 0.03 |
| Diabetes, uncomplicated | 1961 (17.6) | 5015 (18.3) | 16,487 (17.8) | 0.71 |
| Dyslipidemia | 3961 (35.5) | 10,635 (38.7) | 34,387 (37.2) | 0.12 |
| HTN | 6749 (60.5) | 16,787 (61.1) | 54,877 (59.4) | 0.09 |
| Liver disease | 155 (1.4) | 370 (1.3) | 1494 (1.6) | 0.32 |
| Fluid and electrolyte disorders | 2231 (20.0) | 5552 (20.2) | 18,346 (19.9) | 0.9 |
| Metastatic cancer | 2044 (18.3) | 5044 (18.4) | 18,532 (20.0) | 0.04 |
| Obesity | 962 (8.6) | 2320 (8.4) | 7593 (8.2) | 0.77 |
| Peripheral vascular disorders | 877 (7.9) | 2699 (9.8) | 7862 (8.5) | <0.01 |
| Psychoses | 295 (2.6) | 682 (2.5) | 2489 (2.7) | 0.71 |
| Pulmonary circulation disorders | 319 (2.9) | 579 (2.1) | 2085 (2.3) | 0.14 |
| Renal failure | 614 (5.5) | 1653 (6.0) | 4916 (5.3) | 0.15 |
| Weight loss | 570 (5.1) | 1542 (5.6) | 4299 (4.7) | 6410 (4.9) |
| Smoking | 6233 (55.8) | 16,528 (60.2) | 53,561 (58.0) | 0.03 |
| Prior MI | 2996 (26.9) | 8265 (30.1) | 25,316 (27.4) | <0.01 |
| Prior transient ischemic attack/stroke | 2698 (24.2) | 6916 (25.2) | 21,939 (23.7) | 0.11 |
| APRDRG_Risk mortality | 2.0 (0.9) | 1.9 (0.9) | 1.9 (0.9) | <0.01 |
| APRDRG_Severity | 2.2 (0.8) | 2.3 (0.8) | 2.2 (0.8) | <0.01 |
| Charlson comorbidity index | 4.2 (2.6) | 4.2 (2.5) | 4.3 (2.6) | <0.01 |
| Sum of Elixhauser comorbidities | 3.8 (1.6) | 3.8 (1.6) | 3.7 (1.6) | <0.01 |
| **Hospital factors, n (%)** | | | | |
| Hospital region | | | | <0.01 |
| Northeast | 1986 (17.8) | 4689 (17.1) | 16,572 (17.9) | |
| Midwest | 4279 (38.3) | 7609 (27.7) | 23,610 (25.6) | |
| South | 3722 (33.4) | 10,643 (38.8) | 37,454 (40.5) | |

(continued)
South followed by the West in urban teaching centers, which is consistent with early pioneering of this technique in these regions, whereas open lobectomy was more common in the South and Midwest with higher rates outside of teaching hospitals compared with VATS. Finally, we demonstrate an improving survival rate after lobectomy at smaller hospitals for both open and VATS lobectomy during our 7-y study period. This study provides useful benchmark information for thoracic surgeons in national trends not only about the use of minimally invasive surgery but also of outcomes and mortality.

However, our results did not show clinically relevant differences in underlying patient demographics or patient comorbidities except for some differences in geographic apart from a slightly higher prevalence of prior MI in those patients at larger hospitals undergoing VATS. In terms of hospital characteristics between open and VATS lobectomy groups, smaller hospitals were more likely to be teaching hospitals compared with medium- or large-sized hospitals, which may contribute to more favorable outcomes over time for smaller hospitals. Meanwhile, geographic distribution did statistically vary by hospital size, but the authors do not believe; this led to clinically meaningful differences in outcomes. Although we did not identify clinically important differences in morbidity or mortality by hospital size, there were slightly higher rates of major bleeding (3.6% versus 2.6%; $P = 0.03$) and PE (0.9% versus 0.5%; $P = 0.01$) after VATS lobectomy at smaller hospitals compared with the largest hospital size. Nonetheless,

| Variable | Small (n = 11,162) | Medium (n = 27,461) | Large (n = 92,407) | P value |
|----------|-------------------|---------------------|-------------------|---------|
| West     | 1175 (10.5)       | 4521 (16.5)         | 14,772 (16.0)     |         |
| Control/ownership of hospital |                   |                     |                   |         |
| Government or private, collapsed category | 5520 (49.5)       | 13,018 (47.4)       | 40,244 (43.6)     | <0.01   |
| Government, nonfederal | 527 (4.7)        | 763 (2.8)           | 5727 (6.2)        |         |
| Private, nonprofit | 3366 (30.2)      | 10,240 (37.3)       | 38,645 (41.8)     |         |
| Private, invest own | 1725 (15.5)      | 3404 (12.4)         | 6225 (6.7)        |         |
| Location/teaching status of hospital | <0.01<sup>1</sup> |                   |                   |         |
| Rural     | 56 (0.5)          | 318 (1.2)           | 6780 (7.3)        |         |
| Urban nonteaching | 2631 (23.6)     | 8910 (32.5)         | 34,646 (37.5)     |         |
| Urban teaching | 8475 (75.9)   | 18,233 (66.4)       | 50,981 (55.2)     |         |

<sup>1</sup> P < 0.05.

**Table 2** – Outcomes related to hospital size in patients undergoing open lobectomy in the National Inpatient Sample from 2008 to 2014.

| Variable | Small (n = 11,162) | Medium (n = 27,461) | Large (n = 92,407) | P value |
|----------|-------------------|---------------------|-------------------|---------|
| In-hospital outcomes, n (%) |                   |                     |                   |         |
| Acute MI | 153 (1.4)         | 301 (1.1)           | 872 (0.9)         | 0.13    |
| AKI      | 627 (5.6)         | 1721 (6.3)          | 5472 (5.9)        | 0.51    |
| Major bleed | 492 (4.4)     | 1193 (4.3)          | 3913 (4.2)        | 0.89    |
| Pulmonary embolism | 104 (0.9)    | 176 (0.6)           | 697 (0.8)         | 0.39    |
| Stroke   | 80 (0.7)          | 280 (1.0)           | 845 (0.9)         | 0.43    |
| Death    | 272 (2.4)         | 679 (2.5)           | 2020 (2.2)        | 0.37    |
| Admission characteristics, n (%) |                   |                     |                   |         |
| Admission on weekend | 89 (0.8)       | 205 (0.7)           | 899 (1.0)         | 0.28    |
| Disposition | <0.01<sup>1</sup> |                   |                   |         |
| Routine  | 7027 (63.0)       | 16,679 (60.8)       | 55,793 (60.4)     |         |
| Transfer to short-term hospital | 94 (0.8)       | 147 (0.5)           | 380 (0.4)         |         |
| Transfer to SNF, ICF, rehabilitation | 1481 (13.3) | 3492 (12.7)         | 9808 (10.6)       |         |
| Home health care | 2288 (20.5) | 6435 (23.4)         | 24,285 (26.3)     |         |
| Elective | 10,162 (91.1)     | 24,819 (90.5)       | 84,688 (91.5)     | 0.24    |
| LOS (d)  | 8.3 (6.8)         | 8.6 (6.6)           | 8.6 (7.5)         | <0.01   |
| Cost (USD $, inflation adjusted) | 33,813 (31.21) | 33,538 (28.093)     | 34,839 (30.569)   | <0.01   |

<sup>ICF</sup> = intermediate care facility; <sup>SNF</sup> = Skilled nursing facility.

P < 0.05.
Fig. 3 — Temporal trends in surgical volume and mortality for VATS lobectomy and open lobectomy by hospital size within the National Inpatient Sample from 2008 to 2014. (A) For open lobectomy, in-hospital mortality rates remained stable for medium and large hospitals. A statistical improvement in mortality was observed for small hospitals over time. Volume remained relatively stable. (B) A similar trend for VATS lobectomy was observed with in-hospital mortality rates remaining stable for medium and large hospitals. A statistical improvement in mortality was observed for small hospitals over time. Volume remained relatively stable.
Table 3 – Demographics, comorbidities, and hospital factors by hospital size for patients undergoing video-assisted thoracoscopic lobectomy from 2008 to 2014 in the National Inpatient Sample.

| Variable                        | Small (n = 6140) | Medium (n = 12,811) | Large (n = 52,687) | P value |
|---------------------------------|------------------|---------------------|--------------------|---------|
| **Demographics**                |                  |                     |                    |         |
| Age, years, median (IQR)        | 68.0 (9.9)       | 67.8 (9.6)          | 67.8 (9.8)         | <0.01   |
| Female, n (%)                   | 3335 (54.3)      | 7272 (56.8)         | 29,443 (55.9)      | 0.41    |
| Race, n (%)                     |                  |                     |                    |         |
| White                           | 4697 (83.4)      | 10,113 (83.7)       | 40,846 (82.6)      | 0.90    |
| Black                           | 456 (8.1)        | 941 (7.8)           | 3796 (7.7)         |         |
| Hispanic                        | 196 (3.5)        | 368 (3.0)           | 1779 (3.6)         |         |
| Asian or Pacific Islander       | 180 (3.2)        | 365 (3.0)           | 1670 (3.4)         |         |
| Payer, n (%)                    |                  |                     |                    | 0.14    |
| Medicare                        | 3645 (59.4)      | 8304 (64.9)         | 33,018 (62.8)      |         |
| Medicaid                        | 259 (4.2)        | 522 (4.1)           | 2324 (4.4)         |         |
| Private                         | 2092 (34.1)      | 3571 (27.9)         | 15,523 (29.5)      |         |
| Self-pay                        | 42 (0.7)         | 140 (1.1)           | 684 (1.3)          |         |
| Median household income quartile per ZIP code | | | | 0.49 |
| 1                               | 1099 (18.3)      | 2530 (20.1)         | 10,505 (20.3)      |         |
| 2                               | 1591 (26.5)      | 2824 (22.4)         | 12,246 (23.6)      |         |
| 3                               | 1544 (25.7)      | 3442 (27.3)         | 13,007 (25.1)      |         |
| 4                               | 1770 (29.5)      | 3795 (30.1)         | 16,045 (31.0)      |         |
| **Comorbidities, n (%)**        |                  |                     |                    |         |
| Alcohol abuse                   | 156 (2.5)        | 444 (3.5)           | 1477 (2.8)         | 0.16    |
| Atrial fibrillation             | 981 (16.0)       | 2101 (16.4)         | 9166 (17.4)        | 0.32    |
| Deficiency anemia               | 626 (10.2)       | 1552 (12.1)         | 4866 (9.2)         | <0.01   |
| Congestive heart failure        | 198 (3.2)        | 461 (3.6)           | 1892 (3.6)         | 0.77    |
| Chronic pulmonary disease       | 2678 (43.6)      | 6254 (48.8)         | 23,252 (44.1)      | <0.01   |
| Coagulopathy                    | 149 (2.4)        | 321 (2.5)           | 1040 (2.0)         | 0.20    |
| Diabetes, uncomplicated         | 1106 (18.0)      | 2191 (17.1)         | 8655 (16.4)        | 0.34    |
| Dyslipidemia                    | 2373 (38.7)      | 5038 (39.3)         | 21,586 (41.0)      | 0.37    |
| HTN                             | 3527 (57.4)      | 7929 (61.9)         | 31,803 (60.4)      | 0.04    |
| Liver disease                   | 143 (2.3)        | 184 (1.4)           | 770 (1.5)          | 0.06    |
| Fluid and electrolyte disorders | 804 (13.1)       | 1855 (14.5)         | 7343 (13.9)        | 0.64    |
| Metastatic cancer               | 744 (12.1)       | 1747 (13.6)         | 7436 (14.1)        | 0.23    |
| Obesity                         | 438 (7.1)        | 1001 (7.8)          | 4084 (7.8)         | 0.79    |
| Peripheral vascular disorders   | 599 (9.8)        | 1245 (9.7)          | 4678 (8.9)         | 0.35    |
| Psychoses                       | 146 (2.4)        | 386 (3.0)           | 1122 (2.1)         | 0.04    |
| Pulmonary circulation disorders | 165 (2.7)        | 180 (1.4)           | 872 (1.7)          | 0.01    |
| Renal failure                   | 301 (4.9)        | 647 (5.1)           | 2766 (5.3)         | 0.85    |
| Weight loss                     | 186 (3.0)        | 327 (2.5)           | 1560 (3.0)         | 0.55    |
| Smoking                         | 3536 (57.6)      | 7691 (60.0)         | 30,551 (58.0)      | 0.43    |
| Prior MI                         | 1363 (22.2)      | 3592 (28.0)         | 12,995 (24.7)      | <0.01   |
| Prior transient ischemic attack/stroke | 1404 (22.9) | 2918 (22.8)         | 11,561 (21.9)      | 0.57    |
| APRDRG_Risk mortality           | 1.7 (0.8)        | 1.7 (0.8)           | 1.8 (0.8)          | <0.01   |
| APRDRG_Severity                 | 2.0 (0.8)        | 2.1 (0.8)           | 2.0 (0.8)          | <0.01   |
| Charlson comorbidity index      | 3.7 (2.2)        | 3.8 (2.3)           | 3.8 (2.3)          | <0.01   |
| Sum of Elixhauser comorbidities | 3.5 (1.6)        | 3.5 (1.6)           | 3.4 (1.5)          | <0.01   |
| **Hospital factors, n (%)**     |                  |                     |                    |         |
| Hospital region                 |                  |                     |                    | 0.04    |
| Northeast                       | 2330 (38.0)      | 3422 (26.7)         | 14,173 (26.9)      |         |
| Midwest                         | 939 (15.3)       | 1431 (11.2)         | 9354 (17.8)        |         |
| South                           | 1876 (30.6)      | 5696 (44.5)         | 20,002 (38.0)      |         |

(continued)
after risk adjustment, our study failed to demonstrate hospital size as an independent risk factor for adverse outcomes, while unsurprisingly, certain comorbidities and development of postoperative complications were associated with increased mortality risk. Interestingly, Medicaid compared with Medicare was associated with lower mortality risk in open cases, which diverges from earlier findings within the NIS and may represent Medicaid expansion during the study period, which has been shown to be associated with improved mortality for lung cancer. However, the finding that obesity was protective was rather felt to be because of the lack of granularity within the coding of this variable in the database, rather than a true finding.

Over the last decade, there has been an increased emphasis on surgeon/hospital volume effects on overall outcomes. Our study may support the prior studies, which suggest surgeon/and or hospital volume may impact outcomes rather than hospital size alone or geographic region. Furthermore, our study did observe statistically different cost charges for open or for VATS surgery by hospital size. In the case of open lobectomy, we believe the inflation-adjusted charges were clinically insignificant (cost difference of $643 dollars between large and small hospital size). However, for VATS lobectomy, the net difference in inflation-adjusted cost was $8349 between large and small hospital size, which may suggest despite improving outcomes at smaller hospitals, it may be overall cost-effective to perform VATS lobectomy at larger hospitals.

Although we identified an annual improvement in outcomes for both open and VATS lobectomy in smaller

| Variable | Small (n = 6140) | Medium (n = 12,811) | Large (n = 52,687) | P value |
|----------|-----------------|---------------------|-------------------|---------|
| Acute MI | 73 (1.2)        | 85 (0.7)            | 392 (0.7)         | 0.2     |
| AKI      | 244 (4.0)       | 560 (4.3)           | 2159 (4.1)        | 0.79    |
| Major bleed | 220 (3.6)      | 431 (3.4)           | 1380 (2.6)        | 0.03*   |
| Pulmonary embolism | 56 (0.9)   | 30 (0.2)            | 241 (0.5)         | 0.01*   |
| Stroke   | 29 (0.5)        | 60 (0.5)            | 254 (0.5)         | 0.99    |
| Death    | 126 (2.1)       | 177 (1.4)           | 681 (1.3)         | 0.23    |

West 994 (16.2) 2263 (17.7) 9159 (17.4) 0.04*

Government or private, collapsed category 2253 (36.7) 4524 (35.3) 19,894 (37.8)
Government, nonfederal 730 (11.9) 430 (3.4) 3835 (7.3)
Private, nonprofit 2713 (44.2) 6647 (51.9) 25,999 (49.4)
Private, invest own 444 (7.2) 1200 (9.4) 2867 (5.4)

Location/teaching status of hospital
Rural - 66 (0.5) 1779 (3.4)
Urban nonteaching 380 (6.2) 3869 (30.2) 14,397 (27.3)
Urban teaching 5755 (93.7) 8878 (69.3) 36,511 (69.3)

APRDRG = All Patients Refined Diagnosis Related Groups.
*P < 0.05 = n < 11 per NIS guidelines.
hospitals, a similar significant trend was not identified for medium and larger hospitals. We hypothesize these different trends reflect major system-wide changes to smaller hospitals (rather than underlying differences in patient population), with significant advances in patient selection, surgical technique of lobectomies, increased cumulative experience of surgeons at small hospitals, and better perioperative care, as more thoracic surgery has moved out to the community, and with it, academic surgeons.\(^{31}\)

The results of our study should be interpreted in light of both its strengths and limitations. The NIS is derived from hospital claims data without access to individual medical records and is subject to the shortcomings of administrative datasets. Inconsistent coding practices among institutions may have resulted in overestimation or underestimation of patient comorbidities and hospital outcomes, although HCUP quality control measures are in place to minimize these discrepancies. Sampling practices of the NIS also vary from year to year, as hospitals enter and leave the sampling frame, resulting in possible over- or under-sampling by study design. Despite our best efforts to use a validated coding scheme, residual confounding and miscategorization may exist. Furthermore, we were unable to examine long-term outcomes beyond a single admission, which limited our ability to assess trends and the effect of hospital size on readmissions and aggregate costs after the index hospitalization or long-term cancer-free survival after lobectomy. In addition, charges were inflation adjusted and reported by hospital size but not region, which may account for some differences in aggregate hospital costs. Because of the nature of our database, frailty could not be measured directly. The NIS also does not contain details on patient presentation, cancer pathology, surgeon experience, and details of surgical procedure, which would have been important, as these have previously been identified as risk factors for adverse outcome. However, our dataset may provide more information about real-world practice as opposed to databases, such as the GTSD, which is less generalizable because of the voluntary participation of institutions included in it, making it prone to selection bias.\(^{16,17}\)

Conclusions

In this nationally representative, multi-institutional study based on insurance claims data, we demonstrate that utilization of VATS lobectomies has steadily increased over time, more so among small hospitals compared with large hospitals. Although overall mortality was stable during the study period, mortality was only shown to improve in smaller hospitals. Furthermore, mortality rates for VATS remained consistently lower than for open lobectomy. These findings are hypothesis generating and provide useful data for benchmarking hospital performance in the current era of value-based reimbursement.

Author Contributions

A.R.D., S.H., R.S., A.A., M.R., S.S., M.T.J., and G.N.M. all participated in inception and design of the study. A.R.D., S.H., R.S., A.A., and M.R. participated in acquisition of data. A.R.D., S.H., R.S., A.A., M.R., S.S., M.T.J., and G.N.M. participated in data analysis. A.R.D., S.H., R.S., A.A., M.R., S.S., M.T.J., and G.N.M. participated in interpretation of data. A.R.D., S.H., R.S., A.A., M.R., S.S., M.T.J., and G.N.M. participated in drafting the article as well as final approval.

Meeting Presentation

The data have been previously presented at the American College of Surgeons meeting.

Acknowledgments

This study was supported in part by the generous donation of the Jack Mitchell Thoracic Oncology Fellowship. The authors wish to acknowledge Cheryl Zogg, PhD, from the Center for Surgery and Public Health at Brigham and Womens Hospital for providing statistical support.

Disclosure

No financial disclosures or conflicts of interest.

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