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Full Reports

Robotic Versus Thoracoscopic Resection for Lung Cancer: Early Results of a New Robotic Program

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Abstract

Background: Robot-assisted surgical techniques have been introduced in recent years as an alternative minimally invasive approach for lung surgery. While the advantage of video-assisted thoracoscopic surgery (VATS) over thoracotomy for anatomical lung resection has been extensively reported, the results of robotic video-assisted thoracoscopic surgery (RVATS) compared to VATS are still under investigation.
Methods: We performed a retrospective review of lung cancer patients, undergoing minimally invasive segmentectomy or lobectomy between December 2007 and May 2014. A robotic program was introduced in 2011. Relevant early surgical outcomes were compared between VATS and RVATS, including mortality, morbidity, conversion to thoracotomy, length of stay (LOS), and reoperation.
Results: Eighty (60.2%) patients underwent VATS resection, while 53 (39.8%) had a RVATS procedure. The two groups presented no meaningful differences at baseline, in terms of age, race, body mass index, and preoperative comorbidities. Adenocarcinoma was the most common histology in both groups. Patients in the RVATS group had significantly more segmentectomies (11.3% versus 1.2%, $P = .016$). There were no postoperative deaths. RVATS appeared to be associated with fewer conversions to open (13.2% versus 26.2%, $P = .025$) and more lymph nodes retrieved (9 versus 7, $P = .049$). We found no significant differences in terms of other individual complications, including tracheostomy, reintubation, pneumonia, pulmonary embolism, and cerebrovascular events.
Conclusions: According to our results, the introduction of a robotic program did not negatively affect the early surgical outcomes of a well-established oncologic minimally invasive thoracic program. Potential advantages of RVATS still need to be explored in terms of long-term outcomes.

Introduction

Lung cancer is the leading cause of cancer mortality in the United States and represents the second most common cancer in both genders, with more than 221,200 new estimated cases in 2015.[1] New options for chemotherapy and radiotherapy are the main subject of ongoing research efforts, yet surgery still represents the mainstay for treatment of resectable lung cancer. The last two decades have witnessed the rise in popularity and widespread adoption of video-assisted thoracoscopic surgery (VATS) for lung cancer; this approach, in fact, allows for oncologic outcomes noninferior to those yielded by open surgery, while successfully reducing the incidence and magnitude of some of the most common drawbacks of thoracotomy, such as pain, infections, and lengthy postoperative recovery.[2] However, some of VATS' well-known limitations, including nonergonomic stiff instruments and bidimensional view, can lead to highly challenging dissection within the rigid chest cavity and limit the ability to control bleeding.[3] Given this premises, robotic surgery would appear to be a great alternative approach, which combines the best advantages of VATS and thoracotomy while overcoming most of the limitations of both techniques. The surgical robot, in fact, adds to a traditional minimally invasive approach several remarkable improvements, such as tridimensional optics, high-resolution magnification of the surgical field, tremor filtration, and a range of movements that goes even beyond that of the human hand. For these reasons, combined to a very effective marketing campaign, the widespread enthusiasm for this technology led to a quick rise of both surgeon's utilization and patients' demand. Many thoracic programs in the country now use this approach as

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an alternative minimally invasive option, and several studies have shown its feasibility and safety for treatment of lung cancer.[4–9] Some authors even suggest improved outcomes over the VATS approach, and it has been reported that robotics benefit from a shorter learning curve than traditional minimally invasive techniques.[9,10]

We introduced robotic surgery at our Institution in 2011, and with this study we aimed to compare surgical outcomes of VATS and robotic video-assisted thoracoscopic surgery (RVATS) for anatomical lung resections in patients with clinical early stage lung cancer performed between December 2007 and May 2014.

Materials and Methods

Study population

A study population of 133 patients treated for early stage (clinical stage I) nonsmall cell lung cancer at the Johns Hopkins Hospital and Johns Hopkins Bayview Medical Center between 2007 and 2014 comprised the study cohort. Johns Hopkins Cancer Registry (JHCR) personnel abstracted the medical record of patients in accordance with the American College of Surgeon Guidelines. The JHCR collects data on all cancer patients diagnosed and/or treated at this Institution. Following national standards, certified tumor registrars collect data on incidences, primary site, histology, extent of disease, treatment, and outcomes. The registry assures lifetime follow-up of cancer patients, and 96% of patients have current information within the last 14 months. Additional clinical data were abstracted from hospital records and electronic and paper files. The Johns Hopkins University School of Medicine Institutional Review Board approved this study.

Clinical variables

Patient-related characteristics were extracted from the JHCR database and the electronic medical record. Patient-related factors included race, age, gender, and body mass index (BMI). Tumor characteristics included tumor size, histology (adenocarcinoma, squamous cell, *in situ* pulmonary adenocarcinoma, adenosquamous, nonsmall cell, and not otherwise specified), and stage. Preoperative characteristics included forced expiratory volume in 1 second (FEV1) before surgery, history of hypertension, coronary artery disease, diabetes, atrial fibrillation, chronic obstructive pulmonary disease (COPD), and smoking history. Perioperative characteristics included surgical approach, surgical procedure, conversion to open thoracotomy, number of lymph nodes resected, number of days to chest tube removal after surgery, number of days spent in ICU after surgery, and total number of days spent in the hospital (length of stay [LOS]). We collected information on the need for tracheostomy, reintubation, and reoperation while we also identified if patients developed pneumonia, pulmonary embolism, stroke, and other complications during the postoperative hospital stay. Patients were excluded if they were younger than 18 years, had undergone any preoperative radiation or chemotherapy, had a higher clinical stage than IA or IB, required a sleeve resection of the bronchus or the artery, and had lung resection other than a segmentectomy or lobectomy. All surgical procedures were performed for curative intent by board-certified thoracic surgeons. Most of the robotic procedures were performed at Johns Hopkins Bayview Medical Center, and the decision to use the robot was mostly dictated by physician's and/or patient's preference and robot availability.

Surgical technique

We used a standard lateral decubitus position and lung isolation for both VATS and RVATS procedures. Pulmonary lobectomy or segmentectomy was defined as the anatomical removal of an entire lobe or segment of the lung involving dissection and individual ligation of the corresponding branches of the pulmonary artery, vein, and lobar or segmental bronchus. Rib spreading was not used in any of the approaches. VATS technique utilized three total incisions, one of which was extended to 2–3 cm to facilitate dissection and specimen removal. RVATS technique involved a complete portal approach with four robotic arms. One additional 12 mm trocar was placed at the edge of the thoracic cavity with the diaphragm and used for assisting and stapling. The specimen was removed through the assisting port after enlarging it to 3–5 cm in size at the end of the procedure. We used CO_2 insufflation with pressure at 8 mmHg during RVATS. Performing either a systematic mediastinal nodal dissection or nodal sampling was left to the preference of the operating surgeon. Lymph nodal stations routinely assessed included 4, 10, 7, 9, 11 on the right side and 5, 7, 9, 10, 11 on the left side.

Statistical analysis

Comparison of means and medians of continuous variables was performed using the Student's t test (two sided) and nonparametric Mann–Whitney U test, respectively. Comparisons between proportions for binary and categorical variables were performed using the chi-squared test for homogeneity. Fisher's Exact test was used to compare differences in proportions when expected numbers in any cell were less than 5 units. All hypothesis tests were two-sided, and results were considered statistically significant for P-values $\leq .05$.

We assessed univariate and multivariable associations separately between the surgical approach and (1) conversion, (2) perioperative events, and (3) need for reoperation using logistic regression. We assessed the association between surgical approach and total number of days spent in hospital using linear regression. We tested for interactions of selected covariates with the surgical approach and each perioperative outcome. Logistic regression results were reported as odds ratios (OR) with 95% confidence intervals (CIs). Linear regression results are reported as the mean difference in days spent in the hospital with 95% CIs. All analyses were performed using STATA statistical software, v14.0 (StataCorp LP, College Station, TX).

Results

Table 1 describes the study characteristics by the surgical approach: 80 patients (60%) underwent VATS and 53 patients (40%) underwent RVATS. There were no statistically significant differences by the surgical approach for median age, race, and median BMI. The majority of the study population had been diagnosed with adenocarcinoma histology,

Table 1. Comparison of Study Characteristics by Surgical Approach ($N = 133$)

	VATS 80 (60.2%)		*RVATS 53 (39.8%)*		
Characteristics	N	%	N	%	P
Demographics					
Median age (year, IQR)	67.5	62–74	66	60–71	.339
Race					.161
White	63	78.7	36	67.9	
Black/other[a]	17	21.3	17	32.1	
Histology					.015
Adenocarcinoma	62	78.5	29	54.7	
Squamous cell	9	11.4	13	24.5	
Other histology[b]	8	10.1	11	20.8	
Median BMI (IQR)	26.0	24.2–28.1	26.7	23.1–30.9	.570
BMI					.083
<18.5, underweight	2	2.5	5	9.4	
18.5–24.9, normal	25	31.3	12	22.6	
25.0–29.9, overweight	34	42.5	15	28.3	
≥30.0, obese	11	13.7	13	24.5	
N/A	8	10.0	8	15.2	
Median FEV1 percent predicted (IQR)	89.9	79.0–101.0	80.1	63.9–96.4	.028
FEV1 percent predicted					.033
<80.0%	17	21.3	22	41.5	
≥80.0%	49	61.3	22	41.5	
N/A	14	17.5	9	17.0	
Hypertension	41	51.3	32	60.4	.428
Coronary artery disease	11	13.8	10	18.9	.456
Diabetes	8	10.0	7	13.2	.594
Atrial fibrillation	46	7.5	1	1.9	.156
COPD	12	15.0	11	20.8	.390
Ever smoked					<.001
Never	14	17.5	0	0.0	
Ever	62	77.5	42	79.3	
Unknown	4	5.0	11	20.7	
Median pack years smoked (year, IQR)	37	25–50	30	24–50	.688
Surgery year					<.001
2007	1	1.3	0	0.0	
2008	4	5.0	0	0.0	
2009	9	11.2	0	0.0	
2010	17	21.3	0	0.0	
2011	16	20.0	20	37.7	
2012	20	25.0	17	30.2	
2013	13	16.2	13	24.5	
2014	0	0.0	4	7.6	

Missing data (*N*, %): BMI (16, 12.0%), FEV1 (23, 17.3%), Ever smoked and pack years (15, 11.3%).
[a]"Other histology" includes carcinoid (9), in situ pulmonary adenocarcinoma (6), adenosquamous (3), and large cell (2).
[b]"Other race/ethnicity" includes Middle Eastern (5), Asian (3), and Hispanic (1).
BMI, body mass index; COPD, chronic obstructive pulmonary disease; FEV1, forced expiratory volume in 1 second; IQR, interquartile range; RVATS, robotic video-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery.

yet comparatively more in the VATS group had adenocarcinoma than the RVATS group. Median FEV1 was higher among the VATS groups, which probably explains the lower number of sublobar resection compared to the RVATS group. There were no differences in preoperative comorbidity, however, there were more never smokers among the VATS group. Lobectomy was the most prevalent surgical procedure for both groups. Twenty-six percent of the VATS group had a conversion to open thoracotomy compared to 13% among the RVATS group. However the conversion rate was 54.8% in the VATS group before 2011 and 14.3% after 2011, therefore reflecting a learning curve effect in the early years of VATS adoption. Lymph nodal retrieval was significantly higher in the RVATS group. There were no differences in the other perioperative characteristics and perioperative events. No patient died during the postoperative hospital stay (Table 2).

By univariate regression analysis, no patient, preoperative, or perioperative characteristics were associated with the outcomes of interest—conversion to open thoracotomy, length of hospital stay, perioperative events, or reoperation (Table 3). Patients who underwent RVATS were associated with a 64% decrease in odds of conversion to open thoracotomy. The association in the mean difference in days spent in hospital after surgery comparing VATS to RVATS was essentially null (coefficient = 0.95; 95% CI, –0.84 to 2.73; $P = .296$).

Table 2. Comparison of Outcomes by Surgical Approach ($N = 133$)

	VATS 80 (60.2%)		*RVATS 53 (39.8%)*		
Characteristics	N	%	N	%	P
Surgical procedure					.016
Lobectomy	78	97.6	47	88.7	
Bilobectomy	1	1.2	0	0.0	
Segmentectomy	1	1.2	6	11.3	
Conversion					.025
No conversion	56	73.8	46	86.8	
Conversion to open	24	26.2	7	13.2	
Stage					<.001
I	80	100	46	86.8	
II–III	0	0.0	7	13.2	
Median number of lymph nodes resected (IQR)	7	5–10	9	5–13	.049
Median days to chest tube removal (days, IQR)	3	2–4	3	3–6	.244
Median number of days in ICU (days, IQR)	1	0–1	1	1–2	.151
Median length of hospital stay (days, IQR)	5	4–6	5	4–7	.185
Tracheostomy	1	1.3	1	1.9	.929
Reintubation	4	5.0	4	7.6	.713
Pneumonia	3	3.8	2	3.8	.994
Pulmonary embolism	0	0.0	0	0.0	—
Stroke	0	0.0	0	0.0	—
Reoperation	1	1.3	3	5.7	.301
Postoperative mortality	0	0.0	0	0.0	—
Recurrence	3	3.8	6	11.5	.154

IQR, interquartile range; RVATS, robotic video-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery.

Discussion

Our analysis demonstrated no significant differences in overall postoperative mortality or morbidity between patients undergoing anatomical lung resections for cancer with VATS versus RVATS. The average patient of our study was a late middle-aged smoker, thus reflecting the typical epidemiological picture of a lung cancer patient in the western world. Patients in both groups shared very similar preoperative characteristics, in terms of both comorbidities and extension of disease, hence eliminating a significant source of bias. Although our study did not demonstrate a net superiority of the robot over thoracoscopy, it is worth recalling that the comparison was done at the beginning of a new robotic program. While all the surgeons involved in this study had extensive VATS training, their experience with the robot was considerably less conspicuous. This observation yields a very positive connotation, since it suggests that the transition from traditional minimally invasive techniques to robotic surgery happened safely and quickly, without experiencing learning curve-related negative repercussions on surgical outcomes.

We did not observe a difference in mortality between the two approaches; in fact, we did not observe any death at all among the patients of this study. This is likely due to the relatively small total number of patients, rather than to the technique itself, and the question whether the use of the robot affects mortality in anatomical lung resection is better answered with a different study design, which allows to collect data from larger patient populations, such as multicentric trials, national database analyses, or meta-analyses. Data

Table 3. Estimated Association of Selected Perioperative Outcomes Comparing Surgical Approach (RVATS to VATS; $N = 133$)

Outcomes[a]	*Crude point estimate*[b]	*95% CI*	P	*Adjusted point estimate*[c]	*95% CI*	P
Conversion	0.36	0.14 to 0.90	.029	0.18	0.14 to 0.90	.007
Length of hospital stay (days)	0.95	−0.84 to 2.73	.296	0.89	−1.03 to 2.80	.360
Perioperative events[d]	1.88	0.60 to 5.93	.284	1.62	0.47 to 5.66	.448
Reoperation	4.74	0.48 to 46.84	.183	3.86	0.34 to 43.77	.277

[a]VATS = reference group.
[b]Point estimates reflect odds ratios, but for length of hospital stay, which reflects the difference in mean days of hospital stay for RVATS compared to VATS.
[c]Adjusted for stage (I versus II–III).
[d]Perioperative events include occurrence of tracheostomy, reintubation, pneumonia, pulmonary embolism, stroke, or reoperation.
CI, confidence interval; RVATS, robotic video-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery.

from other studies, in fact, using large national and statewide databases, such as the Society of Thoracic Surgeons (STS) database and the State Inpatient Databases (SID), have suggested that robotic surgery yields lower mortality than both thoracotomy and VATS.[9,11] The reason for this observed difference remains unclear and, at this time, caution should be advised in attributing the reduction in mortality to the technical peculiarities of the surgical robot. Many confounders, probably not completely accounted for in these studies, such as selection bias, smaller size of the robotic groups, and concentration of robotic cases in high volume superspecialized centers, might have incorrectly led to such results.[9]

One of our findings worth discussing is the increased number of segmentectomies, likely driven by worse pulmonary function, in the robotic group. Anatomic segmentectomy for early stage lung cancer is becoming increasingly more appealing as the population ages, with a consequent decrease in cardiopulmonary reserve. In fact, it offers comparable oncologic outcomes for early stage cancer to the gold standard (lobectomy) while preserving more lung tissue and function.[5,12] One of the issues limiting the rise in segmentectomies is the perception that this procedure is more challenging than lobar resection and requires extensive knowledge and familiarity with segmental anatomy to individually isolate and divide the appropriate segmental vessels and bronchi.[13] Needless to say, approaching segmentectomy with minimally invasive techniques adds a further layer of complexity. We strongly believe that the advantages in dexterity and depth of visualization delivered by the robot facilitate execution of more complex procedures, therefore allowing for anatomical resection in patients who benefit from lung preservation. It is encouraging that, even in this early experience, with significantly more segmentectomies in the RVATS group, we did not observe a detrimental impact in the overall surgical outcomes.

The lower conversion rate observed in the robotic group represents another interesting finding of this study. There are many possible explanations for these data. We believe that the high incidence of conversion in the VATS group is predominantly the result of the learning curve since most events occurred during the first years after introduction of VATS. We did not observe the same issue during the robotic learning curve and this might be explained by the gained experience in minimally invasive surgery with VATS, facilitating the transition to robotics. Moreover, the presence of tenacious adhesions and more extensive disease than expected was above the most common causes of conversion in both groups. In contrast, while about a third of the conversions in the VATS group were dictated by difficulty in controlling bleeding, a similar scenario justified conversion in only 1 RVATS patient. The most logical explanations for this finding, given the similarities between the two groups, are that the robot allows for a safer more controlled dissection or that it is easier to control bleeding with the robot when compared to VATS, or, most likely, a combination of the two.

The number of nodes retrieved using the robot was higher than that achieved through VATS. This is a welcome finding and it is confirmed in the recent thoracic literature; in 2014, Wilson et al. reported that the rate of nodal upstaging for robotic resection appears to be superior to VATS and similar to thoracotomy.[14] Of note, in their study, pathologic nodal upstaging was used as a surrogate for completeness of nodal harvesting and evaluation. While it is difficult to measure objectively the advantage granted by RVATS in nodal dissection, Wilson et al. postulate that this is attributable to the robot allowing the interlobar fissure to be directly dissected and hilar nodes removed along the pulmonary vessels and the bronchus, in a similar manner to the open procedure. Interestingly, while all our VATS patients remained in pathological stage I, we did observe a higher pathological stage than expected in 7 RVATS patients, 5 of which had true lymph node upstaging, suggesting an advantage in lymph node retrieval with robotics.

The main strength of this article is the use of a well maintained and updated database at a single institution. This allowed for a great degree of insight and detail within the data of every patient. It is also worth mentioning that the choice of using the robot was dictated by surgeon's or patient's preference and this might have avoided some of the selection bias that could have otherwise easily been introduced by surgeons at the beginning of a program.

This study has however several limitations, the most important of which is its retrospective nature, hence prone to introduce confounders that are clearly not accounted for. In addition, due to focusing on very selected procedures and disease, the patient population included in the study is small, which significantly narrows statistical options for analysis. Furthermore, while the presence of a learning curve in both groups is undoubtable, its effect on surgical outcomes is difficult to measure objectively. Finally, it is worth mentioning that personal surgeons' preference played an important role in the extent of lymph node retrieval in our population.

In conclusion, our data suggest that the development of a new robotic program can occur safely within a well-established thoracic program. It is a particularly positive note to remark that there appears to be no learning curve-related detrimental effect on surgical outcomes for RVATS. Finally, there are some potential technique-specific advantages to RVATS in terms of facilitating lymph node retrieval and possibly reducing conversion rate. Therefore, RVATS should be considered a valid option to help promote the adoption of minimally invasive techniques in the field of thoracic surgery.

Disclosure Statement

No competing financial interests exist.

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