Comparing Robotic Lung Resection With Thoracotomy and Video-Assisted Thoracoscopic Surgery Cases Entered Into The Society of Thoracic Surgeons Database

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Objective: The use of robotic lung surgery has increased dramatically despite being a new, costly technology with undefined benefits over standard of care. There is a paucity of published comparative articles justifying its use or cost. Furthermore, outcomes regarding robotic lung resection are either from single institutions with in-house historical comparisons or based on limited numbers. We compared consecutive robotic anatomic lung resections performed at two institutions with matched data from The Society of Thoracic Surgeons (STS) National Database for all open and video-assisted thoracoscopic surgery (VATS) resections. We sought to define any benefits to a robotic approach versus national outcomes after thoracotomy and VATS.

Methods: Data from all consecutive robotic anatomic lung resections were collected from two institutions (n = 181) from January 2010 until January 2012 and matched against the same variables for anatomic resections via thoracotomy (n = 5913) and VATS (n = 4612) from the STS National Database. Patients with clinical N2, N3, and M1 disease were excluded.

Results: There was a significant decrease in 30-day mortality and postoperative blood transfusion after robotic lung resection relative to VATS and thoracotomy. The patients stayed in the hospital 2 days less after robotic surgery than VATS and 4 days less than after thoracotomy. Robotic surgery led to fewer air leaks, intraoperative blood transfusions, need for perioperative bronchoscopy or reintubation, pneumonias, and atrial arrhythmias compared with thoracotomy.

Conclusions: This is the first comparative analysis using national STS data. It suggests potential benefits of robotic surgery relative to VATS and thoracotomy, particularly in reducing length of stay, 30-day mortality, and postoperative blood transfusion.

Key Words: Lung, Lobectomy, Robotics, Thoracoscopy, STS National Database.

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Thoracotomy continues to be the most used incision for performing anatomic resections of the lung, even for early-stage lung cancer, despite the established safety and potential advantages of the thoracoscopic technique.[1] Although other surgical disciplines have been quick to adopt minimally invasive surgery, thoracic surgeons have been more hesitant to do so, especially for anatomic lung resections, despite the invasive nature of a thoracotomy in patients who are often frail and older in age. Although the first video-assisted thoracoscopic surgery (VATS) lobectomy was performed 20 years ago, per The Society of Thoracic Surgeons (STS) National Database, only 44% of lobectomies are performed via VATS, revealing a persistent reluctance to adopt the technique.[2] Critics of VATS cite a limited ability to control bleeding, increased difficulty performing a lymphadenectomy, the sticklike nature of traditional VATS instruments, poorer optics and visualization for a potentially treacherous dissection, as well as a steep and difficult learning curve.[3]

Robotic anatomic lung resection is gaining in popularity as proponents tout better three-dimensional optics and ×10 magnification, easier lymph node dissection, decreased tremor, and 7-degree endowrist capabilities.[4–6] Although VATS adoption has been surprisingly slow despite its published advantages over thoracotomy for lobectomy in early-stage lung cancer,[2] the enthusiasm for robotics has been quite pronounced, mostly based on subjective surgical opinion about its benefits, coupled with a strong marketing campaign and patient demand. The safety and the feasibility of robotic anatomic lung resection have been shown in several case series.[3–5,7–9] Although data are emerging

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comparing robotic lobectomy with thoracotomy and VATS,[2,4,5] the published analyses have been limited to single-institution series compared with historical internal results rather than current national data.[2,10] As such, we have compared consecutive robotic anatomic lung resections from two institutions with matched data obtained from the STS National Database on outcomes of anatomic lung resection performed via VATS and thoracotomy to evaluate any benefit of robotics over standard of care as defined by national data.

METHODS

Data from all consecutive robotic anatomic lung resections were collected from two institutions during the period of January 2010 until January 2012 under the auspices of institutional review board at both institutions and with a data-sharing agreement. All data obtained from the robotic cases were collected prospectively from in-house data registries. Robotic data were then matched to a custom query of the STS Adult National Database for Thoracic Surgery Version 6.0 for the period of 2009 to 2010, which was obtained in November 2011. This was done by replicating the fields collected by the STS registry. These were the most recent thoracotomy and VATS data available from the STS registry for lobectomy and segmentectomy done by thoracotomy or VATS. We attempted to obtain every possible and relevant data point available in the STS database and then matched our data accordingly by replicating the data fields. If any of the data were unavailable in our robotic databases, patient charts were requested and the information was obtained. We included all robotic resections from the first case in each center to account for each institution's learning curve. Patients were included in the analysis if they underwent lobectomy/segmentectomy for any diagnosis, both benign and malignant. Wedge resections were excluded. The robotic cases were performed by a complete portal robotic lobectomy three- or four-arm technique, as previously described elsewhere.[2,3]

Patients were excluded if they were younger than 18 years; had undergone any preoperative radiation or chemotherapy; were American Society of Anaesthesiologists (ASA) V; or were staged clinically as having T3 or higher, N2 or higher, or M1 disease. The Access and Publications Task Force of the STS provided query results in the form of summary tables for both open and VATS. These data were compared with all consecutive robotic anatomic resections from the two institutions. Included data elements focused on matched demographic, preoperative and intraoperative variables, postoperative complications, and discharge status. The authors received an educational grant from Intuitive Surgical (Sunnyvale, CA USA) to acquire the data from the STS and to pay for the performance of all statistical analyses used in this study.

The incidence of individual types of complications was reported for all three cohorts: robotic, open, and VATS. All continuous variables were compared using the Student *t* test, whereas categorical variables were compared using the χ^2 test or the Fisher exact test. A P value of less than 0.05 was considered statistically significant. Statistical analysis was done at an outside institution by a statistician not affiliated with either of the two institutions.

RESULTS

A total of 5913 cases performed via thoracotomy and 4612 cases performed via VATS were identified in the STS National Database during the study period. The primary indications for operation were lung cancer (>80% of all cases assessed), metastatic tumors (5%), and benign tumors (3%). Other benign indications comprised 1% or less of all cases. A total of 181 cases from both institutions were completed on the robot during the included time frame, and all were included in the analysis.

When assessing preoperative patient characteristics, there were no significant differences in age, body mass index, sex,

TABLE 1. Patient Characteristics

Parameter	Open n = 5913	VATS n = 4612	Robotic n = 181	*P* O vs R	*P* V vs R
Age, mean (SD), y	65.0 (12.1)	66.2 (11.3)	64.8 (11.6)	0.82	0.11
BMI, mean (SD), kg/m^2	27.8 (6.6)	27.3 (5.9)	27.7 (6.3)	0.71	0.43
Sex, n (%)					
Male	2961 (50.1)	2053 (44.5)	76 (42.0)	0.0321	0.50
Female	2952 (49.9)	2559 (55.5)	105 (58.0)		
Cigarette smoking, n (%)					
Never smoked	1109 (18.8)	929 (20.1)	39 (21.6)	0.61	0.67
Past smoker	3283 (55.5)	2614 (56.7)	96 (53.0)		
Current smoker	1521 (25.7)	1069 (23.2)	45 (24.9)		
FEV_1, mean % predicted (SD)	80.4 (20.2)	84.1 (21.1)	83.9 (22.2)	0.025	0.91
DLCO, mean % predicted (SD)	73.6 (21.8)	76.1 (22.2)	74.2 (19.9)	0.73	0.25
ASA classification, n (%)					
I	33 (0.6)	30 (0.6)	0	0.99	0.91
II	936 (15.8)	993 (21.5)	20 (11.1)	0.14	1.0
III	4201 (71.0)	3280 (71.1)	69 (38.1)	0.38	0.39
IV	737 (12.5)	308 (6.7)	2 (1.1)	0.0052	0.14

ASA indicates American Society of Anaesthesiologists; BMI, body mass index; DLCO, diffusing capacity of lung for carbon monoxide; FEV_1, forced expiratory volume in 1 second; O, open; R, robotic; V, video-assisted thoracoscopic surgery.

TABLE 2. Clinical Staging

Parameter	Open n = 5913	VATS n = 4612	Robotic n = 181	*P* O vs R	*P* V vs R
T1a	1861 (31.5)	1861 (40.4)	71 (39.2)	0.15	0.35
T1b	1060 (17.9)	947 (20.5)	49 (27.1)	0.0123	0.10
T2a	1428 (24.1)	844 (18.3)	31 (17.1)	0.0067	0.49
T2b	419 (7.1)	144 (3.1)	7 (3.9)	0.07	0.84
N0	4251 (71.9)	3605 (78.2)	158 (87.3)	0.0028	0.34
N1	507 (8.6)	190 (4.1)	5 (2.8)	0.002	0.34

O indicates open; R, robotic; V, video-assisted thoracoscopic surgery.

smoking history, forced expiratory volume in 1 second, diffusing capacity of lung for carbon monoxide, or ASA status between the robotic and VATS patients. The only significant differences in the patients evaluated in this study were between the open and robotic patients, wherein there were more men, lower calculations of forced expiratory volume in 1 second, and a higher percentage of ASA IV patients in the open cohort (Table 1). All other variables assessed revealed no significant difference between the robotic and open patients during preoperative evaluation.

In evaluating clinical stage before resection when applicable, there was no significant difference between the T or N stages in the VATS and robotic comparison. Comparing the robotic and open groups, there was a significant difference in nodal status because more robotic cases were staged as cN0 whereas more open resections were staged as cN1. There was no statistical difference between cT1a tumors, but there was a higher proportion of cT1b cases in the robotic group. A higher proportion of cT2a cases and cT2b was seen in the open group (Table 2). Generally, larger tumors associated with positive hilar nodes were completed more often by thoracotomy than a robotic approach.

There were significant reductions in operative time, postoperative chest tube duration, and length of stay when cases were done robotically compared with both VATS and open surgery (Table 3). The patients stayed in the hospital 3.2 days after a robotic operation, compared with 5.3 days after VATS and 7.3 days after a thoracotomy. The patients seemed to be discharged from the hospital sooner after chest tube removal from a robotic resection (0.3 days) relative to VATS (1.6 days) and thoracotomy (2.5 days).

There was no statistical difference in numerous complications after anatomic resection, regardless of the incision or technology used (Table 4). There were also no significant differences in intraoperative variables or deaths recorded before discharge between the three cohorts (Table 4).

However, in comparing robotic resection with VATS, there were significantly fewer postoperative blood transfusions with a robotic operation (Table 5). A robotic operation also significantly reduced prolonged air leaks greater than 5 days, atelectasis requiring bronchoscopy, atrial arrhythmia requiring treatment, need for intraoperative or postoperative blood transfusion, pneumonia, and need for reintubation relative to thoracotomy (Table 5). There were also significantly fewer deaths at postoperative day 30 after a robotic operation than seen in both the VATS and thoracotomy cohorts.

DISCUSSION

Data are emerging touting that robotic lobectomy can be performed safely, but it remains unclear whether there is any real benefit to a robotic operation relative to VATS or thoracotomy. One suggested benefit of a minimally invasive approach has been a shorter postoperative length of stay compared with thoracotomy, which is again seen in the current study.[3,4] However, our data also suggest that robotic lobectomy may lead to a further reduction in length of stay compared with VATS, which differs from previous comparative studies in which similar lengths of stay were seen between VATS and robotic cases.[2,10] It is possible that these single-institution case-control studies were from groups that managed VATS and robotic patients in a similar fashion.

In addition, postoperative complications are often a cited cause for longer lengths of stay after surgery. However, we found no difference in the types or frequency of complications between robotic and VATS lobectomy, except in the need for postoperative blood transfusion. We can only speculate as to why a VATS lobectomy would require more transfusions relative to robotic lobectomy. The less precise dissection during VATS lobectomy may be responsible for this rate of transfusion difference, and similarly, perhaps, the finer and more stable dissection using the robot leads to less bleeding. Furthermore, there may be an inherent difference in the operative technique

TABLE 3. Perioperative Outcomes

Parameter	Open n = 5913	VATS n = 4612	Robotic n = 181	*P* O vs R	*P* V vs R
Operative time, mean (SD), min	243.7 (88.1)	239.0 (84.2)	199.2 (58.0)	<0.0001	<0.0001
Chest tube duration, mean (SD), d	4.8 (4.0)	3.7 (8.8)	2.9 (2.5)	<0.0001	0.0005
Hospital stay, mean (SD), d	7.3 (7.6)	5.3 (7.2)	3.2 (2.6)	<0.0001	<0.0001

O indicates open; V, video-assisted thoracoscopic surgery; R, robotic.

TABLE 4. Equivalent Complications and Mortality Data

Complications	Open n = 5913	VATS n = 4612	Robotic n = 181	*P* O vs R	*P* V vs R
ARDS	76 (1.3)	23 (0.5)	0	0.17	1.0
Required reoperation for bleeding	66 (1.1)	48 (1.0)	1 (0.6)	0.72	1.0
Bronchopleural fistula	35 (0.6)	12 (0.3)	1 (0.6)	1.0	0.39
DVT	39 (0.7)	16 (0.4)	0	0.63	1.0
Empyema	34 (0.6)	13 (0.3)	2 (1.1)	0.29	0.11
Ileus	72 (1.2)	35 (0.8)	1 (0.6)	0.72	1.0
Myocardial infarct	36 (0.6)	11 (0.2)	0	0.62	1.0
Pulmonary embolus	32 (0.5)	11 (0.2)	0	1.0	1.0
RLN paresis/paralysis	12 (0.2)	5 (0.1)	1 (0.6)	0.32	0.20
Ventilatory support > 48 h	61 (1.0)	23 (0.5)	0	0.26	1.0
Tracheostomy	77 (1.3)	37 (0.8)	0	0.17	0.40
Unexpected return to ICU	287 (4.9)	147 (3.2)	6 (3.3)	0.38	0.83
Mortality, n (%)					
Intraoperative	2 (0.03)	0	0	1.0	—
At discharge	99 (1.7)	36 (0.8)	0	0.12	0.64

ARDS indicates adult respiratory distress syndrome; DVT, deep venous thrombosis requiring medication; ICU, intensive care unit; O, open; R, robotic; RLN, recurrent laryngeal nerve; V, video-assisted thoracoscopic surgery.

between VATS and robotic resection, with the former using more blunt dissection and sweeping of tissues compared with bipolar cauterized robotic dissection. This study also suggests the advantage of robotics as an alternative minimally invasive approach over thoracotomy in terms of length of stay, chest tube duration, and postoperative complications. Whether the observed differences will remain when the robotic platform becomes more universally used remains to be seen.

It is notable that of the two institutions that contributed cases to the robotic cohort, one had a significant and established VATS lobectomy experience before robotic resection was introduced, whereas the other did not and moved directly from thoracotomy to robotics. Also worthy of mention is that the robotic learning curves for both institutions are included in these data, potentially diminishing some of the differences that may have been noted between the groups analyzed. It has been published that a reasonable learning curve for thoracic surgeons performing robotic lobectomy is approximately 18 to 20 cases before a surgeon notes significant improvement in efficiencies and outcomes with the robotic operation.[6] The fact that one of the institutions did not have a significant VATS experience and so readily made the transition to minimally invasive robotic surgery suggests that there may be a cohort of surgeons hesitant to use VATS who may be more comfortable with the robotic platform given its optics, magnification, endowrist capabilities, and facile lymph node dissection and will still produce outcomes equivalent to, and in some cases better than, VATS.

One of the surprising results in this study was that the 30-day postoperative mortality for robotic lobectomy was less than that of both open and VATS cases. We initially discounted these results, particularly compared with the open group, because of the baseline differences in the groups and the difference in cancer stages. However, in a study on robotics using the statewide inpatient sample database, the mortality from robotic lobectomy (n = 430) was 0.23% and statistically significantly different ($P = 0.003$) compared with 1.14% for VATS

TABLE 5. Nonequivalent Complications and Mortality Data

Complications	Open n = 5913	VATS n = 4612	Robotic n = 181	*P* O vs R	*P* V vs R
Air leak > 5 d	634 (10.7)	408 (8.9)	11 (6.1)	0.0491	0.22
Atelectasis requiring bronchoscopy	316 (5.3)	116 (2.5)	3 (1.7)	0.0261	0.63
Atrial arrhythmia	713 (12.1)	426 (9.2)	10 (5.5)	0.0049	0.11
Intraoperative blood transfusion	281 (4.8)	62 (1.3)	0	<0.0001	0.08
Postoperative blood transfusion	458 (7.8)	172 (3.7)	0	<0.0001	0.0019
Pneumonia	299 (5.1)	134 (2.9)	3 (1.7)	0.0355	0.49
Reintubation	277 (4.7)	103 (2.2)	1 (0.6)	0.0033	0.18
Mortality, n (%)					
At POD 30	119 (2.0)	40 (0.9)	0	<0.0001	<0.0001

O indicates open; POD, postoperative day; R, robotic; V, video-assisted thoracoscopic surgery.

(n = 14427) and with 2.53% for open (n = 20238) surgery.[11] Why there is such a difference in both of these studies is unclear. However, it may represent the fact that published robotic series are typically from specialized units with higher surgical volume and compare with the larger administrative data sets and the STS registry, which include data from more general sources. It is interesting to note, however, that this observation was seen in two very different data sets with surgeons of differing expertise and skill sets. Another possible explanation may simply relate to the sample size of the robotic lobectomy group compared with the other cohorts. Despite the limitations, there may be a survival benefit in this early experience, which needs to be clarified in future research.

The more interesting comparison in our opinion is between the VATS and robotic groups because there are now two minimally invasive lobectomy approaches available to the thoracic surgeon. Attendant to that choice for the surgeon are the important issues of added costs to the medical system or hospital; the learning curve of starting a robotic program; as well as potential access issues for patients as they try to choose with whom, where, and how to have surgery performed. We did find that the patients stayed two fewer hospital days after a robotic case relative to VATS and that chest tubes were removed sooner. The only significantly different complication between the two minimally invasive approaches was the need for postoperative blood transfusions. Certainly, it must be acknowledged that the authors may be using a management schema for chest tube removal that is potentially more aggressive than that used by surgeons nationally, but this cannot be ascertained from the data in their present form. We also have no data available on readmission rates or procedures needed postoperatively for clinically significant recurrent effusions.

This data set does define some present-day national norms with respect to complications and discharge variables when a lobectomy is done by a cardiothoracic surgeon and entered into the STS database, including length of stay information. We know from our own single-institution study that we did not see a significant difference in length of stay when comparing our early learning curve robotic cases with mature VATS cases, suggesting that VATS done in experienced hands and within a tight system can be equally efficient in safely and quickly discharging patients from the hospital.[2] It must be acknowledged that comparing two institutions with a higher robotic case volume with the STS National Database may provide data and findings that would be less statistically significant than if the same study were repeated 5 years from now and included all robotic cases entered into the STS database. This is an important limitation of our findings.

There are several other key limitations to this study. First, there were significantly more patients with clinically staged T2a and N1 disease and ASA IV status in the thoracotomy group relative to the robotic cohort, suggesting that larger tumors and those with positive hilar nodes were resected via thoracotomy. This important consideration may partially account for some of the increased complications and duration of chest tube drainage noted in the open cohort. Second, although data are rigorously collected, it remains an administrative database and is subject to the variances in reporting from individuals who voluntarily submit data.

This is the first comparative article evaluating outcomes for lobectomy using the STS National Database. Our analysis suggests that there may be some benefits for robotic lobectomy relative to VATS, including reducing length of stay by 2 days and 30-day postoperative mortality. Our findings also support previously published suggestions that minimally invasive techniques may reduce complications and mortality relative to thoracotomy for early-stage lung cancer as well as some less common benign indications for anatomic lung resection. As more patients undergo robotic anatomic resection, it will be important to continue to monitor outcomes to determine whether these initial differences continue to be significant relative to VATS and to see whether more cases are done by minimally invasive techniques in the future. The next important outcome variables with respect to robotic cases should relate to its oncologic efficacy and related additional costs.

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CLINICAL PERSPECTIVE

Lobectomy remains the de facto standard of care for the treatment of early-stage lung cancer. How the lobe is removed and the outcomes from the available techniques are hotly debated. Advocates for thoracotomy steadfastly argue for the use of palpation and vision to optimize the accuracy and completeness of resection, whereas the minimally invasive enthusiasts claim superiority in recovery and complications without sacrificing local recurrence or survival.

Now, there is division in the ranks of the minimally invasive proponents, video-assisted thoracic surgery (VATS) versus robotics. Equipment of VATS is easily obtained; mastery may be a challenge, but there are numerous venues to learn it. More recently, single-port VATS has been introduced with impressive results. Robotics, on the other hand, may have advantages that are yet to be discovered and may ultimately allow us to avoid single-lung ventilation, a potential hazard. Expense and availability remain significant obstacles.

The authors have analyzed The Society of Thoracic Surgeons (STS) National Database to compare the results, thus far, between open thoracotomy, VATS, and robotic lobectomy. Although the method of comparison is imperfect, in that it is a very early look at the robotic experience for those participants in the STS National Database, we gain some information in the progress. It is difficult to determine whether it is the robot, the technique used, the surgeons performing the procedures, or the patients selected that are under study here. Given the relatively small numbers of robotic lobectomy cases, it is difficult to make claims of robotic superiority, but we can say that the early results do not seem to be worse and justify our further exploration of this new surgical technology.