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ORIGINAL SCIENTIFIC REPORT

Short-Term Readmissions After Open, Thoracoscopic, and Robotic Lobectomy for Lung Cancer Based on the Nationwide Readmissions Database

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Abstract

Background Readmission after surgery is an established surrogate indicator of quality of care. We aimed to compare short-term readmission rates and patient outcomes between open, video-assisted thoracoscopic (VATS), and robotic lobectomies in the Nationwide Readmissions Database (NRD).

Methods Adults who underwent open, VATS, or robotic lobectomy for lung cancer from 2010 to 2014 were evaluated. Propensity-matched analysis was used to assess differences in readmission characteristics, GDP-adjusted cost, and mortality.

Results Of the 129,539 lobectomies for lung cancer, 74,493 (57.5%) were open, 48,185 (37.2%) VATS, and 6861 (5.3%) robotic. Open surgery was associated with significantly higher readmission rate (10.5 vs 9.3%, $p < 0.001$), mortality (2 vs 1.2%, $p < 0.001$), index hospitalization cost [$21,846 (16,158–31,034) vs $20,779 (15,619–27,920), $p < 0.001$], and length of stay [6 (5–9) vs 4 (3–7) days, $p < 0.001$] compared to minimally invasive surgery. The robotic approach had similar mortality, readmission rate, and length of stay compared to VATS, but higher index cost [$23,870 (18,372–31,300) vs $20,279 (15,275–27,375), $p < 0.001$] and incidence of pulmonary complication (35.9 vs 31.6%, $p < 0.001$). The robotic approach was associated with greater direct discharges to home.

Conclusions Analysis of the NRD revealed significantly reduced readmission rates, better clinical outcomes, and lower cost in the minimally invasive approach compared to open surgery. Although VATS and robotic surgery had similar readmission and mortality rates, VATS is associated with significantly reduced risk of short-term complications and lower cost.

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Introduction

Unintended readmission following major surgery has been selected as an indicator for quality of care due to its association with morbidity, mortality, and delayed postoperative recovery [1, 2]. Excess rehospitalizations after selected diagnoses and procedures including acute myocardial infarction, chronic obstructive pulmonary disease, coronary artery bypass grafting, and hip and knee arthroplasty have led to reimbursement penalties of up to 1% by the Centers for Medicare and Medicaid (CMS) under the Hospital Readmissions Reduction Program [1, 3–6]. While pulmonary lobectomy is not currently included in this selection, it is one of the most common procedures performed by thoracic surgeons [7] and penalization for unexpected readmissions may be forthcoming.

Previous studies have reported 30-day readmission rates following overall lobectomy to range from 11.5 to 12.8% [2, 4, 8], which is likely influenced by the inherently high-risk and complex patient population. Various strategies have been devised to enhance patient recovery and reduce postoperative complications that may result in readmission. The use of minimally invasive lobectomy (MIS) for early stage lung cancer has rapidly expanded in recent years and has been shown to yield acceptable clinical and oncologic outcomes [7, 9–14]. While some suggest MIS confers lower readmission rates compared to open surgery, the association between approach and the likelihood of readmission remains unclear [4, 15].

Due to the limited nationwide data on unintended rehospitalizations and its contributing factors, we aimed to characterize short-term readmissions, clinical outcomes, and resource utilization in lung cancer patients undergoing open, video-assisted thoracoscopic (VATS), and robotic lobectomy using the Nationwide Readmissions Database (NRD). These data may contribute to knowledge of predictors and causes of rehospitalization as reported in the NRD and aid with the identification of high-risk lobectomy patients across the USA.

Materials and methods

Database

Discharge records in the Nationwide Readmissions Database (NRD) from 2010 to 2014 were evaluated. The NRD is an inpatient dataset maintained by the Healthcare Cost and Utilization Project (HCUP) that contains an estimated 36 million hospitalizations using a well-validated weighting and stratification algorithm [16]. This unique database was designed to facilitate analyses of national readmission rates for all payers including the uninsured. Discharge records were obtained from all hospital types across the USA, excluding rehabilitation or long-term acute care hospitals. Unique patient linkage numbers from 27 states as identified by the State Inpatient Databases (SID) were used to track patients across hospitals within a state. Given that these linkage numbers do not track patients over multiple years, each calendar year within the NRD functioned as a separate sample from which the relationship between index visit and readmission was determined. Additionally, HCUP cost-to-charge ratio files contain hospital-specific ratios based on all-payer inpatient cost to allow for the translation of hospital charges into actual costs. Costs were adjusted for inflation using annual consumer price index estimates. This study was exempt from the University of California at Los Angeles Institutional Review Board approval due to the de-identified nature of the NRD.

Study population

The study population consisted of all adult patients (>/=18 years) who underwent pulmonary lobectomy for malignant neoplasm of the bronchus or lung. International Classification of Diseases, Ninth Edition, Clinical Modification (ICD-9-CM) procedure codes were used to identify open lobectomy (32.49), VATS (32.41), and robotic lobectomy (32.41 with robotic modifiers 17.45, 17.49). Patients were categorized into open, VATS, robotic, or MIS cohorts, which included both robotic and VATS approaches.

To ensure complete 30-day follow-up within one calendar year, discharges between November 1 and December 31 were excluded from analysis. Further exclusion criteria included patients with prior thoracotomy (ICD-9-CM 34.04), conversion of VATS or robotic lobectomy to open surgery, concurrent malignant disease, and missing verified patient linkage number. Sensitivity analysis based on intent to treat design of patients converted to open surgery was performed. Patients undergoing VATS and robotic surgery who were subsequently converted to open surgery remained in their initial VATS and robotic cohorts, respectively.

Variables of interest

The primary outcome of interest was the relationship between lobectomy surgical approach and 30-day readmission rate. Several secondary endpoints were also considered: in-hospital mortality, hospital costs, index and readmission length of stay, causes for readmission, and independent predictors of readmission. Data collection included age, gender, history of coronary artery disease, congestive heart failure, preexisting or new-onset atrial fibrillation, hypertension, diabetes, hyperlipidemia, peripheral vascular disease, chronic pulmonary disease, renal insufficiency, prior or current tobacco use, primary expected payer, hospital teaching status, and hospital bed size. The Elixhauser Comorbidity Index was used to measure 30 categories of comorbidity based on ICD-9-CM diagnosis codes [17]. Underinsured status was defined as having Medicaid, self-pay, or no charge as the primary expected payer for the index admission. Medicare severity diagnosis-related group (MS-DRG) codes with corresponding MS-DRG titles were used to identify diagnoses and procedures at readmission including pneumothorax, respiratory system diagnosis, simple pneumonia and pleurisy, pleural effusion, pulmonary embolism, chronic obstructive pulmonary disease, cardiac arrhythmia, heart failure and shock, sepsis, postoperative infection, gastrointestinal disorder or hemorrhage, and major chest procedure.

Statistical analysis

Data extraction and analyses were performed with STATA 14.0 software (StataCorp, College Station, TX). Survey weighting methodology including sample weights and hospital clusters [16] were used in demographic comparison, propensity score matching, and the final outcomes analysis. Patient demographics, hospital characteristics, and outcomes were evaluated using the *t* test for continuous variables, Rao–Scott Chi-square test for categorical variables, and Chi-square test for trends. Continuous variables were summarized as median (interquartile range). Statistical significance was defined as a *p* value less than 0.05.

We used a propensity score approach to match subjects for two primary comparisons: open versus MIS and VATS versus robotics. The propensity scores were developed by using logistic regression with open versus MIS as the outcome. Covariates included age, gender, baseline comorbidities, method of payment, hospital bed size, location, and teaching status. A one-to-one nearest neighbor propensity score matching model was performed, followed by tests of the balancing property of observed covariates using the commands *pscore, pbalchk, psmatch2*, and *psgraph*. The same methodology was used in the propensity score matching of the VATS and robotic cohorts. Next, we used regression models to compare surgical procedures and clinical outcomes. These models used mixed effects logistic regression which included random effect for propensity score match and survey weights. Univariable analysis of the covariates previously described was considered in the initial analysis. Independent variables with a p-value less than 0.2 on univariable analysis were used in a multivariable regression model to identify independent predictors of 30-day readmission.

Results

Patient demographics and hospital characteristics

During the 5-year study period, a weighted estimate of 129,539 patients underwent lobectomy for lung cancer. Overall, 74,493 (57.5%) cases were performed open, 48,185 (37.2%) VATS, and 6861 (5.3%) robotically. Conversion to open surgery was seen in 17.2% of VATS and 1.6% of robotic cases. Patient characteristics for the total patient population are summarized in Table 1. Overall, patients undergoing MIS on average were older (67.8 vs 67.4 years, $p < 0.001$), more likely to be female (55.8 vs 50.2%, $p < 0.001$), and had a lower Elixhauser comorbidity score (3.43 vs 3.67, $p < 0.001$) compared to those undergoing open lobectomy. On MIS subgroup analysis, patients undergoing robotic lobectomy were older (68.4 vs 67.8 years, $p < 0.001$), more likely to have a history of smoking (65% vs 61.4%, $p = 0.006$), and had a higher Elixhauser comorbidity score (3.47 vs 3.43, $p < 0.001$) compared to the VATS group. Baseline characteristics for patients readmitted and not readmitted within 30 days are given in Table 2. Patients in the readmitted group were of older age (68.6 vs 67.5 years, $p < 0.001$) and had a significantly higher Elixhauser comorbidity score (3.92 vs 3.52, $p < 0.001$) than those who were not readmitted. Among the readmitted sample, patients receiving open surgery had a greater Elixhauser comorbidity score compared to MIS (4.0 vs 3.8, $p < 0.001$); yet, the robotic and VATS groups had equivalent Elixhauser comorbidity scores (3.9 vs 3.8, $p = 0.18$).

Outcomes

In propensity-matched analysis, 13,601 (10.5%) patients were readmitted within 30 days following lobectomy (Table 3). Open surgery was associated with a significantly greater 30-day readmission rate compared to MIS (10.5% vs 9.3%, $p < 0.001$), while the readmission rates were similar between VATS and robotic (8.8% vs 8.5%, $p = 0.67$). In a separate analysis based on intent to treat design of patients converted to open surgery, the open cohort continued to have higher readmission compared to MIS (10.6% vs 9.3%, $p < 0.001$), while the readmission rate remained nonsignificant between VATS and robotic (8.7% vs 8.5%, $p = 0.69$).

The primary diagnoses and procedures at readmission across all three approaches are given in Table 4. At readmission, the robotic group had significantly higher rate of

Table 1 Baseline clinical characteristics for each procedure type

Baseline characteristics	Open N = 74,493 (57.5%)	MIS N = 55,046 (42.5%)	p Value	VATS N = 48,185 (37.2%)	Robotic N = 6861 (5.3%)	p Value
Age (years ± SD)	67.4 ± 9.5	67.8 ± 10	<0.001	67.8 ± 9.8	68.4 ± 9.5	<0.001
Female	37,415 (50.2%)	30,694 (55.8%)	<0.001	26,876 (55.8%)	3817 (55.6%)	0.9
Coronary artery disease	15,511 (20.8%)	10,527 (19.1%)	<0.001	9231 (19.2%)	1296 (18.9%)	0.8
Congestive heart failure	2972 (4%)	1734 (3.1%)	<0.001	1523 (3.2%)	210 (3.1%)	0.8
Atrial fibrillation	14,244 (19.1%)	9128 (16.6%)	<0.001	8092 (16.8%)	1035 (15.1%)	0.03
Hypertension	38,324 (51.5%)	29,306 (53.2%)	0.002	25,427 (52.8%)	3880 (56.6%)	<0.001
Diabetes	13,426 (18%)	9422 (17.1%)	0.01	8181 (17%)	1241 (18.1%)	0.17
Hyperlipidemia	28,970 (38.9%)	22,528 (40.9%)	<0.001	19,809 (41.1%)	2718 (39.6%)	0.33
Peripheral vascular disease	6383 (8.6%)	4916 (8.9%)	0.30	4360 (9.1%)	556 (8.1%)	0.2
Chronic pulmonary disease	36,484 (49%)	23,249 (42.2%)	<0.001	20,192 (41.9%)	3057 (44.6%)	0.03
Renal insufficiency	4142 (5.6%)	2916 (5.3%)	0.30	2577 (5.4%)	339 (4.9%)	0.4
Smoking (current/former)	46,233 (62.1%)	34,027 (61.8%)	0.73	29,568 (61.4%)	4459 (65.0%)	0.006
Elixhauser comorbidity score	3.67	3.43	<0.001	3.43	3.47	<0.001
Primary expected payer						
Medicare	47,923 (64.3%)	35,114 (63.8%)	0.46	30,444 (63.2%)	4670 (68.1%)	0.002
Private	19,941 (26.8%)	15,980 (29%)	0.004	14,182 (29.4%)	1797 (26.2%)	0.03
Underinsured (Medicaid, self-pay, no charge)	4983 (6.7%)	3016 (5.5%)	<0.001	2730 (5.7%)	287 (4.2%)	0.007
Hospital status						
Metropolitan, non-teaching	23,221 (31.2%)	12,066 (21.9%)	<0.001	10,692 (22.2%)	1374 (20.0%)	0.47
Metropolitan, teaching	47,497 (63.8%)	42,313 (76.9%)	<0.001	36,931 (76.6%)	5382 (78.4%)	0.56
Non-metropolitan	3775 (5.1%)	667 (1.2%)	<0.001	562 (1.2%)	105 (1.5%)	0.59
Small bed size	6329 (8.5%)	5385 (9.8%)	0.34	4480 (9.0%)	906 (13.2%)	0.28
Medium bed size	14,202 (19.1%)	7540 (13.7%)	<0.001	6457 (13.4%)	1083 (15.8%)	0.32
Large bed size	53,962 (72.4%)	42,121 (76.5%)	0.02	37,248 (77.3%)	4873 (71.0%)	0.12

undergoing a major chest procedure (6.01% vs 3.01%, $p = 0.03$), compared to VATS. MIS had significantly higher rate of pneumothorax (9.87% vs 7.34%, $p = 0.003$) at readmission, yet lower rate of sepsis (3.43% vs 5.47%, $p = 0.001$) compared to the open cohort.

Open lobectomy was associated with greater in-hospital mortality (2.02 vs 1.18%, $p < 0.001$), costs [$21,846 (16,158–31,034) vs $20,779 (15,619–27,920), $p < 0.001$], and length of stay [6 (5–9) vs 4 (3–7) days, $p < 0.001$] compared to MIS (Table 3). Among MIS, robotic lobectomy had higher costs [$23,870 (18,372–31,300) vs $20,279 (15,275–27,375), $p < 0.001$], discharges to home (94.0% vs 91.9%, $p = 0.006$), and rate of pulmonary complication (35.9% vs 31.6%, $p < 0.001$) compared to VATS. However, in-hospital mortality (0.96% vs 0.77%, $p = 0.42$) and length of stay [4 (3–6) vs 5 (3–7) days, $p = 0.14$] were similar between robotic and VATS, respectively. Upon intent to treat analysis of patients converted to open surgery, in-hospital mortality remained nonsignificant between VATS and robotic groups (0.99% vs 0.96%, $p = 0.89$). Open surgery had higher in-hospital mortality compared to MIS (2% vs 1.2%, $p < 0.001$). Further readmission characteristics are described in Table 3.

Predictors of readmission

Multivariable logistic regression analysis for 30-day readmission is described in Table 5. Open approach (OR 1.12, $p < 0.001$), age (OR 1.005, $p = 0.01$), coronary artery disease (OR 1.17, $p = 0.01$), congestive heart failure (OR 1.49, $p < 0.001$), preexisting or new-onset atrial fibrillation (OR 1.36, $p < 0.001$), peripheral vascular disease (OR 1.13, $p = 0.004$), chronic pulmonary disease (OR 1.26, $p < 0.001$), renal insufficiency (OR 1.14, $p = 0.02$), and pulmonary complications (OR 1.18, $p < 0.001$) were independent predictors of 30-day readmission. Female gender (OR 0.83, $p < 0.001$), hyperlipidemia (OR 0.89, $p < 0.001$), and history of smoking (OR 0.91, $p = 0.003$) were associated with reducing the likelihood of readmission.

Table 2 Baseline characteristics of patients readmitted and not readmitted within 30 days

Baseline characteristics	Readmitted within 30 days N = 13,601 (10.5%)	Not readmitted within 30 days N = 115,937 (89.5%)	p Value
Age (years ± SD)	68.6 ± 9.7	67.5 ± 9.7	<0.001
Female	6363 (46.7%)	61,745 (53.3%)	<0.001
Coronary artery disease	3382 (24.8%)	22,655 (19.5%)	<0.001
Congestive heart failure	876 (6.4%)	3829 (3.3%)	<0.001
Atrial fibrillation	3373 (24.8%)	19,999 (17.3%)	<0.001
Hypertension	6914 (50.7%)	60,715 (52.4%)	0.06
Diabetes	2567 (18.8%)	20,280 (17.5%)	0.02
Hyperlipidemia	5141 (37.7%)	46,356 (40%)	<0.001
Peripheral vascular disease	1454 (10.7%)	9845 (8.5%)	<0.001
Chronic pulmonary disease	7123 (52.3%)	52,609 (45.4%)	<0.001
Renal insufficiency	932 (6.8%)	6126 (5.3%)	<0.001
Smoking (current/former)	8062 (59.1%)	72,197 (62.3%)	<0.001
Elixhauser comorbidity score	3.92	3.52	<0.001
Primary expected payer			
Medicare	9306 (68.3%)	73,731 (63.6%)	<0.001
Private	3208 (23.5%)	32,712 (28.2%)	<0.001
Underinsured (Medicaid, self-pay, no charge)	858 (6.3%)	7140 (6.2%)	0.74
Hospital status			
Metropolitan, non-teaching	3907 (28.7%)	31,379 (27.1%)	0.03
Metropolitan, teaching	9212 (67.6%)	80,597 (69.5%)	0.01
Non-metropolitan	508 (3.7%)	3934 (3.4%)	0.25
Small bed size	1198 (8.5%)	10,516 (9.1%)	0.54
Medium bed size	14,202 (19.1%)	19,573 (16.9%)	0.11
Large bed size	53,962 (72.4%)	85,821 (74%)	0.08

Table 3 Outcomes post-propensity matching

Outcome	Open N = 22,412 (57.5%)	MIS N = 22,412 (42.5%)	p Value	VATS N = 3217 (37.5%)	Robotic N = 3217 (5.3%)	p Value
In-hospital mortality (%)	2.02	1.18	<0.001	0.77	0.96	0.42
Cost	21,846 (16,158–31,034)	20,779 (15,619–27,920)	<0.001	20,279 (15,275–27,375)	23,870 (18,372–31,300)	<0.001
Length of stay	6 (5–9)	4 (3–7)	<0.001	5 (3–7)	4 (3–6)	0.14
Pulmonary complication (%)	38.9	32.7	<0.001	31.6	35.9	<0.001
Discharge home (%)	88.1	92.2	<0.001	91.9	94.0	0.006
Readmission visit						
30-day readmission rate (%)	10.5	9.3	<0.001	8.8	8.5	0.67
Cost	8860 (4962–18,485)	8193 (4353–16,425)	0.01	8088 (4522–16,031)	9565 (4746–19,891)	0.75
Length of stay	5 (3–9)	4 (2–7)	<0.001	4 (2–7)	4 (2–9)	0.13

Cost and length of stay (LOS) data are reported as median (IQR) in 2014 US dollars and in days, respectively

Discussion

In our study of the Nationwide Readmissions Database (NRD) from 2010 to 2014, we report an all-cause readmission rate of 10.5%, which is in accordance with the current literature [2, 4, 15, 18, 19]. A study using the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) database reported a 30-day readmission rate of 11.9% following all thoracic operations [18]. Additionally, Hu and colleagues' recent

Table 4 Primary diagnoses and procedures at 30-day readmission

Diagnoses	Open $N = 8450$ (62.0%)	MIS $N = 5177$ (38.0%)	p Value	VATS $N = 4607$ (33.8%)	Robotic $N = 571$(4.2%)	p Value
Pneumothorax	7.3	9.9	0.003	10.1	8.4	0.42
Respiratory system diagnosis	8.1	7.6	0.67	7.8	6.3	0.4
Simple pneumonia and pleurisy	7.8	7.0	0.37	7.1	6.5	0.75
Pleural effusion	5	5.5	0.48	5.3	7	0.27
Pulmonary embolism	3.9	3.3	0.37	3.3	3.4	0.87
Chronic obstructive pulmonary disease	2.6	2.2	0.45	2.1	3.2	0.29
Cardiac arrhythmia	3.4	3.7	0.59	3.6	4.9	0.26
Heart failure and shock	1.9	1.3	0.13	1.2	2.4	0.13
Sepsis	5.5	3.4	0.001	3.3	4.5	0.28
Postoperative infection	4.5	4.0	0.4	4.2	2.3	0.12
Gastrointestinal disorder or hemorrhage	3.9	4.4	0.42	4.3	4.7	0.81
Procedures						
Major chest procedure	2.8	3.3	0.33	3	6	0.03

Diagnoses and procedures are reported as percentages

analysis of the SEER–Medicare database revealed an overall 30-day readmission rate of 12.8% for lung cancer resection [2]. However, the SEER–Medicare dataset has limited operative admission information and excludes records of patients under the age of 65. Stiles and colleagues report a 30-day readmission rate of 11.5% in an analysis of the State Inpatient Database in the Healthcare Cost and Utilization Project (SID HCUP), which obtains admission records from the states of California, Florida, and New York [4]. In contrast, our analysis of a nationally representative sample in the NRD allows for a more broadly generalizable study and may better represent operative experiences across the USA.

We further characterize readmissions by identifying the common diagnoses and procedures at the second hospitalization. Of note, this coding process is subject to the limitations of the NRD and may not concretely distinguish an admission directly related to the lobectomy from that secondary to other causes. While patients undergoing open surgery had a lower incidence of pneumothorax compared to MIS at the time of readmission, both the robotic and VATS cohorts had similar rates of all pulmonary diagnoses at readmission, including pneumothorax, pneumonia, pleurisy, and pleural effusion. This is in line with the current literature documenting pulmonary causes and postoperative infection as significant contributors to unplanned rehospitalization [1, 5, 19, 20].

Our investigation illustrated similar 30-day readmission among the robotic and VATS cohorts, while open surgery had a greater incidence of readmission compared to MIS. Patients with advanced stages of malignancy, central lesions, or status post-chemotherapy/radiation therapy [21] may be more likely to undergo open surgery, creating selection bias. These underlying factors as well as the higher burden of comorbid conditions made evident by the Elixhauser comorbidity score for the open surgery group likely contribute to this higher readmission rate. The longer length of stay and greater incidence of pulmonary complications associated with robotic lobectomy at index admission may be due to the greater burden of hypertension, chronic pulmonary disease, and smoking history in

Table 5 Predictors of 30-day readmission after lobectomy

Variable	Adjusted odds ratio	95% confidence interval	p Value
Open	1.12	1.06–1.20	<0.001
VATS	Reference	–	–
Robotic	0.89	0.77–1.02	0.09
Congestive heart failure	1.49	1.32–1.70	<0.001
Atrial fibrillation	1.36	11.27–1.46	<0.001
Chronic pulmonary disease	1.26	1.19–1.34	<0.001
Pulmonary complications	1.18	1.11–1.25	<0.001
Coronary artery disease	1.17	1.09–1.24	<0.001
Peripheral vascular disease	1.13	1.03–1.24	0.004
Renal insufficiency	1.14	1.01–1.28	0.02
Age (years)	1.005	1.001–1.009	0.01
Smoking	0.91	0.86–0.97	0.003
Hyperlipidemia	0.89	0.84–0.95	<0.001
Female	0.83	0.79–0.89	<0.001

Multivariable regression analysis to identify independent variables associated with all-cause readmission within 30 days that patient population. The greater costs associated with robotic lobectomy are consistent with the current literature on resource utilization and cost-effectiveness of the contemporary robot [7, 12]. Robotic surgery often requires an additional surgeon, a specialized team, and longer operative times. The use of disposable tools and maintenance costs of up to $180,000 per year are also likely drivers of the greater costs compared to VATS [7, 12]. Upon readmission, the VATS and robotic groups had equivalent hospital costs and lengths of stay, which may be due to a similar burden of underlying disease states as supported by the equivalent Elixhauser comorbidity scores.

In an effort to maintain economic efficiency and develop more conscientious processes in healthcare resource utilization, predictors of readmission are under comprehensive investigation. In our analysis of patient demographics and surgical approach, the variables associated with 30-day readmission included older age, open surgery, several individual comorbidities, and pulmonary complications at the index admission. These results are in agreement with other series [1, 2] and develop the existing body of evidence through the use of a large nationwide database and multivariable regression analysis. In contrast, a recent single-institution series [15] and an analysis using SID HCUP [4] failed to identify surgical approach as an independent predictor of readmission. The significance of these differences is difficult to evaluate due to the difference in sample size and patient population among these studies.

The likelihood of readmission is further complicated by unalterable patient demographics and variability in peri- and postoperative factors such as geographic location of the acute care hospital, family support, and access to outpatient care [1, 4, 5]. In a single-institution investigation, Dickinson and colleagues suggest physiologic status, residence in a nursing home, and a low preoperative FEV_1 can predict mortality and unplanned readmissions following elective lung resection [1]. Thus, building awareness of comorbidities, frailty status, and pathologic diagnosis necessitating lung resection and utilizing preoperative rehabilitation may aid in the identification of higher-risk patients and reduce the likelihood of readmission [1, 22].

The present study has several important limitations, including its retrospective methodology. One concern noted in the current readmissions literature is the difficulty in capturing all readmission events after pulmonary lobectomy [1, 2, 19]. Interestingly, it has been reported that 17% of rehospitalizations took place at an institution other than the one that performed the index lobectomy [19]. Patient linkage numbers identify hospitalizations within a given state in one calendar year; thus, a readmission at an establishment in a different state or in the following year would not be included in our dataset. Along similar lines, mortality data on patients who died outside of the hospital were not obtained, which may underestimate our reported mortality outcomes.

The NRD is an administrative database that lacks detailed clinical data including preoperative pulmonary function tests and laboratory tests, perioperative characteristics, length of ICU stay, and medications. The ICD-9 coding for surgical procedures and baseline comorbidities is subject to the limitations of the NRD, and the likely under-coding of these variables may create an inaccurate representation of our patient population. Unfortunately, there is also an absence of granular oncologic data such as the staging of lung cancer, histologic subtype, the presence of induction therapy, and tumor location and size. Given that these clinical factors may considerably impact readmissions after pulmonary lobectomy, the absence of these components must be taken into consideration throughout our analysis.

Investigators evaluating readmissions have often commented on the difficulties of distinguishing an unplanned rehospitalization related to the index surgery from that secondary to another underlying condition [1, 4, 19]. To help mitigate this concern, we utilized MS-DRG codes which are defined by a particular set of patient attributes including principal diagnosis/procedure, sex, and discharge status. Moreover, we assume that non-surgery-related readmissions are likely to be relatively balanced, in principle, among our patient groups and are thus may not considerably impact our analysis.

In addition, a selection bias for surgical approach and thus the significant differences in patient populations in each group presents a difficulty in drawing concrete conclusions when comparing clinical outcomes. Excluding patients who underwent MIS approaches that required conversion to open surgery can potentially bias our investigation. We carefully conducted a separate analysis based on intent to treat design to include patients converted to open surgery and found the relationships between 30-day readmissions and surgical approach were largely unchanged from our initial findings. Although our large sample size allows us to identify subtle differences, it remains difficult to interpret the associated clinical relevance of statistically significant differences that are minor in absolute terms (for example, differences of age on the order of months are unlikely to be clinically significant). Additionally, the surgeon's learning curve for operating with video-assisted and robotic techniques may also affect patient outcomes including morbidity and mortality, and this quality was not accounted for in our study [23, 24].

In conclusion, MIS for lung cancer resection reduces readmission rates and provides exceptional patient-centered and economic benefits compared to open surgery. Except for a higher rate of discharge to home, robotic lobectomy illustrated no significant advantage over VATS, but had higher costs, length of stay, and incidence of pulmonary complications. Open surgery, age, cardiopulmonary comorbidities, and pulmonary complications at the index admission were all independent predictors of 30-day readmission. An improved understanding of risk factors for rehospitalization after pulmonary lobectomy with appropriate intervention may enable relevant preventative interventions and alleviate the economic burden of unplanned readmissions.

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Author's contribution KLB took part in study design, data collection, data analysis, data interpretation, article drafting, and critical revision; NM performed article drafting; YJS was involved in data collection; DE carried out data analysis and critical revision; PB conducted study design, article drafting, and critical revision; and JY took part in study design, data analysis, data interpretation, and critical revision.

Compliance with ethical standards

Conflict of interest The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this manuscript.

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