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Research Paper

Early adoption of robotic lung resection in an established video assisted thoracic surgery practice

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HIGHLIGHTS

- Benefits of robotic surgery are seen even in well-established VATS practice.
- Robotic-assisted lung resection results in better lymph node sampling.
- Patients with robotic resection had higher 72-hour pain scores and 48-hour narcotic use.
- Morbidity and length of stay were equivalent between the two approaches.

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ABSTRACT

Background: Reported advantages to robotic thoracic surgery include shorter length of stay (LOS), improved lymphadenectomy, and decreased complications. It is uncertain if these benefits occur when introducing robotics into a well-established video-assisted thoracoscopy (VATS) practice. We compared the two approaches to investigate these advantages.
Materials and methods: IRB approval was obtained for this project. Patients who underwent segmentectomy or lobectomy from May 2016–December 2018 were propensity-matched 2: 1 (VATS: robotic) and compared using weighted logistic regression with age, gender, Charlson Comorbidity Index, surgery type, stage, Exparel, and epidural as covariates. Complication rates, operation times, number of sampled lymph nodes, pain level, disposition, and LOS were compared using Wilcoxon rank-sum and with Rao-Scott Chi-squared tests.
Results: 213 patients (142 VATS and 71 robot) were matched. Duration of robotic cases was longer than VATS (median 186 min (IQR 78) vs. 164 min (IQR 78.75); $p < 0.001$). Significantly more lymph nodes (median 11 (IQR 7.50) vs. 8 (IQR 7.00); $p = 0.004$) and stations were sampled (median 4 (IQR 2.00) vs. 3 (IQR 1.00); $p < 0.001$) with the robot. Interestingly, robotic resections had higher 72-hour pain scores (median 3 (IQR 3.25) vs. 2 (IQR 3.50); $p = 0.04$) and 48-hour opioid usage (median 37.50 morphine milligram equivalents (MME) (IQR 45.50) vs. 22.50 MME (IQR 37.50); $p = 0.01$). Morbidity, LOS, and disposition were similar (all $p > 0.05$).
Conclusions: The robotic approach facilitates better lymph node sampling, even in an established VATS practice.

Introduction

In the last thirty years, video-assisted thoracic surgery (VATS) has been established as a safe and efficient standard for lung resection in both early stage and locally invasive non-small cell lung cancers (NSCLC) [1,2]. Since the first robotic lobectomy in 2001, the robotic techniques have become increasingly popular in the last two decades. Robotic-assisted thoracic surgery (RATS) has been reported to provide significant improvements in post-operative outcomes over open surgery including fewer complications, lower 30-day mortality and shorter length of stay [3]. A retrospective study by Adams et al. comparing RATS to open lobectomy also found RATS to be associated with lower rates of

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postoperative blood transfusion, fewer prolonged air leaks, and shorter duration of chest tube placement [4]. These benefits to the RATS approach are not universally demonstrated when compared to VATS. Results from studies analyzing the two approaches have been contradictory, especially concerning post-operative pain or lymph node harvest [5]. RATS has been shown in general to be comparable to VATS regarding length of stay or post-operative complications [6].

Utilization of the robotic platform is not without its challenges. One barrier is the cost to the hospital system. Each robot costs between $1 million and $2.5 million and is associated with annual maintenance fees, which are estimated at about $100,000 [6]. Robot-assisted procedures are also associated with higher hospital costs, with incremental increases for both lobectomy and wedge resection at $4565 and $2992 compared to VATS, respectively [7]. These may be attributed to the increased staffing and more expensive materials required for RATS.

While the downsides and benefits of robotic-assisted lung resections have been extensively reported, it is still unclear whether RATS will provide the desired benefits to justify its implementation in a well-established VATS practice. A case series by Jang et al. comparing robot-assisted lobectomy to VATS showed similar postoperative outcomes between the two and suggests that robot-assisted lobectomy could be rapidly adapted by experienced VATS surgeons after just a few cases [8].

Therefore, we aimed to ascertain the benefit of adopting the robotic platform in our well-established VATS practice comprised of over 20 surgeons who perform over 1000 VATS procedures annually. We analyzed operative times, sampled lymph nodes, LOS, and patient outcomes in both robotic and video-assisted lung resections performed by our experienced surgeons.

Materials and methods

Approval was obtained for this study through the Institutional Review Board at Brigham and Women's Hospital. Informed consent was waived. Using the divisional outcomes database managed within the Division of Thoracic Surgery, we conducted a retrospective analysis of prospectively collected data of patients who underwent VATS or robotic segmentectomy or lobectomy from May 2016–December 2018. This database monitors perioperative variables and outcomes for all surgical patients and is audited twice weekly by attending surgeons for accuracy. Wedge resections, pneumonectomies, sleeve lobectomies, and open cases were excluded from the analysis. Sociodemographic factors (age, gender, comorbidities as measured by the Charlson Comorbidity Index), surgical factors (surgery type, approach, conversion, operative time, lymph nodes sampled), pain variables (pain scores at PACU, 12 h, 24 h, 48 h, and 72 h and morphine milligram equivalents at 24 and 48 h), and postoperative factors (complications by Clavien-Dindo grade, hospital length of stay, disposition) were then compared between those who underwent VATS lobectomy or segmentectomy and those who underwent robotic lobectomy or segmentectomy. The cohort was then propensity-matched in a 2:1 fashion utilizing a logistic regression model accounting for age, gender, Charlson Comorbidity Index, surgery type, cancer stage, postoperative pain control strategy (Exparel or thoracic epidural) (Supplementary Fig. 1). The same factors were then compared between matched groups utilizing Wilcoxon rank-sum tests for continuous variables and Rao-Scott tests for categorical variables. All statistical analyses were completed utilizing R Statistical Software, version 4.1.0 (R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was determined by a p value < 0.05.

Results

A total of 222 patients were included in the study cohort before propensity matching. There were 67 segmentectomies (30.2 %) and 155 lobectomies (155 or 69.8 %). Most of these patients underwent VATS technique (151, 68.0 %) while 71 (32.0 %) underwent robotic resection. After propensity matching, there were a total of 213 patients included in the analysis (142 or 66.7 % VATS and 71 or 33.3 % robotic). As expected after matching, there were no statistically significant differences in age, gender, comorbidities, or preoperative lung function between VATS and robotic cases (all $p > 0.05$). Table 1 displays the sociodemographic, preoperative, and intraoperative factors for the unmatched and matched cohort.

In the matched cohort, there were 150 lobectomies (70.4 %) and 63 segmentectomies (29.6 %) (Table 1). Robotic cases took longer to perform (median operating time 186 min [IQR 78] vs. 164 min [IQR 79], $p < 0.001$), but there were no statistically significant differences in the number of conversions to open or the rates of intraoperative hemorrhage (both $p > 0.05$). When examining the number of lymph nodes sampled, the robotic approach appeared to yield more lymph nodes total (median 11 lymph nodes [IQR 7.50] vs. 8 lymph nodes [IQR 7.00], $p = 0.01$), more stations sampled (median 5 stations [IQR 2.00] vs. 4 stations (IQR 2.00), $p < 0.001$), and more mediastinal stations sampled (median 8 stations [IQR 7.50] vs. 6 stations [IQR 6.00], $p = 0.01$). When examining specific lymph node stations, robotic cases appeared to have higher rates of sampling from stations 6 (14.1 % vs. 4.23 %, $p = 0.01$) and 10 (63.4 % vs. 45.77 %, $p = 0.02$) when compared to the VATS approach.

There were no statistically significant differences between matched cohorts with regards to postoperative complications, hospital length of stay, and disposition (all $p > 0.05$) (Table 2). Median hospital length of stay was 3 days for both groups (IQR 3, $p = 0.94$) and most patients from each group were discharged home with services (55 or 77.5 % robotic and 106 or 74.6 % VATS, $p = 0.88$).

Most of the patients in both the VATS and robotic group received liposomal bupivacaine as part of their postoperative pain regimen (39 or 54.9 % robotic cases and 91 or 64.1 % VATS cases) (Table 3). Of note, there was a statistically significant difference in epidural rates between surgical approaches. Overall, more VATS cases (51 or 35.9 %) received epidurals when compared to robotic cases (12 or 16.9 %, $p = 0.01$). There were no significant differences in pain scores at PACU, 12 h, 24 h, or 48 h post-operatively. However, there were significantly higher pain scores at 72 h post-operatively in the robotic group (median 3 [IQR 3.25] vs. median 2 [IQR 3.50], $p = 0.04$). Similarly, there were no significant differences in morphine milligram equivalents at 24 h post-operatively, but the robotic group had higher requirements at 48 h (median 37.50 [IQR 45.50] vs. 22.50 [IQR 37.50], $p = 0.01$).

Discussion

To our knowledge, this is the first study to evaluate whether RATS maintains its benefits after its integration into an already well-established, prolific VATS institution. Our retrospective analysis demonstrated a continued benefit of robotic-assisted lung resections on several categories even in a well-established VATS practice. There were more lymph nodes and mediastinal stations sampled during robotic surgery compared to those sampled during VATS. Morbidity and LOS were similar between the two approaches.

The use of robotic surgery has increased exponentially over the years [9]. Since its advent, countless studies have been published comparing RATS to VATS. Most found that robotic surgery often resulted in longer operating times compared to VATS, but there was no difference in hospital LOS, post-operative complications, or rates of conversion to thoracotomy [3,6,7,10]. Our results also aligned with these findings. Operating times might decrease as surgeons become increasingly familiar with the robot. Arnold and colleagues discovered that the learning curve for a RATS lobectomy is 22 cases, and mastery can be achieved with over 60 cases [11]. Operative time and intra-operative blood loss usually decrease after the initial learning period [12]. Stringfield and colleagues evaluated their robotic program over a 10-year span and also concluded that operative times across several surgical specialties decrease as surgeons and nursing staff gain more

Table 1
Sociodemographic and perioperative factors of cohort.

Variable		Unmatched total	Unmatched VATS	Unmatched robot		Matched total	Matched VATS	Matched robot	
		222	151 (68.0 %)	71 (32.0 %)	*p*-Value	213	142 (66.7 %)	71 (33.3 %)	*p*-Value
Demographics									
Age, years	Median (IQR)	68.40 (13.7)	68.58 (13.0)	68.25 (15.2)	0.59	68.20 (13.8)	68.10 (13.0)	68.25 (15.2)	0.85
Gender, male	n (%)	87 (39.2)	55 (36.4)	32 (45.1)	0.28	84 (39.4)	52 (36.6)	32 (45.1)	0.26
Charlson Index	Median (IQR)	4 (3.0)	4 (2.0)	5 (4.0)	**0.003**	4 (3.00)	4 (2.00)	5 (4.0)	**0.01**
FEV1%	Median (IQR)	0.89 (0.3)	0.88 (0.3)	0.89 (0.21)	0.57	0.88 (0.3)	0.88 (0.3)	0.89 (0.2)	0.47
Surgery type					0.55				0.55
Lobectomy	n (%)	155 (69.8)	103 (68.2)	52 (73.2)		150 (70.4)	98 (69.0)	52 (73.2)	
Segmentectomy	n (%)	67 (30.2)	48 (31.8)	19 (26.8)		63 (29.6)	44 (31.0)	19 (26.8)	
Surgical variables									
Conversion	n (%)	10 (4.5)	8 (5.3 %)	2 (2.8)[a]	0.63	10 (4.7 %)	8 (5.6 %)	2 (2.8)[a]	0.52
Hemorrhage/hemothorax	n (%)	3 (1.4)	2 (1.3)	1 (1.4)	>0.99	3 (1.4)	2 (1.4)	1 (1.4)	>0.99
Operative time, minutes	Median (IQR)	172.30 (73.0)	161 (75.5)	186 (78.0)	**<0.001**	174 (73.0)	164 (78.7)	186 (78.0)	**<0.001**
Patients with LN sampled	n (%)	221 (99.5)	150 (99.3)	71 (100.0)	>0.99	212 (99.5)	141 (99.3)	71 (100.0)	0.41
Total number of stations sampled	Median (IQR)	4 (2.0)	4 (2.0)	5 (2.0)	**<0.001**	4 (2.0)	4 (2.0)	5 (2.0)	**<0.001**
Total mediastinal LN sampled (stations 2–9)	Median (IQR)	6 (6.0)	5 (5.5)	8 (7.5)	**0.003**	6 (7.0)	6 (6.0)	8 (7.5)	**0.01**
Total number LN sampled (all LN)	Median (IQR)	9 (8.00)	8 (7.00)	11 (7.50)	**0.004**	9 (8.00)	8 (7.00)	11 (7.50)	**0.01**

Bolded p-values are statistically significant ($p < 0.05$).
VATS = video assisted thoracic surgery.
IQR = interquartile range.
FEV1% = percent of predicted forced expiratory volume in 1 s.
LN = lymph node.
[a] One patient converted to VATS.

Table 2
Postoperative complications and outcomes of both the unmatched and matched cohort.

Variable		Unmatched total	Unmatched VATS	Unmatched robot		Matched total	Matched VATS	Matched robot	
		222	151 (68.01 %)	71 (31.98 %)	*p*-Value	213	142 (66.67 %)	71 (33.33 %)	*p*-Value
Postoperative variables									
Patients with complications	n (%)	58 (26.1)	42 (27.8)	16 (22.5)	0.5	54 (25.4)	38 (26.8)	16 (22.5)	0.53
Grade II	n (%)	54 (24.3)	41 (27.2)	13 (18.3)	0.21	50 (23.5)	37 (26.1)	13 (18.3)	0.25
Grade III	n (%)	12 (5.4)	7 (4.6)	5 (7.04)	0.67	12 (5.6)	7 (4.9)	5 (7.0)	0.54
Grade IV	n (%)	2 (0.9)	1 (0.7)	1 (1.4)	>0.99	2 (0.94)	1 (0.7)	1 (1.4)	0.61
Grade V	n (%)	N/A				N/A			
Hospital LOS, days	Median (IQR)	3 (2.75)	3 (2.50)	3 (2.50)	0.92	3 (3.00)	3 (3.00)	3 (2.50)	0.94
Disposition					0.91				0.88
Home	n (%)	45 (20.3)	31 (20.5)	14 (19.7)		44 (20.7)	30 (21.1)	14 (19.7)	
Home with Services	n (%)	169 (76.1)	114 (75.5)	55 (77.5)		161 (75.6)	106 (74.6)	55 (77.5)	
Rehab	n (%)	7 (3.2)	5 (3.3)	2 (2.8)		7 (3.3)	5 (3.5)	2 (2.8)	
Nursing Home	n (%)	1 (0.5)	1 (0.7)	0 (0.0)		1 (0.5)	1 (0.7)	0 (0.0)	

VATS = video assisted thoracic surgery.
IQR = interquartile range.

experience and comfort. Inevitably, some variability remains on a case-by-case basis [13].

Studies analyzing lymph node dissection between the two surgical approaches have been contradictory. We found that RATS resulted in greater sampling of overall lymph nodes and mediastinal stations, specifically station 6 and 10. Sampling of station 10 is particularly interesting because it can act as a bridging node between the mediastinum and the parenchymal nodes, and it that might not be well sampled with VATS. Previous studies have reported similar findings, including increased dissection of N1 nodes, specifically 11 and 12 [14–16]. In contrast, other studies have demonstrated no significant difference between RATS and VATS in the dissection of the number of stations or overall lymph nodes [17,18]. In fact, Wilson and colleagues reported higher rates of nodal upstaging during RATS lobectomy or segmentectomy compared to patients undergoing VATS. However, in this study, lymph node dissection was up to the discretion of the surgeon with no set standard followed, which may have significantly influenced their findings [19].

Existing literature comparing RATS to VATS on post-operative pain is also contradictory. Kwon et al. found no significant differences in

Table 3
Pain variables of both the unmatched and matched cohort.

Variable		Unmatched total	Unmatched VATS	Unmatched robot		Matched total	Matched VATS	Matched robot	
		222	151 (68.01 %)	71 (31.9 %)	*p*-Value	213	142 (66.7 %)	71 (33.3 %)	*p*-Value
Liposomal Bupivacaine	n (%)	139 (62.6)	100 (66.2)	39 (54.9)	0.14	130 (61.0)	91 (64.1)	39 (54.9)	0.22
Epidural	n (%)	63 (28.4)	51 (33.8)	12 (16.9)	**0.02**	63 (29.6)	51 (35.9)	12 (16.9)	**0.01**
Pain scores, median (IQR)									
PACU	Median (IQR)	6 (8.00)	6 (8.00)	6 (6.50)	>0.99	6 (8.00)	5.50 (8.00)	6 (6.50)	0.97
12 Hours	Median (IQR)	4 (4.00)	4 (4.00)	4 (3.00)	0.87	4 (4.00)	4 (4.00)	4 (3.00)	0.84
24 Hours	Median (IQR)	4 (4.00)	4 (3.50)	4 (4.00)	0.6	4 (4.00)	4 (3.00)	4 (4.00)	0.58
[a]48 Hours	Median (IQR)	3 (2.50)	3 (2.00)	3 (3.00)	0.41	3 (3.00)	3 (2.00)	3 (3.00)	0.36
[b]72 Hours	Median (IQR)	2 (4.00)	2 (3.00)	3 (3.25)	**0.03**	2 (3.00)	2 (3.50)	3 (3.25)	**0.04**
MME, median (IQR)									
24 Hours	Median (IQR)	47.75 (50.50)	41 (62.00)	52 (35.50)	0.54	48 (51.00)	43 (62.88)	52 (35.50)	0.56
48 Hours	Median (IQR)	25.12 (44.12)	22.50 (37.50)	37.50 (45.50)	**0.01**	29 (43.50)	22.50 (37.50)	37.50 (45.50)	**0.01**

Bolded p-values are statistically significant ($p < 0.05$).
VATS = video assisted thoracic surgery.
IQR = interquartile range.
MME = morphine milligram equivalents.
[a] 206 pts total, 141 VATS, 65 robotic.
[b] 143 pts total, 103 VATS, 40 robotic.

morphine equivalents or acute pain, defined as <10 days post-operatively, between these two surgical approaches [5]. Louie et al. reported a shorter duration of narcotic use after discharge for patients who had undergone RATS [20]. However, it's important to note that in this study, all patients received an extensive multimodal regimen while hospitalized, and registered nurse practitioners determined the amount of narcotics to administer. They were not blinded to the procedure, which could have introduced bias. Additionally, in hospital post-operative pain scores were not reported. Patients in our cohort who underwent robotic surgery reported higher pain scores 72 h post-operatively and had higher morphine milligram equivalents 48 h post-operatively. This may be due to more VATS patients receiving epidurals compared to RATS patients. It could also be attributed to the learning curve associated with the robot. When VATS was first implemented, pain scores were often comparable to those reported after a thoracotomy. Most of these VATS patients had chronic pain along the thoracoabdominal distribution of the intercostal nerve, usually at the site of the camera port. Increased torquing of the instruments during thoracoscopic surgery likely increased the trauma to the neurovascular bundle from intercostal muscles [21]. As surgeons improved their thoracoscopic skills and understanding of port placements, pain scores decreased, and early recovery after VATS was seen. We might notice a similar trend with robotic surgery as we continue to enhance our understanding of this technology.

Although we did not specifically explore the factors that supported the implementation of robotic surgery into our already busy VATS practice, the overall similarities between our findings and previous studies suggests that integration of robotic surgery was safe and feasible at our institution. A standardized pathway is in place for robotic training, which consists of online modules, simulation modules (e.g. Morristown protocol), observation of cases at usually another institution, and hands-on proctoring for at least 5 cases. Only after these measures are achieved do our surgeons operate independently on the robot. This curriculum is similar to the validated, stepwise progression that has been described in literature [22–24]. As previously mentioned, although differences between our results and prior studies were noted regarding pain scores after RATS, this might be mitigated with increased familiarity and experience on the robot.

There are several limitations to acknowledge. First, the retrospective nature of this analysis introduces inherent bias between the RATS and VATS groups regarding case selection. It is possible that surgeons chose to perform certain surgeries one way over another depending on their individual comfort with an approach. However, we have a large practice with over 20 thoracic surgeons, which may offset individual biases. Second, we also did not specifically compare RATS lobectomy to VATS lobectomy or RATS segmentectomy to VATS segmentectomy. Perhaps disparities would have been revealed given the intrinsic differences between the two surgeries. However, our aim was to assess the benefits of RATS overall, and ascertaining differences between specific surgeries was outside the scope of this study. Third, although we included epidural placement, our pain analysis did not incorporate granular details of additional multimodal regimen that was likely administered in the peri-operative period. This would influence overall pain scores and morphine milligram equivalents. Fourth, when evaluating operative times, we did not account for individual surgeons in this study, nor did we separately analyze segmentectomy and lobectomy. Overall surgical experience, familiarity with the robot, and the type of surgery performed would impact operative times. However, once again, our large practice would likely balance any differences. Lastly, as with any propensity matched study, it is possible that residual confounders remain despite propensity matching. However, we tried to account for some of the most important variables. Long-term multicenter studies may be helpful in reinforcing these findings and providing insight into any staging benefits offered by the RATS approach.

Conclusions

In summary, benefits of robotic surgery persist even after its integration into a busy practice with experienced VATS surgeons. This may in part reflect the standardized training pathways that ensure safe integration of new technology while minimizing detrimental effects on patient outcomes. Even in established practices, change is possible and is necessary as new technology is introduced over time.

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Ethics approval

IRB approval was obtained, and informed consent was waived.

CRediT authorship contribution statement

Ashley L. Deeb: Writing – review & editing, Resources, Investigation, Data curation. **Luis De Leon:** Writing – review & editing, Resources, Investigation, Data curation. **Emanuele Mazzola:** Writing – review & editing, Formal analysis. **Suden Kucukak:** Writing – review & editing, Resources, Data curation. **Anupama Singh:** Writing – review & editing, Writing – original draft, Methodology. **Miles McAllister:** Writing – review & editing, Methodology. **Matthew Garrity:** Writing – review & editing, Resources, Data curation. **Michael T. Jaklitsch:** Writing – review & editing, Methodology, Conceptualization. **Jon O. Wee:** Writing – review & editing, Methodology, Conceptualization. **Matthew M. Rochefort:** Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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