Surgery 165 (2019) 455–460

Contents lists available at ScienceDirect

Surgery

journal homepage: www.elsevier.com/locate/surg

Postoperative complications decrease the cost-effectiveness of robotic-assisted lobectomy

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ARTICLE INFO

Article history:
Accepted 30 August 2018
Available online 27 September 2018

ABSTRACT

Background: Cost of robotic-assisted (RATS) lobectomy remains a major concern. We sought to define variability in cost and factors associated with increased hospital expenses after RATS lobectomy for early stage non–small cell lung cancer.
Methods: We performed a retrospective review of patients who underwent RATS lobectomy for stages I–IIIA non–small cell lung cancer at a single institution between 2012 and 2014. Clinical outcomes were linked to hospital financial data. Linear regression analysis was used to test the impact of patient factors and postoperative outcomes on cost.
Results: A total of 137 patients underwent RATS lobectomy, predominantly for stage IA (73%, $n = 100$). Overall in-hospital morbidity was 29.2% ($n = 40$), median length of stay was 5 days (range 1–27 days). Postoperative cost accounted for approximately 50% of total cost of hospitalization and varied significantly (mean \$9,618.38 ± \$10,779.65), resulting in an average total hospital cost of \$19,565 (±\$11,620.42). Male sex and upper lobe predominant disease were independently associated with increased cost, whereas higher preoperative diffusing capacity of lung for carbon monoxide (DLCO) was cost-protective. Hospital expenses associated with prolonged hospitalization were \$2,376.23 per day (95% CI \$2,178–2,573.60). The most common complication associated with increased cost was atrial fibrillation (\$5,609.13; 95% CI \$2,095.42–\$9,122.84). Postoperative atelectasis requiring bronchoscopy, respiratory failure, pulmonary embolism, and reoperation were seen less frequently in this cohort of patients but were associated with significant additional cost.
Conclusion: Hospital cost of RATS lobectomy can vary significantly. In addition to patient risk factors, differences in cost are mainly driven by postoperative events. Initiatives aimed to reduce common yet expensive complications have the potential to improve overall cost-effectiveness of RATS lobectomy.

Introduction

Robotic-assisted thoracoscopic surgery (RATS) is gaining popularity for resection of non–small cell lung cancer (NSCLC). Nationally, the use of RATS lobectomy for lung cancer has tripled between 2010 and 2012 in the US and currently exceeds 10% of lobectomies.[1] The advantages of the robotic technology include articulating instruments with 7 degrees of freedom, 3:1 motion scaling, tremor filtration, and improved visualization with a high-resolution 3D camera.[2] Although the robotic technology is embraced by many surgeons to perform complex thoracic oncologic procedures, the cost and inherent value of the robotic procedure remain the main concerns.[3] Robot-specific cost factors include the instruments, each with limited number of uses; the specialized disposable supplies and drapes; the capital investment, including purchase price of the robotic unit; and the annual maintenance fees in the service contract, which can significantly increase the cost of the operation.[4] Added cost may be a barrier to implementation of robotic thoracic surgery programs, as hospital administrators are carefully examining the profitability and impact on hospital budget versus the benefits of innovation and offering this modern technology.[5]

To maintain cost-effectiveness and improve the overall value, improvements in outcomes of robotic lung resection are needed to compensate for the high upfront costs. In the current literature, hospital costs associated with robotic lobectomy vary greatly among studies. Highest cost figures for robotic lobectomy are derived from population-based cost analyses, and lowest costs are

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https://doi.org/10.1016/j.surg.2018.08.024
0039-6060/

reported by a single high-volume center, with a nearly 30% difference in total hospital cost.[6,7]

In the present study, we aim to define the variability in cost and identify factors driving increased hospital expenses after RATS lobectomy for early-stage NSCLC. We hypothesize that there are specific patient factors and common postoperative complications that account for the cost variability of RATS lobectomy. Once identified, these factors can be used as targets for cost reduction through quality improvement initiatives, better enabling surgeons and institutions to focus on resource utilization to maximize the value of RATS lobectomy.

Patients and Methods

This is a retrospective cohort study of patients who underwent RATS lobectomy between 2012 and 2014 identified in our institutional Society of Thoracic Surgery General Thoracic Surgery Database (STS-GTSD). The study was approved by the Ohio State Institutional Review Board and a waiver for patient consent was obtained. The inclusion criteria were all adult patients with clinical stages I–IIIA NSCLC with available financial data. Patients who underwent sublobar resection, bronchoplastic or sleeve resection, bilobectomy, or pneumonectomy were excluded. Patients with Pancoast tumors or concomitant chest wall resection were also excluded. Cases that started robotically and were converted to thoracotomy were excluded, however a separate cost analysis of these cases was performed. All procedures were performed actively involving and training surgical residents and cardiothoracic fellows. The selection of surgical approach was at the discretion of the respective surgeon. Robotic lobectomy was performed with a 4-arm technique with ports placed in line in the 8th intercostal space. An additional access port (12 mm) was used to for suction and stapling. Initially used was the Da Vinci Si robot and, in 2014, surgeons transitioned to the Xi model (Intuitive Surgical, Sunnyvale, CA). Intercostal nerve blocks were routinely performed for postoperative pain control using long-acting local anesthetic (0.25% bupivacaine with epinephrine). Universal postoperative goals included extubation in the operative room and recovery on a dedicated thoracic nursing ward. Primary postoperative care was guided by a team consisting of the attending surgeon and a group of full-time advanced practice providers and residents. Decision for discharge was made by the surgeon. Patient demographics, clinical characteristics, operative variables, and postoperative outcomes were reviewed. Lung cancer stages were defined by the American Joint Committee on Cancer (AJCC) 7th Edition of Lung Cancer Staging guidelines.[8] Major and minor morbidity were defined by STS-GTSD standards.[9] Clinical data from the institutional STS-GTSD were then linked to hospital financial data, including costs, charges, and payments associated with each case, which were provided by the billing department. Costs are defined as the expenses incurred by the institution. These can be divided into direct and indirect costs, with direct cost comprising items used, utility occupied, and services provided in the conduct of the operation, and indirect cost being the overhead cost and amortization of capital. Direct costs were determined at the discharge level and include both fixed and variable costs. Costs were divided into operating room (OR) cost and postoperative cost, which add to the total hospital cost. Institution-based indirect costs, such as overhead cost, administration, utilities, and maintenance were not included in the analysis. Robot-specific indirect costs were calculated per case. This included capital depreciation of purchase price plus annual maintenance contracts, divided by an average case volume per robot per year at our institution during the study period. Charges were calculated separately as the amount that is billed to the payor. Payment was determined as the dollar amount that is received by the payor. Contribution margin was defined as the difference between total payment and total direct hospital cost.

Statistical analysis

Descriptive statistics were used to define baseline patient demographics, clinical characteristics, and postoperative outcomes. Continuous data are presented as median values with interquartile ranges (IQR) or mean values with standard deviations (SD), based on the presence of normal distribution. Categorical data are expressed in counts with percentages. Linear regression analysis was used to identify variables associated with hospital costs, and the cost associated with prolonged hospitalization. Variables were grouped into patient factors and postoperative outcomes. There were 2 separate regression analyses performed to identify the impact of patient and preoperative factors with total direct hospital cost and the impact of operative factors and postoperative events on postoperative cost, as previously described.[10] Results are reported as added costs with 95% confidence intervals (CI). All variables with a significance of P less than or equal to .1 in the univariate analysis were included in the multivariate model. All figures display means, with error bars representing 95% CI. Relative incremental cost was defined as cost divided by the mean total direct cost of an uncomplicated lobectomy and was expressed as a percentage. All statistical tests were 2-sided with alpha threshold of significance set at 0.05. Data analysis was performed using SPSS 24.0 (LEAD Technologies, Inc., Chicago, IL) statistical software package.

Results

Demographics

Available financial data for 137 patients who underwent RATS lobectomy were included in the analysis. Patients had a mean age of 66.8 (± 9.6) years, and 56.7% were female. The majority of patients underwent resection for primary lung adenocarcinoma (75.9%) and had clinical stage I disease (90.5%). There were 4 patients (2.9%) who had stage IIIA disease and underwent induction therapy. Tumors were most frequently located in the upper or middle lobe (64.2%). Clinical and pathologic data are summarized in Table 1.

Perioperative outcomes

Overall in-hospital morbidity and complication rate was 29.2% ($n = 40$), which included 12 patients (8.8%) who had multiple complications. Perioperative outcomes are detailed in Table 2. Median length of stay was 5 days (IQR 3–7). For uncomplicated robotic lobectomy, median length of stay was 4 days (IQR 3–6). Mortality at 60 days was 2.2%. Major complications included primarily respiratory events; postoperative respiratory failure requiring reintubation affecting 8 patients (5.8%) and pulmonary embolism suffered by 3 patients (2.2%). A total of 4 patients had an unplanned return to the operating room (2.9%). Atrial fibrillation with rapid ventricular response was the most common minor complication, affecting 17 patients (12.4%). Other frequent minor complications were postoperative pneumonia (8%) and prolonged air leak (6.6%).

Hospital cost analysis

The mean total direct hospital cost for RATS lobectomy was $19,565 (±$11,620.42). A breakdown of all hospital costs, charges, and payments is provided in Table 3. Approximately half of the total hospital cost was incurred in the operating room (mean OR cost

Table 1
Patient demographics and clinical characteristics

Characteristic	$n = 137$
Age in y, mean (±SD)	66.8 (±9.6)
Sex	
Female	78 (56.9%)
Male	39 (43.1%)
Smoking history	
Never smoker	19 (13.9%)
Former smoker	50 (36.5%)
Active smoker	68 (49.6%)
FEV1 [%, predicted], mean (±SD)	78.1 (±20.3)
DLCO [%, predicted], mean (±SD)	71.4 (±19.6)
Chronic obstructive pulmonary disease	44 (32.1%)
Coronary artery disease	37 (27%)
Clinical stage[a]	
IA	100 (73.0%)
IB	24 (17.5%)
IIA	4 (2.9%)
IIB	5 (3.6%)
IIIA	4 (2.9%)
Histology	
Adenocarcinoma	104 (75.9%)
Squamous cell carcinoma	33 (24.1%)
Induction chemotherapy	4 (2.9%)
Lobe resected	
RUL	44 (32.1%)
RML	7 (5.1%)
RLL	29 (21.2%)
LUL	37 (27%)
LLL	20 (14.6%)
Pathologic T-stage*	
T1	63 (46%)
T2	62 (45.3%)
T3	12 (8.7%)
Pathologic N-stage*	
N0	116 (84.7%)
N1	12 (8.8%)
N2	9 (6.6%)
Pathologic atage*	
I	105 (76.6%)
II	21 (15.3%)
III	11 (8%)

* based on American Joint Committee on Cancer 7th Edition*FEV1*, forced expiratory volume in 1 second; *RUL*, right upper lobe; *RML*, right middle lobe; *RLL*, right lower lobe; *LUL*, left upper lobe; *LLL*, left lower lobe

$9,947.16 ± $2,681.00). The greatest variability was seen in postoperative direct cost (mean $9,618.38 ± $10,779.65), with interquartile range spanning $4,980.24 to $10,537.23 per patient. Hospital cost increased with prolonged length of stay by $2,376.23 per day (95% CI $2,178–2,573.60). Highly variable hospital costs and total hospital payments (Table 3) resulted in a wide distribution of contribution margins (mean $13,066.62 ±$23,873.47). Considering the annual case volume of 328.25–417.75 robotic cases per year at our institution, the purchase price of two Si robots ($1,210,000 and $1,550,000), and maintenance cost of $149,000 per robot per year, the added robotic specific indirect cost calculated at $1,656.77 per case.

Factors associated with cost variability

The results of a multivariate analysis of patient factors associated with the variability in total hospital cost are presented in Table 4. Few patient factors were independently associated with cost. Male patients had a higher mean total hospital cost, which was on average $5,953.59 more than their female counterparts ($P = .002$). Patients who underwent lobectomy for upper lobe tumors had an average increased cost of $1,902.05 ($P = .045$). A higher preoperative diffusing capacity of lung for carbon monoxide (DLCO) was cost-protective, with a cost reduction of $131.54 per additional 1% of predicted DLCO (Table 4).

There were 7 patients (5%) who underwent a diagnostic wedge before anatomic resection, which was not associated with added cost −$3,083.42 (95%CI −$8,390.68–$2,223.84). Similarly, conversion to thoracotomy at the time of RATS lobectomy did not have a statistically significant impact on cost with a total hospital cost ($21,522.78 for conversion vs 19,565.54 for nonconversion, $P = .48$). Postoperative outcomes had the greatest impact on hospital cost after RATS lobectomy. The added impact of additional complications is depicted in Fig 1. Relative to uncomplicated lobectomy, cost with 1 postoperative complication is higher by 35.7% or $5,751.24 (95% CI $4,012.26–$7,490.22), by 76.9% or $12,288.61 (95% CI $8,878.56–$15.698.66) with 2 complications, and by 245.9% or $39,630.40 (95% CI $36,220.36–$43,040.46) with 3 or more complications. An unanticipated return to the operating room was the single event associated with the highest added postoperative cost of $21,640.37 (95% CI $12,891.79–$30,388.94). Reasons for return to the operating room included tracheostomy for 2 instances of respiratory failure, catheter-based intervention for stroke, and laparotomy for small bowel obstruction. Atrial fibrillation was the most common complication and had a mean added cost of $5,609.13 (95% CI $2,095.42–$9,122.84) (Table 5). The relative incremental costs of specific postoperative events are visualized in Fig 2.

Discussion

As the experience of RATS lobectomy is growing worldwide, critics have questioned its value from a health economic standpoint. The cost associated with robotic technology remains a

Table 2
Postoperative outcomes

Outcome	$n = 137$
Length of hospitalization [days], median (IQR)	5 (3–7)
Length of hospitalization for uncomplicated robotic lobectomy [days], median (IQR)	4 (3–6)
Operating room time [minutes], median (IQR)	182 (137–249)
Any postoperative complication	40 (29.2%)
Multiple complications	12 (8.8%)
Major complications	
Respiratory failure	8 (5.8%)
Myocardial infarction	4 (2.9%)
Pulmonary embolus	3 (2.2%)
Unplanned return to OR	4 (2.9%)
Minor complications	
Prolonged air leak (>5 days)	9 (6.6%)
Atrial fibrillation	17 (12.4%)
Atelectasis requiring bronchoscopy	6 (4.4%)
Pneumonia	11 (8%)
60-day mortality	3 (2.2%)

Table 3
Hospital costs and charges

Cost per case	Mean	SD	Median	25th percentile	75th percentile
OR cost	$9,947.16	$2,681.99	$9,216.29	$8,129.90	$11,389.05
Postoperative (direct) cost	$9,618.38	$10,779.65	$6,692.45	$4,980.24	$10,537.23
Total (direct) cost	$19,565.54	$11,620.42	$16,266.58	$14,189.00	$20,231.81
Total charges	$125,926.65	$63,318.43	$107,456.12	$94,447.51	$136,905.95
Total payments	$33,115.60	$30,572.75	$22,351.50	$13,013.82	$47,467.47
Contribution margin	$13,066.62	$23,873.46	$3,551.26	−$3,096.02	$27,232.49

Table 4
Multivariate linear regression analysis of patient risk factors and added total cost

Patient factors	*n*, (%)	Added total hospital cost	95% CI	*P* value
Male gender	59 (43.1%)	$5,953.59	$2,210.35–$9,696.83	**.002**
DLCO (per %)	Mean 71.4 ±19.7	−$131.54	−$37.096−−$225.98	**.007**
Upper lobe disease	81 (59.1%)	$1,902.05	$84.48–$7,608.86	**.045**

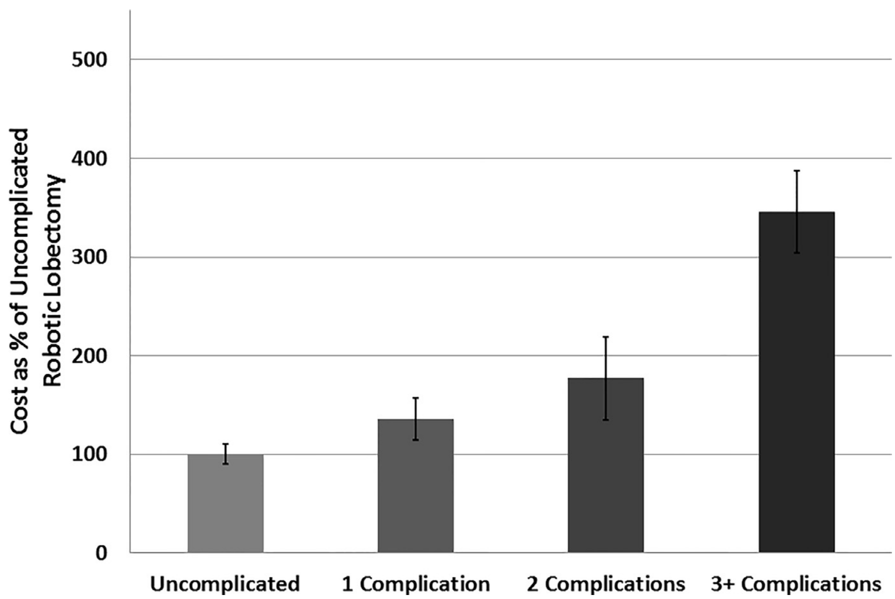

Figure 1. Impact of total cost by number of complications. Bar graphs reflect means with 95% CI.

Table 5
Multivariate linear regression analysis of postoperative outcomes and added postoperative cost

Outcomes	*n*, (%)	Added postoperative cost	95% CI	*P* value
Atelectasis (req. bronchoscopy)	6 (4.4%)	$6,859.40	$582.33–$13,056.55	**.032**
Pneumonia	11 (8.0%)	$2,444.23	−$2,680.37–$7,268.83	.35
Respiratory failure	8 (5.8%)	$13,841.76	$8,076.02–$19,607.51	**<.001**
Myocardial infarction	4 (2.9%)	$382.61	−$6,476.59–$7,241.81	.91
Pulmonary embolus	3 (2.2%)	$17,478.91	$8,181.50–$26,776.32	**<.001**
Atrial fibrillation (with RVR)	17 (12.4%)	$5,609.13	$2,095.42–$9,122.84	**.002**
Unplanned return to OR	4 (2.9%)	$21,640.37	$12,891.79–$30,388.94	**<.001**

major concern, and efforts are being directed at improving cost-effectiveness. In this retrospective cost analysis of RATS lobectomy, we point out a significant variability in hospital costs between patients at a single high-volume center and potentials for cost reductions. Although the operating room expenses of robotic lobectomies were significant, approximately half of the total hospital costs were incurred in the postoperative setting. Overall, morbidity was low, but postoperative complications and a prolonged stay added considerable hospital expenses, accounting for the biggest variability in total cost.

To our knowledge, this is the first study to systematically analyze factors associated with cost after robotic lobectomy. Cost factors can be categorized into patient factors, OR costs, and postoperative complications. Patient factors associated with increased cost included male sex, worse pulmonary function, and upper lobe disease, which mirror those described for video-assisted thoracic surgery (VATS) lobectomy by Medbery and colleagues.[10] These factors may be helpful to identify patients at risk for increased cost and allocate additional resources to prevent costly complications. Geller et al. have previously examined the impact of individual complications after lobectomy by thoracotomy and VATS and found that major pulmonary complications were the most expensive, and atrial arrhythmias were the most common.[11] In the present series, we show that this holds true for patients undergoing robotic lobectomy. Although respiratory and other major complications were also associated with significant cost, they were fortunately rare. Postoperative atrial fibrillation was common by contrast, and the rate after RATS lobectomy in this series (12%) was

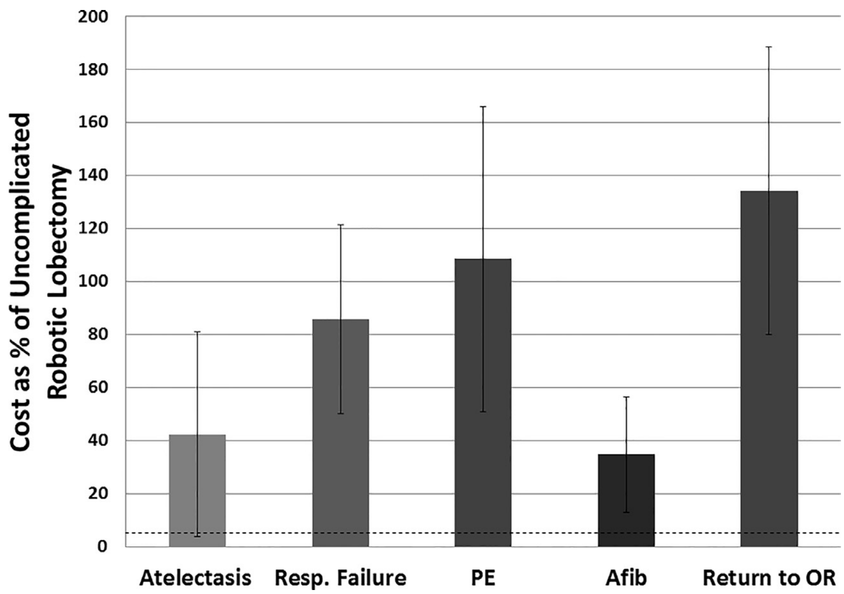

Figure 2. Impact of total cost by complication type. Bar graphs reflect means with 95% CI, relative incremental total hospital cost per event. Dashed line represents the upper bound 95% CI of uncomplicated lobectomy cost. PE, pulmonary embolus; Afib, atrial fibrillation with rapid ventricular response.

similar to that reported in the literature for VATS and open lobectomy surgery, ranging between 8 and 13%.[12–14] Even higher rates of postoperative atrial fibrillation—up to 19% after RATS lobectomy—have been reported by Ng et al.[15] The relative cost increase of atrial fibrillation events in relation to an uncomplicated lobectomy in this study was 34% (Fig 2). Additional cost includes prolonged hospitalization, additional tests and medications, and possible cardiology consultation. Implementing strategies to minimize postoperative atrial fibrillation is therefore a major target for cost reduction. Our current practice is to continue beta-blockade in patients taking beta-blockers preoperatively. Additional pharmacologic atrial fibrillation strategies, such as prophylactic diltiazem or amiodarone, are classified as IIA recommendation by the STS practice guidelines and may be appropriate for patients undergoing robotic lobectomy. For selection of amiodarone prophylaxis, Amar et al. have shown that patients with even slightly elevated brain natriuretic peptide (over 30 pg/mL) may be at higher risk.[16] The Prevention of Atrial Fibrillation in High-risk Patients Undergoing Lung Cancer Surgery (PRESAGE) trial also showed a significant reduction in postoperative atrial fibrillation after lung cancer surgery using prophylactic metoprolol or losartan in patients with elevated brain natriuretic peptide.[17]

In the current health care environment and transition to bundled payment systems, increased scrutiny is placed on institutions to deliver cost-effective care. Implementing new technology such as robotic surgery can therefore be challenging because of the high upfront capital investment and ongoing maintenance costs. In a systemic review of the cost literature for robotic lobectomy, we found that the cost of RATS is still higher than VATS, but equal to or less than the traditional open lobectomy, with most studies accounting only for direct costs.[4,6,7,18–21] Although existing analyses have demonstrated that cost of robotic lobectomy exceeds VATS approach, there is evidence to suggest that high-volume centers that have surpassed their learning curve with RATS lobectomy can operate at lower per-procedure costs. At a the highest-volume center, total cost of RATS lobectomy was the lowest. This institution also reported the shortest length of stay after RATS lobectomy, with an average hospitalization of 2 days.[7] In the present study, the added cost of an additional day in the hospital averaged 12% of the total cost for hospitalization, and the median length of stay was 5 days. Work is needed to expedite recovery, improve outcomes, and manage patient expectations, which may be realized through standardized recovery pathways. Previous fast-track pathways have been explored with mixed success in pilot studies of patients undergoing lung resection for cancer, and multiple ongoing trials are exploring the broader application of enhanced recovery protocols.[22–25] Ramadan et al. have shown that small changes to perioperative protocols can be successful in decreasing operative times of robotic lobectomy.[26] This group was able to reduce the use of invasive lines and epidural catheters to a minimum, using a value streaming approach. Thought-out protocols aimed to streamline recovery may therefore be most effective in further reducing the overall costs of robotic lobectomy. We are currently exploring the impact of enhanced recovery protocols for robotic lobectomy patients as a means to shorten hospitalization and reduce postoperative events at our center.

The inherent value of robotic lobectomy may be realized through a combination of cost-reduction strategies and improved outcomes. Minimally invasive approaches to pulmonary resection, including VATS and RATS lobectomy, have already displaced the conventional open surgical approach with fewer postoperative complications, less pain and blood loss, shorter hospitalization, and improved 30-day survival.[27–32] In a 2017 meta-analysis, Emmert et al further identified a trend of reduced hospital stay and drainage duration with RATS compared to VATS lobectomy.[3] Additional attention to prevention of the postoperative complications identified in the present study may further improve cost-effectiveness for RATS lobectomy. Lower costs will lead to increased contribution margin, which can in turn be used to cover the indirect costs, thereby leading to true profitability of RATS lobectomy.

Important limitations to the present study should be acknowledged. First, this is a retrospective review with financial data from one institution. Cost factors can be different between health-care organizations and may not be directly transferable. Also, this study spans remote years and does not account for changes in cost over time. Certain complications, such as myocardial infarction, were rare, and as such cost was highly variable and statistical significance was not reached. The impact of advances in the robotic technology, including the introduction of the newest generation of the robot as well as the robotic stapler, are not accounted for in the present analysis. Cost comparison to VATS or open lobectomy is relevant, but was outside the scope of our study. Despite these limitations, the cost variability that we have described may provide valuable targets for future cost savings.

Conclusion

Hospital cost of robotic lobectomy varies significantly, even within a single institution. Postoperative complications and prolonged hospitalization have a substantial impact on the overall cost. Efforts to further improve postoperative outcomes have the potential to greatly increase cost-effectiveness. Prevention strategies for common and expensive complications, such as atrial fibrillation, should therefore be the focus of quality improvements in RATS lobectomy.

Conflicts of interest

The authors have indicated that they have no conflicts of interest regarding the content of this article.

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