ORIGINAL ARTICLE

Evaluating the implementation of robotic thoracic surgery on a Veterans Administration Hospital

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Abstract

Robotic thoracic surgery has demonstrated benefits. We aimed to evaluate implementation of a robotic thoracic surgery program on postoperative outcomes at our Veteran's Administration Medical Center (VAMC). We retrospectively reviewed our VAMC database from 2015 to 2021. Patients who underwent surgery with intention to treat lung nodules were included. Primary outcome was patient length of stay (LOS). Patients were grouped by surgical approach and stratified to before and after adoption of robotic surgery. Univariate comparison of postoperative outcomes was performed using Wilcoxon rank sums and chi-squared tests. Multivariate regression was performed to control for ASA class. P values < 0.05 were considered significant. Outcomes of 108 patients were assessed. 63 operations (58%) occurred before and 45 (42%) after robotic surgery implementation. There were no differences in patient preoperative characteristics. More patients underwent minimally invasive surgery (MIS) in the post-implementation era than pre-implementation (85% vs. 42%, $p < 0.001$). Robotic operations comprised 53% of operations post-implementation. On univariate analysis, patients in the post-implementation era had a shorter LOS vs. pre-implementation, regardless of surgical approach (mean 4.7 vs. 6.0 days, $p = 0.04$). On multivariate analysis, patients who underwent MIS had a shorter LOS [median 4 days (IQR 2–6 days) vs. 7 days (6–9 days), $p < 0.001$] and were more likely to be discharged home than to inpatient facilities [OR (95% CI) 13.00 (1.61–104.70), $p = 0.02$]. Robotic thoracic surgery program implementation at a VAMC decreased patient LOS and increased the likelihood of discharging home. Implementation at other VAMCs may be associated with improvement in some patient outcomes.

Keywords Veterans administration · VA · Thoracic · Robotic surgery · Implementation

Introduction

Robotic surgery's popularity as a treatment modality continues to rise [1–3]. Several surgical subspecialties, including gynecologic surgery, foregut surgery, and thoracic surgery have integrated this surgical modality, and it is becoming the first line surgical treatment for several disease processes and pathologies. Robotic surgery provides several advantages over traditional minimally invasive surgery, including use of wristed instruments that provide increased degrees of freedom, a stabilized camera with three-dimensional visualization, and the ability to control more than two instruments by a single surgeon [4–6]. Despite several benefits of robotic surgery, it has not been universally adopted by surgeons and hospital systems.

Practice at Veterans Administration Medical Centers (VAMCs) involves unique evaluation, treatment culture and resource allocation that differ from most Non-VAMC

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hospital systems. Veteran patients also have distinct medical needs due to combat exposure, including exposure to agent orange or other biochemical warfare devices [7, 8] and high rates of post-traumatic stress disorder[9–11], especially in patients with traumatic brain injuries [12]. The Veterans Health Administration provides complex surgical care to the unique patient population it serves. Patient outcomes at VAMCs are often equivalent to outcomes at civilian hospitals [13], even in certain complex, low volume subspecialties like kidney transplant [14]. However, veterans with newly diagnosed lung cancer have historically suffered worse survival than patients at civilian hospitals [15]. Therefore, optimizing the perioperative care of early-stage lung cancer patients remains an important quality improvement initiative for VAMCs.

Efforts to increase centralization, sophistication, and surgeon specialization within VAMCs are paramount to improving patient outcomes. Several studies show that centralizing patient care at high volume, specialized centers with experienced surgeons improves outcomes [16–20]. It has been well described that patients who require lung resection for cancer have better postoperative and oncologic outcomes when the operation is performed by a general thoracic surgeon compared to a cardiothoracic surgeon [21] or a general surgeon [22], and some of this variation can be attributed to both hospital and surgeon specific operative volume [21]. Adoption and centralization of complex procedures improves patient outcomes via the employment of both standardized clinical pathways [23], sophisticated clinical services [24] and treatment options like robotic surgery.

We recently implemented a thoracic robotic surgical program at our local VAMC hospital. Despite robotic surgical techniques being mature and of increasing availability, implementation of thoracic robotic surgical programs at hospitals throughout the VA health system have not been universally adopted. Because of this program's novelty within VAMCs, the impact of implementation of thoracic robotic programs on surgical patient outcomes within VAMCs has not yet been described in the literature. The purpose of this study was to determine the effect of implementing a robotic surgery program at a VA hospital on patient postoperative outcomes. We hypothesized that the implementation of a thoracic robotic surgery program would decrease occurrence of postoperative morbidity and shorten length of stay (LOS).

Methods

Ethical oversight

This study was approved by the Colorado Multiple Institutional Review Board (protocol #20-2777), the Veterans Administration Subcommittee on Research Safety (#20614), and the Veterans Administration Research and Development Service (approved February 24, 2021).

Study design

This was a retrospective review of prospectively collected data within our local VAMC, the Rocky Mountain Regional Veterans Administration Medical Center (RMRVAMC). Using surgeon case logs, all thoracic operations that occurred at the VAMC between January 1, 2015, and December 3, 2020, were identified. These were performed by two of the authors (CDS, RAM). All patients who underwent operations for intention to treat lung masses were included in the analysis. We identified the robotic implementation date by identifying the earliest use the robotic platform within the database. Patients were grouped into a pre-robotic implementation era cohort, from January 1, 2015, to the last surgery before the date of the first robotic operation, March 18, 2018, and a post-robotic implementation era cohort, from the date of the first robotic operation on March 18, 2018, until December 3, 2020. Patients were then subcategorized based on operative approach, dividing them into video-assisted thoracic surgery (VATS), robotic surgery, or open surgery cohorts. We defined minimally invasive surgery (MIS) as either VATS or robotic surgery. The demographic, perioperative and postoperative data in the VAMC database was reviewed and recorded for comparison analysis.

Statistical analysis

We performed three separate comparisons: pre-robotic era vs. post-robotic era; MIS vs. open surgery; and robotic vs. open surgery. Postoperative outcomes were compared between the groups within these three groups. Univariate analysis was performed using Wilcoxon rank sums for continuous variables and chi-squared analysis or Fisher's exact test for categorical variables, where appropriate. Multivariate logistic regression was performed controlling for American Society of Anesthesiologists physical status classification (ASA class) for all binary outcomes and a general estimating equation assuming a negative binomial distribution for postoperative length of stay. We chose to control for ASA class because only one preoperative characteristic (presence of connective tissue disease) met traditional standards for inclusion in a multivariate analysis, and ASA class served as a surrogate for overall preoperative patient health. Two-sided p values < 0.05 were considered statistically significant. All statistical analysis was performed using SAS version 9.4 [SAS Inc, Cary, NC].

Results

A total of 222 patients underwent thoracic surgery at the RMRVAMC during the study period. Of this cohort, 108 patients underwent surgery for treatment of lung masses and were included. The first robotic surgery was performed on March 18, 2018. Table 1 presents the patient characteristics in the pre- and post-implementation eras. There were 63 patients (58%) who had operations prior to robotic surgery program implementation and 45 patients (42%) who had operations performed after implementation. A total of 21 patients (19%) underwent VATS operations, 32 patients (30%) underwent robotic surgery, and 55 patients (51%) underwent open surgery. Patients were similar before and after robotic surgery program implementation (all $p > 0.05$), and robotic operations accounted for 53% of cases after implementation. More patients underwent MIS in the post-implementation era than the pre-implementation era (85% vs. 42%, $p < 0.001$).

Table 2 presents the patient characteristics by operative approach. While patients who underwent robotic operations were older (mean age = 70 years old) compared to VATS (mean age = 65) or open (mean age = 66) approaches ($p = 0.04$), there were no other patient demographics or medical comorbidities that were significantly different between the three approaches (all $p > 0.08$). Patients who underwent VATS were significantly more likely to have a wedge resection performed and were less likely to have squamous cell carcinoma on final tumor pathology compared to patients who underwent either robotic or open approaches, who were more likely to undergo lobectomy and had significantly more squamous cell carcinoma on final pathology ($p < 0.0001$ and 0.001, respectively).

Table 3 presents perioperative outcomes pre- and post-robotic thoracic surgery program implementation. On univariate analysis, patients who underwent surgery after robotic thoracic surgery implementation had longer operations (mean 231 vs. 162 min, $p < 0.0001$) but a shorter LOS regardless of surgical approach [median (interquartile range (IQR)); 5 days (3–7 days) vs. 6 days (5–9 days), $p = 0.04$]. Estimated blood loss (EBL) was lower and discharge home was higher post-implementation, but these trends did not reach statistical significance ($p = 0.31$ and 0.76, respectively). The occurrence of intraoperative complications including cardiac arrest, vascular injury, conversion to open surgery, and inability to extubate patient postoperatively, and the occurrence of postoperative complications including overall in-hospital morbidity, cardiac arrhythmia, requiring placement of an additional chest tube, pneumonia, urinary tract infection, surgical site infection, stroke, reintubation, unplanned readmission, and 30-day mortality were not statistically different between the two groups (all $p > 0.14$).

Table 4 demonstrates the perioperative outcomes for MIS and open surgical approaches. Patients who underwent MIS had a shorter LOS [median 4 days (IQR 2–6 days) vs. median 7 days (IQR 6–9 days) $p < 0.001$], had lower EBL [median 50 mL (IQR 25–100 mL) vs. median 100 mL (IQR 50–250 mL), $p < 0.001$], and were more likely to be discharged home compared to an inpatient facility than those who had open approaches [Odds ratio (95% Confidence Interval (CI)) 13.00 (1.61–104.70), $p = 0.02$]. There were no 30-day mortalities in either group. In subgroup analysis of MIS, patients who underwent either VATS or robotic approach had shorter LOS [medians 2 days (2–6 days) and 5 (3–7 days), respectively], lower EBL [medians 25 mL (20–50 mL) and 50 mL (50–250 mL), respectively], and were more likely to be discharged home (VATS 100%, robotic 97%, open 80%) than patients who underwent open operations (LOS: $p < 0.001$; EBL: $p < 0.001$; discharge home: $p = 0.01$). In hospital complications (25% vs. 33%) and intraoperative complications (8% vs. 11%) were lower in the MIS group vs. the open group, but these differences in outcomes did not reach statistical significance ($p = 0.74$ and 0.40, respectively).

On multivariate analysis, decreased LOS remained significantly lower in the post-robotic implementation era after controlling for ASA Class ($p = 0.009$). Discharge to home remained more likely in the MIS group on multivariate analysis ($p = 0.018$), and patients who underwent MIS had shorter LOS on multivariate analysis ($p = 0.010$) regardless of their temporal cohort compared to open operations. On subgroup multivariate analysis, the association of shorter length of stay for patients who underwent robotic operations ($p = 0.009$) and VATS operations ($p < 0.001$) compared to open operations remained significant. However, while splitting the MIS cohort into VATS operations and robotic operations, discharge to home no longer was statistically significant in multivariate analysis ($p = 0.08$).

Discussion

Our results demonstrate that implementing a thoracic robotic surgery program at a VAMC results in overall improvement of outcomes, regardless of surgical approach. The proportion of MIS surgeries performed at our VAMC hospital almost doubled after the program was implemented, which resulted in shortened LOS and increased likelihood of discharge home for those patients. Discharge home was significantly better in multivariate analysis for MIS approaches despite losing significance for VATS and robotic approaches individually. This is likely related to decreased power of the analysis when performing this in a subgroup. Robotic program implementation did not significantly affect patient

Table 1 Patient and operative characteristics in the pre- and post-robotic implementation cohort

Patient characteristics[b]	Pre-robotic Era	Post-robotic Era[a]	p value
Total sample, n (%)	63 (58)	45 (42)	0.35
Age (in years), mean	66	68	0.33
Race/ethnicity, n (%)			
White	57 (90)	42 (93)	0.73
Hispanic origin	6 (10)	7 (16)	0.38
Smoking status, n (%)			0.65
Current	19 (30)	12 (27)	
Former	34 (54)	28 (62)	
Never	10 (16)	5 (11)	
Medical comorbidities[c]			
Obese, n (%)	21 (33)	17 (38)	0.88
Home oxygen use, n (%)	13 (21)	10 (22)	1.00
Prior stroke, n (%)	1 (2)	1 (2)	1.00
Dementia, n (%)	1 (2)	0 (0)	1.00
Congestive heart failure, n (%)	1 (2)	3 (7)	0.31
Coronary artery disease, n (%)	10 (16)	4 (9)	0.39
Prior percutaneous coronary intervention, n (%)	8 (13)	3 (7)	0.35
Prior cardiothoracic operation, n (%)	5 (8)	4 (9)	1.00
Hypertension, n (%)	39 (62)	24 (53)	0.43
Peripheral vascular disease, n (%)	5 (8)	5 (11)	0.74
Chronic obstructive pulmonary disease, n (%)	14 (22)	9 (20)	0.82
Dyspnea, n (%)	17 (27)	14 (31)	0.67
Chronic kidney disease, n (%)	3 (5)	5 (11)	0.27
Require dialysis, n (%)	1 (2)	2 (4)	0.60
Diabetes mellitus, n (%)	18 (29)	16 (36)	0.53
Bleeding disorder, n (%)	2 (3)	3 (7)	0.65
Connective tissue disorder, n (%)	0 (0)	3 (7)	0.07
Peptic ulcer disease, n (%)	2 (3)	0 (0)	0.51
Chronic liver disease, n (%)	6 (10)	3 (7)	0.73
Lymphoma, n (%)	1 (2)	0 (0)	1.00
ASA Class, n (%)			0.28
Class 1	11 (18)	10 (22)	
Class 2	17 (27)	17 (38)	
Class 3	35 (56)	18 (40)	
Operative characteristics			
Laterality, n (%)			0.69
Left	25 (40)	16 (36)	
Right	38 (60)	29 (64)	
Operation performed, n (%)			0.50
Wedge Resection	13 (21)	14 (31)	
Segmentectomy	5 (8)	2 (4)	
Lobectomy	42 (67)	26 (58)	
Pneumonectomy	3 (5)	2 (4)	
Nodule location, n (%)			0.12
Right upper lobe	20 (32)	17 (38)	
Right middle lobe	2 (3)	6 (13)	
Right lower lobe	16 (25)	6 (13)	
Left upper lobe	12 (19)	11 (24)	
Left lower lobe	13 (21)	5 (11)	
Tumor pathology, n (%)			0.06
Adenocarcinoma	25 (40)	21 (47)	

Table 1 (continued)

Patient characteristics[b]	Pre-robotic Era	Post-robotic Era[a]	p value
Benign granuloma	1 (2)	2 (4)	
Carcinoid tumor	2 (3)	2 (4)	
Mesothelioma	1 (2)	0 (0)	
Metastasis	0 (0)	5 (11)	
Neuroendocrine tumor	1 (2)	0 (0)	
Sarcoma	2 (3)	0 (0)	
Small cell lung cancer	7 (11)	1 (2)	
Squamous cell lung cancer	13 (21)	11 (24)	
Unknown	11 (18)	3 (7)	

[a]Implementation date: March 18, 2018

[b]*ASA Class* American Society of Anesthesiology physical status classification

[c]No patient had current pneumonia, respiratory failure, pulmonary hypertension, acute renal failure, leukemia, or human immunodeficiency virus

perioperative morbidity or mortality, but intraoperative complications and EBL trended better after robotic surgery implementation. However, the novelty of this platform at VAMCs and the associated small sample size of the robotic cohort may have underpowered the study for some outcomes. The study highlights the impact that thoracic robotic surgery could have if implemented at other VAMCs.

Implementing a thoracic robotic surgery program at our VAMC had facilitators that made implementation seamless. Our team benefitted tremendously from the presence of a robotic surgery program in both general and urologic surgery that served as the blueprint for robotic surgery implementation in thoracic surgery. Our VAMC has a dedicated robotic surgery team that staffs these operations for general and urologic surgery; all operative cases are staffed by trained robotic specialists, including an operative scrub nurse familiar with the platform and industry representatives available to troubleshoot platform issues. Additionally, our VAMC has a dedicated cardiothoracic (CT) surgical team that consists of dedicated CT surgeons, anesthesiologists, scrub technicians, and nursing staff. To train our CT surgical team (especially the operative nurses and scrub technicians) on the platform, our robotic surgical team and CT team co-scrubbed all thoracic robotic operations for 6 months. At that point, competency with the platform amongst all participating team members was demonstrated, and the CT surgical team began staffing robotic thoracic operations independently. Once the program was fully implemented, many operations that previously were scheduled for open or VATS cases were booked as robotic cases, with our surgeons preferring to schedule most cases with indications for minimally invasive approach as robotic operations rather than VATS operations. The surgeons who perform these operations also operate at the adjacent quaternary referral hospital, where they gained comfort and experience performing thoracic operations using the robot prior to implementation of the robotic program at the VAMC. Despite this, thoracic surgeons were required to be supervised by robotic surgery certified colleagues within the VAMC until competency with the platform was observed.

The two board-certified cardiothoracic surgeons involved in this transition (CDS, RAM) alternated weeks of coverage of the VAMC, so each operated 2–3 days per month there. The VAMC OR block schedule allowed for one ½ day of thoracic surgery per week. Of this OR time, one day per month was dedicated to robotic surgery. Thus, one, and occasionally two, robotic thoracic operations per month were performed at the VAMC, the surgeons typically favoring anatomic lung resections for lung cancer. Concurrently, they were already high-volume robotic surgeons with established practices at the adjacent academic medical center, performing approximately 100 robotic operations per year there. After 1 year, an additional ½ day per month was available for robotic thoracic surgery.

While relatively seamless to implement robotic thoracic surgery because of the existing robotic surgery programs, there were several barriers to implementation including increased operative time, longer turnover, and the presence of just one robotic system. At our VAMC, each surgical subspecialty receives one dedicated robotic day per week where there is no competition for robotic platform use. While this allows for a dedicated robotic thoracic surgery day, it does decrease the total potential thoracic surgery weekly operative volume. Improving the operative volume at the VAMC, by adding another robotic platform to increase availability to robotic surgery, increasing block times, or decreasing turnover time, could have improved efficiency with robotic thoracic surgery. The CT surgery team only obtaining operative experience with the platform once per week at the VAMC likely contributed to the increased operative time we found in our study.

The standard timeout conducted prior to surgery included review of safety protocols and ensuring surgical instruments

Table 2 Patient and operative characteristics for each operative approach

Patient characteristics[a]	VATS	Robotic	Open	p value
Total sample, n (%)	21 (19)	32 (30)	55 (51)	
Age (in years), mean	65	70	66	**0.04**
Race/ethnicity, n (%)				
White	18 (86)	30 (94)	51 (93)	0.55
Hispanic origin	4 (19)	3 (9)	6 (11)	0.56
Smoking status, n (%)				0.08
Current	5 (24)	5 (16)	21 (38)	
Former	11 (52)	24 (75)	27 (49)	
Never	5 (24)	3 (9)	7 (13)	
Medical comorbidities[b]				
Obese, n (%)	10 (48)	11 (34)	17 (31)	0.51
Home oxygen use, n (%)	5 (24)	5 (16)	13 (24)	0.66
Prior stroke, n (%)	1 (5)	0 (0)	1 (2)	0.34
Dementia, n (%)	0 (0)	0 (0)	1 (2)	0.75
Congestive heart failure, n (%)	1 (5)	2 (6)	1 (2)	0.47
Coronary artery disease, n (%)	4 (19)	3 (9)	7 (13)	0.58
Prior percutaneous coronary intervention, n (%)	3 (14)	2 (6)	6 (11)	0.53
Prior cardiothoracic operation, n (%)	3 (14)	4 (13)	2 (4)	0.15
Hypertension, n (%)	13 (62)	16 (50)	34 (62)	0.52
Peripheral vascular disease, n (%)	0 (0)	4 (13)	6 (11)	0.25
Chronic obstructive pulmonary disease, n (%)	6 (29)	15 (47)	21 (38)	0.49
Dyspnea, n (%)	8 (38)	9 (28)	14 (25)	0.55
Chronic kidney disease, n (%)	1 (5)	3 (9)	4 (7)	0.80
Require dialysis, n (%)	0 (0)	2 (6)	1 (2)	0.37
Diabetes mellitus, n (%)	5 (24)	9 (28)	20 (36)	0.53
Bleeding disorder, n (%)	0 (0)	2 (6)	3 (5)	0.64
Connective tissue disorder, n (%)	2 (10)	1 (3)	0 (0)	0.08
Peptic ulcer disease, n (%)	1 (5)	0 (0)	1 (2)	0.34
Chronic liver disease, n (%)	2 (10)	1 (3)	6 (11)	0.45
Lymphoma, n (%)	0 (0)	0 (0)	1 (2)	0.75
ASA Class, n (%)				0.62
Class 1	3 (14)	8 (25)	10 (18)	
Class 2	6 (29)	12 (38)	16 (29)	
Class 3	12 (57)	12 (38)	29 (53)	
Operative characteristics				
Laterality, n (%)				0.28
Left	11 (52)	10 (31)	20 (36)	
Right	10 (48)	22 (69)	35 (64)	
Operation performed, n (%)				**< 0.0001**
Wedge resection	15 (71)	9 (28)	3 (5)	
Segmentectomy	1 (5)	2 (6)	4 (7)	
Lobectomy	5 (24)	21 (66)	42 (76)	
Pneumonectomy	0 (0)	0 (0)	5 (9)	
Nodule location, n (%)				0.11
Right upper lobe	5 (24)	13 (41)	19 (35)	
Right middle lobe	0 (0)	4 (13)	4 (7)	
Right lower lobe	5 (24)	5 (16)	12 (22)	
Left upper lobe	3 (14)	8 (25)	12 (22)	
Left lower lobe	8 (38)	2 (6)	8 (15)	
Tumor pathology, n (%)				**0.001**
Adenocarcinoma	6 (29)	19 (59)	21 (38)	

Table 2 (continued)

Patient characteristics[a]	VATS	Robotic	Open	p value
Benign granuloma	2 (10)	1 (3)	0 (0)	
Carcinoid tumor	2 (10)	1 (3)	1 (2)	
Mesothelioma	1 (5)	0 (0)	0 (0)	
Metastasis	0 (0)	3 (9)	2 (4)	
Neuroendocrine tumor	0 (0)	0 (0)	1 (2)	
Sarcoma	0 (0)	0 (0)	2 (4)	
Small cell lung cancer	1 (5)	0 (0)	7 (13)	
Squamous cell lung cancer	1 (5)	7 (22)	16 (29)	
Unknown	8 (38)	1 (3)	5 (9)	

Bold values indicate statistically significant p values ($p < 0.05$)

[a]*ASA Class* American Society of Anesthesiology physical status classification

[b]No patient had current pneumonia, respiratory failure, pulmonary hypertension, acute renal failure, leukemia, or human immunodeficiency virus

were available in the operating room should there be a need to emergently undock and convert to an open operation. Safety scenarios were reviewed periodically to ensure the CT and robotic surgical teams were prepared. During the study,

Table 3 Comparison of perioperative outcomes pre- and post-robotic program implementation

Perioperative outcomes	Pre-robotic Era	Post-robotic Era[a]	p value
Total Sample, n (%)	63 (58)	45 (42)	0.35
Intraoperative complication, n (%)	8 (13)	2 (4)	0.14
Cardiac arrest	1 (2)	0 (0)	0.71
Vascular injury	3 (5)	1 (2)	0.47
Conversion to open surgery	3 (5)	1 (2)	0.47
Unable to extubate in operating room	1 (2)	0 (0)	0.71
In hospital complication, n (%)	15 (24)	13 (29)	0.55
Cardiac arrhythmia	6 (10)	7 (16)	0.34
Placement of additional chest tube	2 (3)	4 (9)	0.16
Pneumonia	2 (3)	0 (0)	0.34
Urinary tract infection	2 (3)	0 (0)	0.34
Surgical site infection	0 (0)	1 (2)	0.21
Postoperative reintubation	2 (3)	0 (0)	0.34
Unplanned reoperation	0 (0)	1 (2)	0.21
Stroke	1 (2)	0 (0)	0.71
Disposition, n (%)			0.14
Home	55 (87)	41 (91)	
Acute rehabilitation	1 (2)	3 (7)	
Subacute rehabilitation	4 (6)	0 (0)	
Long term care facility	2 (3)	0 (0)	
Hospital-to-hospital transfer	1 (2)	1 (2)	
Operative duration in minutes, mean (SD)	162 (80)	231 (82)	**< 0.0001**
Estimated blood loss (mL)			0.31
Median [IQR]	100 [50–200]	50 [50–100]	
Mean	57	51	
Length of stay (days)			**0.04**
Median [IQR]	6 [5–9]	5 [3–7]	
Mean	6	4.7	

Bold values indicate statistically significant p values ($p < 0.05$)

[a]Implementation date: March 18, 2018

IQR interquartile range. No 30-day mortalities observed

Table 4 Comparison of perioperative outcomes between minimally invasive surgical approaches versus open surgical approaches

Perioperative outcomes[b]	MIS[a]	VATS	Robotic	Open	p value
Total Sample, n (%)	53 (49)	21 (19)	32 (30)	55 (51)	
Intraoperative complication, n (%)	4 (8)	3 (14)	1 (3)	6 (11)	0.32
Cardiac arrest	0 (0)	0 (0)	0 (0)	1 (2)	0.75
Vascular injury	0 (0)	0 (0)	0 (0)	4 (7)	0.21
Conversion to open surgery'	4 (8)	3 (14)	1 (3)	n/a	n/a
Inability to extubate	0 (0)	0 (0)	0 (0)	1 (2)	0.74
In hospital complication, n (%)	13 (25)	3 (14)	10 (31)	15 (27)	0.39
Cardiac arrhythmia	7 (13)	1 (5)	6 (19)	6 (11)	0.28
Placement of additional chest tube	4 (8)	1 (5)	3 (9)	2 (4)	0.48
Pneumonia	1 (2)	1 (5)	0 (0)	1 (2)	0.34
Urinary tract infection	0 (0)	0 (0)	0 (0)	2 (4)	0.57
Surgical site infection	0 (0)	0 (0)	0 (0)	1 (2)	0.75
Postoperative reintubation	0 (0)	0 (0)	0 (0)	2 (4)	0.57
Unplanned reoperation	1 (2)	0 (0)	1 (3)	0 (0)	0.34
Stroke	0 (0)	0 (0)	0 (0)	1 (2)	0.75
Discharge home, n (%)	52 (98)	21 (100)	31 (97)	44 (80)	**0.01**
OR (CI)[b]	13.00 (1.61–104.70)				**0.02**
Estimated blood loss (mL)					**< 0.001**
Median [IQR]	50 [25–100]	25 [20–50]	50 [50–100]	100 [50–250]	
Mean	42	28	51	67	
Length of stay (days)					**< 0.001**
Median [IQR]	4 [2–6]	2 [2–6]	5 [3–7]	7 [6–9]	
Mean	4.0	2.9	4.7	6.8	

Bold values indicate statistically significant p values ($p < 0.05$)

[a]*MIS* minimally invasive surgery, includes robotic surgery and videoscope assisted thoracic surgery (VATS)

[b]*IQR* interquartile range

OR (CI) Odds ratio (confidence interval), which was performed for MIS approaches compared to open approach.'Conversion to open surgery only compared between VATS and robotic: no statistical difference ($p = 0.22$) No 30-day mortalities observed

one robotic lobectomy was converted to open for bleeding from a pulmonary artery stump after a stapler failure. This went smoothly and the patient tolerated the operative event without any long-term sequelae.

Shortened LOS and improved discharge home are especially significant in the current medical climate. While increased operative time required to perform robotic operations is common complaint amongst surgeons who aren't proponents of the robotic platform, this well-known phenomenon is generally mediated once a surgeon performs a certain number of operations using the platform. A meta-analysis of 12 studies investigating the learning curve of robotic anatomic pulmonary resection showed the steepest improvement of operative time occurs between 20 and 40 cases with a relative plateau in operative time that occurs after 40–60 cases [25]. Our entire robotic cohort included 32 patients amongst two operating surgeons during the study timeline, so it is unsurprising that improvements in operative duration had not yet been realized. These outcomes benefit patients and hospital systems alike by decreasing healthcare associated costs and freeing limited inpatient hospital beds. In settings of intense resource scarcity like that seen in the COVID-19 pandemic, pressure to discharge patients is high. Hospital systems have been tasked with carefully triaging which operations should be performed because a greater proportion of inpatient beds are becoming occupied by patients with COVD-19. Improving patient turnover and preparing patients for home discharge increase the likelihood that these operations can occur without occupying scarce beds for prolonged hospitalizations. These operations are more likely to continue in times of resource scarcity, which will facilitate timely care in this patient population.

There have been several studies demonstrating the benefits of robotic surgery like enhanced ergonomics and technical advantages like seamless motion, decreased surgeon fatigue, tremor filtering, three-dimensional vision and increased degrees of motion [4]. Further benefits of MIS have been specifically observed in thoracic surgery outcomes, including decreased LOS and fewer non-home discharges after VATS anatomic lung resections as compared

to open procedures [26, 27]. Applying robotic technology and techniques to thoracic surgery has previously shown benefits across several procedures. For lobectomies, robotic approaches have demonstrated shorter LOS versus open approaches [28], which is consistent with our findings. Operations performed using the robotic platform have demonstrated improved lymph nodes harvest in mediastinal lymph node dissections for cancer procedures than in VATS approaches [29]. The adoption of robotic techniques is associated with an increase in parenchymal-sparing anatomic lung resections, with increased use of segmentectomies instead of lobectomies for low stage lung cancers[30]. Mediastinal mass resection has also demonstrated improved outcome with robotic approaches including shorter LOS, fewer surgical complications, lower doses of myasthenia gravis therapeutic drugs [31], and superior cumulative complete remission rates in robotic thymectomy versus open thymectomy [32]. Further applications and benefits of robotic thoracic surgery will continue to be explored as this technology's application continues to evolve.

Widespread robotic surgery implementation throughout the Veterans Health Administration remains an ongoing effort. The hospital which has performed the most robotic surgeries of all VAMC hospitals implemented its program in 2017 and completed its first thousand robotic operations in late 2019 [33]. Other VA hospitals are now beginning the implementation process, but many still do not offer robotic surgery. Implementation of thoracic robotic surgery programs at other VAMCs throughout the country will likely improve outcomes similarly to what we observed. These, in conjunction with implementation of enhanced recovery after surgery programs may further improve patient outcomes. A long term, multi-institutional study may provide insight into thoracic and other specialty robotic surgery implementation at the Veterans Health Administration nationwide.

Strengths of this study include that it explores the outcomes of robotic surgery implementation in a setting not previously identified in the literature. Our VAMC documented all operations throughout the last decade, which allowed for a full analysis of the entire patient cohort without exclusions for missing or incomplete data. Important limitations include: (1) the small sample size of the target population, which may have underpowered the study to analyze some outcomes; (2) this was a single institution study in a Western geographical region, which may not be generalizable to patients at all VAMCs; (3) we used a retrospective study design, which is less desirable than a prospective study; (4) due to our database's limitations, several thoracic surgery specific outcomes were not analyzed, nor were outcomes for other surgical subspecialties despite the fact that general surgeons and urologic surgeons also use this platform at the VA hospital; (5) the fact that surgeons performed different operations using the different operative approaches may have

been planned preoperatively, and if so, this introduces the possibility of selection bias; and (6) only one cohort of surgical patients (intention to treat lung masses) was explored. Analyzing other types of thoracic surgery (e.g., esophagectomy or mediastinal mass resection) may have revealed different effects on outcomes after robotic program implementation than we observed in this study.

Conclusion

In conclusion, implementation of a thoracic robotic surgery program significantly increased the amount of MIS operations performed at our VAMC. This resulted in decreased patient LOS regardless of surgical approach. Patients who underwent robotic operations were more also likely to be discharged to home versus other destinations. Improvements in these outcomes are notable as they decrease strain on patients, hospitals, and patient care facilities alike. Given these findings, the Veterans Health Administration should consider employing resources to develop thoracic robotic surgery programs across VAMCs nationwide.

Declarations

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