Comparing robot-assisted thoracic surgical lobectomy with conventional video-assisted thoracic surgical lobectomy and wedge resection: Results from a multihospital database (Premier)

Scott J. Swanson, MD,^a Daniel L. Miller, MD,^b Robert Joseph McKenna, Jr, MD,^c John Howington, MD,^d M. Blair Marshall, MD,^e Andrew C. Yoo, MD,^f Matthew Moore, MHA,^g Candace L. Gunnarsson, EdD,^h and Bryan F. Meyers, MDⁱ

Background: Video-assisted thoracic surgical (VATS) lobectomies and wedge resections result in less morbidity and shorter length of stay than resections via thoracotomy. The impact of robot-assisted thoracic surgical (RATS) lobectomy on clinical and economic outcomes has not been examined. This study compared hospital costs and clinical outcomes for VATS lobectomies and wedge resections versus RATS.

Methods: Using the Premier hospital database, patients aged ≥ 18 years with a record of thoracoscopic lobectomy, segmental resection, or excision of a lesion or tissue from the lung between 2009 and 2011 were identified. Procedures using robotic technology were identified if 1 of 2 conditions were met: (1) a robotic *International Classification of Diseases, Ninth Revision* procedure code or (2) the text fields in the hospital record indicated that the robot was used. Using a propensity score and based on severity and comorbidities, certain demographics and hospital characteristics were matched. The association between VATS or RATS and adverse events, hospital costs, surgery time, and length of stay was examined.

Results: Of 15,502 patient records analyzed, 96% ($n = 14,837$) were performed without robotic assistance. Using robotic assistance was associated with higher average hospital costs per patient. The average cost of inpatient procedures with RATS was \$25,040.70 versus \$20,476.60 for VATS ($P = .0001$) for lobectomies and \$19,592.40 versus \$16,600.10 ($P = .0001$) for wedge resections, respectively. Inpatient operating times were longer for RATS lobectomy than VATS lobectomy (4.49 hours vs 4.23 hours; $P = .0959$) and wedge resection (3.26 vs 2.86 hours; $P = .0003$). Length of stay was similar with no differences in adverse events.

Conclusions: RATS lobectomy and wedge resection seem to have higher hospital costs and longer operating times, without any differences in adverse events. (J Thorac Cardiovasc Surg 2014;147:929-37)

From the Division of Minimally Invasive Thoracic Surgery,^a Brigham and Women's Hospital, Dana-Farber Cancer Institute, Harvard Medical School, Boston, Mass; Division of Thoracic Surgery,^b Emory University Healthcare, Atlanta, Ga; Division of Thoracic Surgery,^c Cedars Sinai Medical Center, Los Angeles, Calif; Division of Thoracic Surgery and Surgical Quality,^d NorthShore University Health System, Evanston, Ill; Division of Thoracic Surgery,^e Georgetown University Medical Center, Washington, DC; Ethicon Endo-Surgery, Inc a Johnson & Johnson Company,^f Cincinnati, Ohio; Healthcare Policy and Economics,^g Ethicon Endo-Surgery, Cincinnati, Ohio; S² Statistical Solutions, Inc.,^h Cincinnati, Ohio; and Division of Cardiothoracic Surgery,ⁱ Barnes-Jewish Hospital Plaza, Washington University in St. Louis, St. Louis, Mo.

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Address for reprints: Candace L. Gunnarsson, 11176 Main St, Cincinnati, OH 45241 (E-mail: candaceg@s2stats.com).

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Lung surgery for the purpose of diagnosis or treatment has evolved in the past 2 decades. Historically, surgery involving the lung was accomplished using 1 of 2 main approaches, depending on the clinical indication: via a thoracoscope inserted using a small incision or by an open thoracotomy, involving a larger incision and rib spreading to improve visibility and access for control of the surgical anatomy.

Thoracoscopic procedures have been transformed by the ongoing refinement of video-assisted thoracoscopic surgery (VATS) techniques and equipment, particularly high-definition cameras and monitors. For traditional thoracotomy indications, VATS is an evolving technique and is increasingly applied in situations where traditional open thoracotomy has long been used. There is a small but increasing literature to support the growth of VATS in this context. However, VATS is still an evolving phenomenon, with a developing research base,¹⁻⁴ and with a variable definition.³⁻⁵ Variations exist in the number of port incisions and the appropriate incision length.

The purported benefits of VATS in lung surgery compared with open thoracotomy in the literature

Abbreviations and Acronyms

APR-	= All Patient Refined Diagnosis Related
DRG	Groups
ICD-9	= <i>International Classification of Diseases, Ninth Edition</i>
RATS	= robot-assisted thoracic surgical
SD	= standard deviation
VATS	= video-assisted thoracic surgical

published to date includes smaller incisions, less pain, less blood loss, less respiratory compromise, less complications, and faster recovery times, all translating into shorter length of stay and similar survival.⁶ These findings have been reported in systematic reviews of randomized and nonrandomized clinical trials,⁷ and in comparative studies.² In a comparative study of patients with lung cancer, Cajipe and colleagues,⁸ found that there were fewer complications in VATS patients (14 of 46, 30%) than their open counterparts (26 of 45, 58%; $P = .009$). VATS patients also had a chest tube for a shorter time and shorter length of stay. In multivariate analysis, VATS was associated independently with a reduced risk of complications (odds ratio, 0.359; $P = .04$).

The impact of RATS on clinical and economic outcomes has not been examined, however. This study compared hospital costs and clinical outcomes for VATS lung resection versus RATS lung resection.

Despite several publications in support of robotic surgery, controversy still remains over limited high-quality evidence of improved clinical outcomes compared with traditional minimally invasive approaches. Clinical outcomes suggest that robotic surgery is equivalent to conventional minimally invasive procedures when important end points such as conversion to open surgery, hospital stay, and recovery time are considered.^{9,10}

The adoption and diffusion of this technology in thoracic surgery, coupled with limited high-quality evidence of improved outcomes compared with traditional VATS procedures, raises important questions about resource allocation. The systems typically cost between \$1 million and \$2.5 million¹¹ plus an additional expensive yearly service contract. Additional direct costs of robotic-assisted surgery include instrument disposables and potentially increased procedure time.

In this era of comparative effectiveness and health care reform in the United States, and with concerns about resource utilization at the forefront, the trend toward RATS deserves further evaluation. Therefore, this study examined the clinical and economic outcomes (cost and utilization) in patients undergoing VATS lung resection versus RATS lung resection.

MATERIALS AND METHODS**Data Source**

The Premier hospital database was used as the data source for this study.¹² This database contains complete data on patient billing, hospital costs, and coding histories from more than 600 health care facilities throughout the United States. The data for this study were extracted from more than 25 million inpatient discharges and 175 million hospital outpatient visits from acute care facilities, ambulatory surgery centers, and clinics across the nation.

A protocol describing the analysis objectives, criteria for patient selection, data elements of interest, and statistical methods was submitted to the New England Institutional Review Board (NEIRB) and exemption was obtained.

Eligible patients were ≥ 8 years of age and had undergone a VATS lobectomy or wedge resection between 2009 and 2011, for which the lobectomy or wedge resection was the primary reason for surgery. Patients were categorized according to the following types of VATS procedure: lobectomy (code 32.41), wedge resection (code 32.30 or 32.20).

Lobectomy and wedge resection procedures using robotic technology were identified if 1 of the 2 following conditions were met: (1) a robotic *International Classification of Diseases, Ninth Edition* (ICD-9) procedure code accompanied the primary procedure code of interest or (2) text fields were found when mining the hospital charge master file for each patient indicating use of the robot. Procedures that involved conversion from minimally invasive to open or between robotic and VATS approaches were excluded from the analysis dataset.

For all eligible patients, elements describing hospital cost, surgery time, length of stay, use of robot, type of thoracic procedure, and indication for procedure were obtained from the data. Cost analysis (calculation) reflected the cost of the robotic procedure to the hospital but did not include acquisition or the annual maintenance fee for the da Vinci robot (Intuitive Surgical, Inc, Sunnyvale, Calif). The preoperative All Patient Refined Diagnosis Related Groups (APR-DRG) severity level was used as an index of comorbidity. The 3M APR-DRG Classification System is a widely adopted proprietary risk adjustment classification tool that uses information from routine claims data to produce valid and reliable severity measurement and risk adjustment scores.¹³ It is used to account for differences related to an individual's severity of illness or risk of mortality in large datasets. Comorbid conditions that might influence procedure selection or outcomes of interest, such as the presence of cardiovascular or pulmonary disease, cancer, or diabetes mellitus, were obtained using ICD-9 diagnosis codes. [Appendix Table 1](#) provides a detailed list of all ICD-9 codes for each condition included in the study. Information on sociodemographic characteristics and health insurance status was also included, as were descriptors of the care setting, namely census region, urban or rural setting, teaching hospital status, and facility bed count.

TABLE 1. Attrition

Description	Number of patients remaining	Number of patients dropped for this reason
Total number of patients in Premier database 2009 Q1 to 2011 Q2	102,914,774	
Patients with a primary procedure code for lobectomy or wedge resection (32.20, 32.30, 32.41)	15,965	102,898,809
Patients 18 y or older at date of procedure	15,596	369
Patients with inpatient visits only	15,502	94

TABLE 2. Patient demographics—before match

Category	Lobectomy					Wedge resection				
	RATS		VATS		P value	RATS		VATS		P value
	N	Percent	N	Percent		N	Percent	N	Percent	
Total number	335	100	3818	100		330	100	11,019	100	
Age (mean)	66.36		66.27		.8856	61.81		59.56		.0126
Age group					.9089					.1606
18-40 y	7	2.09	83	2.17		32	9.7	1443	13.1	
41-50 y	25	7.46	243	6.36		28	8.48	1302	11.82	
51-60 y	60	17.91	738	19.33		75	22.73	2263	20.54	
61-70 y	109	32.54	1288	33.73		98	29.7	2959	26.85	
71-80 y	102	30.45	1145	29.99		75	22.73	2359	21.41	
>80 y	32	9.55	321	8.41		22	6.67	693	6.29	
Gender					.4484					.7783
Female	176	52.54	2088	54.69		169	51.21	5451	49.47	
Male	159	47.46	1730	45.31		161	48.79	5564	50.49	
Unknown	0	0	0	0		0	0	4	0.04	
Insurance					<.0001					.7399
Government	195	58.21	2490	65.22		186	56.36	5973	54.21	
Managed care	124	37.01	977	25.59		103	31.21	3617	32.83	
Other	16	4.78	351	9.19		41	12.42	1429	12.97	
Race					<.0001					.0011
White	240	71.64	3012	78.89		264	80	8021	72.79	
African American	14	4.18	327	8.56		21	6.36	1045	9.48	
Hispanic	40	11.94	60	1.57		16	4.85	345	3.13	
Other	41	12.24	419	10.97		29	8.79	1608	14.59	
Health status*					.1353					.001
APR-DRG severity level (1, 2)	267	79.7	2905	76.09		273	82.73	8236	74.74	
APR-DRG severity level (3, 4)	68	20.3	913	23.91		57	17.27	2783	25.26	
Malignancy indication					.0093					.0006
No lung cancer	48	14.33	376	9.85		168	50.91	6761	61.36	
Primary neoplasm of the lung	266	79.4	3268	85.59		116	35.15	3064	27.81	
Metastases other than lung	21	6.27	174	4.56		46	13.94	1194	10.84	
Comorbid conditions										
Myocardial infarction, acute or old	30	8.96	358	9.38	.7994	30	9.09	825	7.49	.2767
Congestive heart failure	22	6.57	235	6.16	.7641	24	7.27	900	8.17	.5580
Chronic or unspecified heart failure	6	1.79	58	1.52	.6985	3	0.91	287	2.6	.0544
Peripheral vascular disease	30	8.96	396	10.37	.4125	25	7.58	798	7.24	.8178
Dementia	9	2.69	54	1.41	.0678	5	1.52	139	1.26	.6849
Chronic pulmonary disease	171	51.04	1917	50.21	.7694	163	49.39	5649	51.27	.5026
Connective tissue disease	8	2.39	149	3.9	.1634	18	5.45	549	4.98	.6980
Liver disease	18	5.37	184	4.82	.6514	23	6.97	647	5.87	.4043
Chronic viral hepatitis	0	0	33	0.86	.0876	5	1.52	113	1.03	.3876
Renal insufficiency, chronic	22	6.57	270	7.07	.7291	18	5.45	801	7.27	.2094
Diabetes mellitus	82	24.48	770	20.17	.0611	51	15.45	2161	19.61	.0603

RATS, Robot-assisted thoracic surgery; VATS, video-assisted thoracic surgery; APR-DRG, all patient refined diagnosis related group. *APR-DRG severity level was used as an index of preoperative comorbidity.

Adverse events (identified by ICD-9 codes) that occurred intraoperatively and within 30 days postoperatively that included pulmonary complications were flagged and included in the analysis. These were further grouped as major or minor complications for analysis. A detailed list of each event and the corresponding ICD-9 code is found in [Appendix Table 2](#).

Statistical Analysis

The study objective was to use the Premier hospital database to compare clinical and economic outcomes in patients undergoing lobectomy or

wedge resection using VATS versus RATS. Outcomes of interest included adverse events (minor and major), hospital costs, length of stay, and surgery time. Costs were the actual costs incurred by the hospital for all treatments and services related to the lobectomy and wedge resection and did not include robotic capital or service contracts.

A quasi-randomization method called propensity scoring was used to create groups of analyzable patients who were well matched. Propensity scores were assigned based on likely predictors of the outcome of interest. Covariates on which to match were selected based on their availability in the Premier database, as well as their general acceptance as factors associated with the outcomes of interest. The goal of this propensity-matching

TABLE 3. Hospital demographics based on patient counts

Category	Lobectomy					Wedge resection				
	RATS		VATS		P value	RATS		VATS		P value
	N	Percent	N	Percent		N	Percent	N	Percent	
Total number	335	100	3818	100		330	100	11,019	100	
Census region					<.0001					<.0001
Northeast	52	15.52	908	23.78		77	23.33	2858	25.94	
West	0	0	603	15.79		22	6.67	1755	15.93	
South	253	75.52	1693	44.34		200	60.61	4160	37.75	
Midwest	30	8.96	614	16.08		31	9.39	2246	20.38	
Location					.1851					.0539
Urban	315	94.03	3650	95.6		319	96.67	10,375	94.16	
Not urban	20	5.97	168	4.4		11	3.33	644	5.84	
Type					<.0001					<.0001
Teaching	292	87.16	2132	55.84		281	85.15	5744	52.13	
Nonteaching	43	12.84	1686	44.16		49	14.85	5275	47.87	
Bed count					.0023					.0585
<50	0	0	0	0		0	0	7	0.06	
51–100	0	0	15	0.39		0	0	40	0.36	
101–200	1	0.3	141	3.69		6	1.82	515	4.67	
>200	334	99.7	3662	95.91		324	98.18	10,457	94.9	

RATS, Robot-assisted thoracic surgery; VATS, video-assisted thoracic surgery.

analysis was to find pairs of patients receiving lobectomy or wedge resection via RATS or VATS procedures, who shared like propensities based on the matching variables. An SAS macro from the Mayo Clinic used nearest-neighbor matching on the estimated propensity scores to choose matches for the patients who had a RATS procedure.¹⁴ Propensity scores were calculated for receipt of robotic procedures for each patient included in the analysis based on a nonparsimonious multivariable logistic regression model. Patients were matched on the following characteristics: severity group, age, gender, race, region, size of facility, teaching facility (yes/no), location of facility, insurance group, malignancy status, chronic pulmonary disease, chronic viral hepatitis, connective tissue disease, congestive heart failure, diabetes mellitus, liver disease, myocardial infarction, acute or old, other chronic or unspecified heart failure, peripheral vascular disease, and chronic renal insufficiency. The robotic and nonrobotic patients were randomly ordered and a nonrobotic patient with a propensity score closest to the first robotic patient was chosen. Assessment of residual bias was conducted by evaluating the differences in the distribution of patient characteristics before and after matching.

To assess the extent to which the propensity matching reduced confounders, the distribution of several variables before and after matching were compared, including age, gender, race, insurance type, health status, malignancy indication, region, location, facility type, facility size, and comorbid conditions among the patients in the cohorts. Group comparisons were made using χ^2 tests. Least square means were used to test for differences between the matched cohorts on the 3 continuous variables of interest: hospital cost, surgery time, and length of stay. Logistic regression models were used to test for significant differences between the 2 groups and to generate odds ratios on the following categories of adverse events/complications: major and minor. To further assess any residual bias that may occur because only a few hospitals represent most of the robotic procedures in the sample, sensitivity analysis was conducted by running multiple regression models on 1 of the hospitals in which most of the robotic procedures were performed and a nonrobotic hospital meeting the same hospital characteristics. Ordinary least squares regression models were run for hospital costs and logistic regression models were run for adverse events, both major and minor. Analyses were performed using SAS Version 9.2 (SAS Institute Inc., Cary, NC).

RESULTS

A total of 15,502 patient records from 305 hospitals were analyzed. The patient attrition process is shown in Table 1. Ninety-six percent of these thoracic procedures were traditional VATS ($n = 14,837$); lung resection was performed with RATS in 665 procedures, 4% of the total. In the robotic group, 335 lobectomies and 330 wedge resections were performed.

Before matching, patients undergoing RATS lobectomy had similar distributions for age, gender, and health status. Those undergoing RATS resection had similar distributions for age, gender, and insurance type compared with those undergoing VATS lung resection (Table 2). Furthermore, few differences in comorbidities were noted between robot and nonrobot groups. Characteristics of the hospitals showed notable differences for region, teaching versus nonteaching, and bed count. For teaching versus nonteaching and bed count, most of the robotic procedures were performed in teaching hospitals (292 of 335 lobectomies, 281 of 330 wedge resections) with more than 200 beds (334 of 335 lobectomies, 324 of 330 wedge resections), compared with nonrobotic procedures, with almost half coming from nonteaching hospitals (44% lobectomy, 48% wedge resection) with greater variation in bed size (Table 3).

To balance cohorts and mitigate the possibility of confounders and the large discrepancy in sample size between robotic and nonrobotic procedures, patients were matched using a propensity score, as described earlier, on certain demographic and hospital characteristics. After matching, a total of 1240 patients remained; 590 lobectomies and 650 wedge resections in each group

TABLE 4. Patient demographics—matched cohorts

Category	Lobectomy					Wedge resection				
	RATS		VATS		P value	RATS		VATS		P value
	N	Percent	N	Percent		N	Percent	N	Percent	
Total number	295	100	295	100		325	100	325	100	
Age (mean)	66.43		66.54		.9112	61.74		61.50		.8403
Age group					.9596					.9307
18–40 y	7	2.37	5	1.69		32	9.85	34	10.46	
41–50 y	21	7.12	18	6.1		28	8.62	32	9.85	
51–60 y	51	17.29	58	19.66		74	22.77	63	19.38	
61–70 y	99	33.56	98	33.22		95	29.23	98	30.15	
71–80 y	88	29.83	88	29.83		75	23.08	78	24	
>80 y	29	9.83	28	9.49		21	6.46	20	6.15	
Gender					.4574					.0698
Female	154	52.2	163	55.25		167	51.38	190	58.46	
Male	141	47.8	132	44.75		158	48.62	135	41.54	
Unknown										
Insurance					.6862					.7658
Government	173	58.64	180	61.02		183	56.31	174	53.54	
Managed care	106	35.93	103	34.92		101	31.08	106	32.62	
Other	16	5.42	12	4.07		41	12.62	45	13.85	
Race					.4626					.9712
White	235	79.66	249	84.41		264	81.23	264	81.23	
African American	14	4.75	11	3.73		21	6.46	21	6.46	
Hispanic	7	2.37	7	2.37		11	3.38	13	4	
Other	39	13.22	28	9.49		29	8.92	27	8.31	
Health status*					.7597					.1921
APR-DRG severity level (1, 2)	233	78.98	236	80		269	82.77	281	86.46	
APR-DRG severity level (3, 4)	62	21.02	59	20		56	17.23	44	13.54	
Malignancy indication					.9706					.5428
No lung cancer	40	13.56	38	12.88		167	51.38	169	52	
Primary neoplasm of the lung	238	80.68	240	81.36		113	34.77	120	36.92	
Metastases other than lung	17	5.76	17	5.76		45	13.85	36	11.08	
Census region					<.0001					.9672
Northeast	50	16.95	94	31.86		77	23.69	82	25.23	
West	0	0	23	7.8		22	6.77	23	7.08	
South	215	72.88	123	41.69		195	60	190	58.46	
Midwest	30	10.17	55	18.64		31	9.54	30	9.23	
Location					.4915					.2464
Urban	275	93.22	279	94.58		314	96.62	308	94.77	
Not urban	20	6.78	16	5.42		11	3.38	17	5.23	
Type					.3974					1.0000
Teaching	252	85.42	259	87.8		276	84.92	276	84.92	
Nonteaching	43	14.58	36	12.2		49	15.08	49	15.08	
Bed count					.5627					.0117
<50	0	0	0	0						
51–100	0	0	0	0		0	0	1	0.31	
101–200	1	0.34	2	0.68		6	1.85	20	6.15	
>200	294	99.66	293	99.32		319	98.15	304	93.54	
Comorbid conditions										
Myocardial infarction, acute or old	26	8.81	24	8.14	.7675	29	8.92	28	8.62	.8897
Congestive heart failure	21	7.12	16	5.42	.3959	22	6.77	20	6.15	.7497
Chronic or unspecified heart failure	6	2.03	8	2.71	.5885	3	0.92	3	0.92	1.0000
Peripheral vascular disease	25	8.47	27	9.15	.7715	25	7.69	24	7.38	.8819
Dementia	8	2.71	3	1.02	.1281	5	1.54	3	0.92	.4768
Chronic pulmonary disease	148	50.17	153	51.86	.6805	161	49.54	165	50.77	.7537

(Continued)

TABLE 4. Continued

Category	Lobectomy					Wedge resection				
	RATS		VATS		P value	RATS		VATS		P value
	N	Percent	N	Percent		N	Percent	N	Percent	
Connective tissue disease	8	2.71	8	2.71	1.0000	18	5.54	17	5.23	.8620
Liver disease	16	5.42	9	3.05	.1525	22	6.77	15	4.62	.2360
Chronic viral hepatitis	0	0	2	0.68	.1566	5	1.54	3	0.92	.4768
Renal insufficiency, chronic	21	7.12	10	3.39	.0424	18	5.54	17	5.23	.8620
Diabetes mellitus	68	23.05	60	20.34	.4242	50	15.38	52	16	.8292

RATS, Robot-assisted thoracic surgery; VATS, video-assisted thoracic surgery; APR-DRG, all patient refined diagnosis related group. *APR-DRG severity level was used as an index of preoperative comorbidity.

from 132 hospitals; of these, there were 40 hospitals (30%) where robotic procedures were being performed. Patient characteristics, comorbid conditions, and hospital characteristics after matching are represented in Table 4. After matching, patients were balanced with respect to demographics, comorbid conditions, and hospital characteristics, with the exception of region for the lobectomy cohort and bed count for the wedge resection cohort.

After matching, cohorts were tested for differences in average hospital costs, operating room time, and length of stay (Table 5). The average cost of inpatient procedures with/without robotic assistance was \$25,040.70 versus \$20,476.58 ($P = .0001$) for lobectomies and \$19,592.42 versus \$16,600.13 ($P = .0001$) for wedge resections, respectively. Operating room times were longer, although not statistically different for robotic lobectomy (4.49 vs 4.23 hours; $P = .0959$). Operating room times were increased for robotic wedge resection versus nonrobotic wedge resection (3.26 vs 2.86 hours; $P = .0003$). Average length of stay of both cohorts was not statistically different for lobectomy (6.07 vs 5.83 days; $P = .6131$) and wedge resection (5.23 vs 5.38 days; $P = .7188$).

Adverse events occurring in the postoperative period, up to 30 days after discharge, were tabulated and grouped into

major and minor. Complications rates between robotic and nonrobotic surgery cohorts, regardless of whether they were examined within a perioperative 30-day period or only within the original perioperative hospital stay (Table 6) were reported. The odds of an event occurring were not significantly different for major and minor events in either time period for lobectomy or wedge resection (Table 7).

Sensitivity Analysis

In the propensity model, the following hospital characteristics were adjusted: location (urban vs rural), region, teaching status, and bed size. However, more hospitals contributed to our sample of nonrobotic procedures than robotic procedures. Of the 132 hospitals in our sample, only 40 had robotic procedures. Therefore, to further assess any residual bias that may occur because only a few hospitals represented most of the robotic procedures in the sample, the 1 hospital in which 126 lobectomies and 71 wedge resections were performed was matched to a nonrobotic hospital meeting the same hospital characteristics: southern, urban, teaching with a bed count of 500. Only the patients from these 2 hospitals were analyzed. Results of the ordinary least squares cost model revealed significantly higher differences in costs for RATS lobectomy

TABLE 5. Length of stay, hospital costs, and surgery time after matching

	Lobectomy			Wedge resection		
	RATS	VATS	P value	RATS	VATS	P value
Length of stay (d)						
Median	4	4		4	4	
Mean	6.07	5.83	.6131	5.23	5.38	0.7188
SD	6.44	5.03		5.18	5.27	
Total hospital costs (\$)						
Median	21,833.34	18,080.11		17,341.33	13,640.52	
Mean	25,040.70	20,476.58	<.0001	19,592.42	16,600.13	.0001
SD	13,164.01	10,977.67		9,293.64	10,367.82	
Operating room time (h)						
Median	4.25	4		2.93	2.5	
Mean	4.49	4.23	.0959	3.26	2.86	.0003
SD	1.98	1.73		1.41	1.31	

RATS, Robot-assisted thoracic surgery; VATS, video-assisted thoracic surgery; SD, standard deviation.

TABLE 6. Adverse events among matched data by analysis groups

Category	Lobectomy								Wedge resection							
	RATS				VATS				RATS				VATS			
	During		During or after		During		During or after		During		During or after		During		During or after	
	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent
Total number	295	100	295	100	295	100	295	100	325	100	325	100	325	100	325	100
Any major event	40	13.56	50	16.95	50	16.95	56	18.98	53	16.31	71	21.85	41	12.62	51	15.69
Acute respiratory failure	16	5.42	18	6.1	20	6.78	22	7.46	21	6.46	32	9.85	20	6.15	22	6.77
Empyema	1	0.34	2	0.68	1	0.34	2	0.68	1	0.31	3	0.92	4	1.23	4	1.23
Bronchopleural fistula	5	1.69	5	1.69	2	0.68	3	1.02	3	0.92	3	0.92	1	0.31	1	0.31
Pneumonia	18	6.1	25	8.47	27	9.15	29	9.83	28	8.62	33	10.15	16	4.92	24	7.38
Any minor event	100	33.90	109	36.95	101	34.24	113	38.31	100	30.77	108	33.23	106	32.62	114	35.08
Air leak and other pneumothorax	70	23.73	75	25.42	65	22.03	70	23.73	78	24	80	24.62	78	24	81	24.92
Atelectasis/pulmonary collapse	30	10.17	33	11.19	36	12.2	43	14.58	19	5.85	25	7.69	24	7.38	28	8.62
Cellulitis	0	0	1	0.34	0	0	0	0	0	0	0	0	0	0	1	0.31
Chylothorax	1	0.34	1	0.34	3	1.02	3	1.02								
Spontaneous tension pneumothorax	0	0	0	0	1	0.34	2	0.68	3	0.92	3	0.92	4	1.23	4	1.23

RATS, Robot-assisted thoracic surgery; VATS, video-assisted thoracic surgery; SD, standard deviation.

versus VATS lobectomy (\$30,365 vs \$20,238) and RATS wedge resection versus VATS wedge resection (\$27,969 vs \$17,887). Regarding adverse events, results were confirmatory for major events in both lobectomy and wedge resection with no statistical differences. Regarding minor events, there were no differences for patients undergoing wedge resection. However, there was a significant difference for lobectomies. Patients who underwent lobectomy with the robot were 4.24 (odds ratio) times more likely to have a minor event than their nonrobotic counterparts ($P < .0001$).

DISCUSSION

Based on our matched cohorts, there seems to be no differences between robot-assisted lobectomy and wedge resection procedures when considering intraoperative and postoperative complications. After matching and creating 2 balanced cohorts, robot-assisted procedures were associated with higher hospital costs, with an average incremental cost per procedure of \$4565 for lobectomy and \$2992 for wedge resection. Robot-assisted wedge procedures were also associated with longer operating room times.

The findings related to higher hospital costs associated with robotic surgery are consistent with similar studies in the literature evaluating minimally invasive surgical procedures^{15,16}; robotic surgery is consistently more expensive.

Another important consideration is that the costs associated with robotic surgery in these studies do not account for substantial acquisition costs for the robot. The robotic unit costs between \$1 million and \$2.5 million, and is associated with annual maintenance costs of \$100,000 to \$180,000.¹⁷ The combination of limited high-quality clinical evidence comparing traditional VATS and RATS lobectomy and wedge resection to date and relatively high costs raises questions about the cost-effectiveness of this technology. In addition, robotic surgery ideally requires a dedicated operating team and an additional surgeon at the table, who are not generally required for standard VATS procedures. This cost is difficult to assess but certainly needs to be considered.

Important strengths of this analysis included the prospectively developed protocol that directed the analysis, the quasi-randomization propensity scoring methodology that

TABLE 7. Adverse events after matching

	Lobectomy				Wedge resection			
	Odds ratio estimate	Lower CI	Upper CI	P value	Odds ratio estimate	Lower CI	Upper CI	P value
Original hospital stay or within 30 d of follow-up								
Major	0.864	0.537	1.389	.5458	1.24	0.807	1.905	.3265
Minor	1.015	0.722	1.427	.9308	0.971	0.695	1.357	.8647
Original hospital stay only								
Major	0.789	0.473	1.316	.3645	1.224	0.763	1.963	.4013
Minor	1.032	0.728	1.462	.8589	0.927	0.659	1.304	.6639

CI, Confidence interval.

GTS

was used, the broad geographic and demographic representation of US hospitals included in the sample, and the fact that these data are relatively recent and represent a national setting. This study also had some noteworthy limitations. Because the data were mined from a hospital administrative database used for billing purposes, certain data points could not be captured or could not be clearly identified. Examples include patient body mass index and patient behavior such as smoking habits. An analysis of pain scores, quality of life, morbidity, and time to return to work would be interesting contributions to the literature, but these data are not available in the database used in this analysis. This analysis was limited to patients who underwent VATS or RATS procedures only, and excluded those procedures that were converted from RATS to VATS or to open thoracotomy. Furthermore, data regarding the precision of robotic versus nonrobotic procedures, including surgical margins and adequacy of lymph node dissection, could not be evaluated. The dataset provides operating room time and is not suited to further exploration regarding time allotted to set-up, bronchoscopy, take down of adhesions, preresection examination or other subcategories. The analysis was limited to a 30-day perioperative period, which limits analysis related to long-term survival or potential long-term complications. However, these limitations are inherent to the data source and could be rationalized to affect both cohorts similarly; therefore, the risk of bias in 1 cohort is lessened. The surgeon and institutional learning curve for using robotic technology could not be evaluated. Because robotic lung surgery is a relatively new procedure, there may be future potential efficiencies in both cost and time related to increasing familiarity with this technology.

CONCLUSIONS

This study represents the most up-to-date and expansive analysis of cost and effectiveness outcomes associated with RATS and VATS procedures in a national setting. These findings reveal little clinical differences in perioperative adverse events. Coupled with the increased cost of the robot per case and increased operative times for robotic lobectomy and wedge resections, results suggest that further consideration is warranted before using this technology when standard VATS seems to provide better results. Future studies that evaluate cost relative to robotic-assisted case volume and prospective randomized

controlled studies focusing on comparative effectiveness between traditional and robotic-assisted thoracic procedures are needed.

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APPENDIX TABLE 1. Comorbid conditions

Condition	ICD-9 code
Myocardial infarction, acute or old	410.xx, 412
Congestive heart failure	428.0
Other chronic or unspecified heart failure	428.20, 428.22, 428.30, 428.32, 428.40, 428.42, 428.9
Peripheral vascular disease	440.xx, 443.8x, 443.9
Dementia	290.xx, 294.xx, 331.0, 331.11, 331.19, 331.2, 331.7, 331.82
Chronic pulmonary disease	490.xx-494.xx, 495.x, 496, 500-505
Connective tissue disease	710.xx, 714.xx
Liver disease	571.x, 572.x, 573.xx
Chronic viral hepatitis	070.22-070.23, 070.32-070.33, 070.44, 070.54
Renal insufficiency, chronic	585.xx
Diabetes mellitus	249.xx, 250.xx
Hemiplegia	342.xx
Due to cerebral palsy	343.1, 343.4
Due to previous cardiovascular accident	438.2x

ICD, International Classification of Diseases.

APPENDIX TABLE 2. Postoperative procedure-specific complications

Category	Pulmonary	ICD-9 code
Major	Acute respiratory failure	518.81, 518.84 , 518.5
Major	Empyema	510.9
Major	Bronchopleural fistula	510.0
Major	Pneumonia	480.x to 486, 507.0
Minor	Spontaneous tension pneumothorax	512.0
Minor	Atelectasis/pulmonary collapse	518.0
Minor	Air leak and other pneumothorax	512.1, 512.8
Minor	Chylothorax	457.8
Minor	Cellulitis	682.2

ICD, International Classification of Diseases.