Original Article

Enhanced recovery after surgery pathway leads to decreased length of stay for patients undergoing minimally invasive lung resection

Madeline L. Fryer[1], Benjamin A. Palleiko[1]^, Isabel Emmerick[1], Allison Crawford[1], Mamatha Kadiyala[2], Feiran Lou[1], Karl Uy[1], Mark W. Maxfield[1]

[1]Department of Surgery, UMass Chan Medical School, Worcester, MA, USA; [2]Department of Anesthesiology, UMass Chan Medical School, Worcester, MA, USA

Contributions: (I) Conception and design: ML Fryer, BA Palleiko, F Lou, K Uy, MW Maxfield; (II) Administrative support: I Emmerick; (III) Provision of study materials or patients: ML Fryer, BA Palleiko, I Emmerick, M Kadiyala; (IV) Collection and assembly of data: ML Fryer, BA Palleiko, I Emmerick, A Crawford; (V) Data analysis and interpretation: All authors; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Benjamin A. Palleiko, BS. Department of Surgery, UMass Chan Medical School, 67 Belmont St, Worcester, MA 01605, USA. Email: Benjamin.Palleiko@umassmed.edu.

Background: Enhanced recovery after surgery (ERAS) protocols in thoracic surgery have been demonstrated to impact length of stay (LOS), complication rates, and postoperative opioid use. However, ERAS protocols for minimally invasive lung resections have not been well described. Given most lung resections are now performed minimally invasively, there is a gap in the literature regarding the efficacy of ERAS protocols in this setting. In this study, we analyzed patient outcomes following implementation of an ERAS protocol for minimally invasive lung resections.

Methods: Outcome data was retrospectively collected for 442 patients undergoing minimally invasive lung resections between January 1st, 2015 and October 26th, 2021. Patients were divided into either a pre-ERAS (n=193) or ERAS (n=249) group. Primary outcomes included LOS, postoperative complications, intensive care unit (ICU) admission status, 30-day hospital readmissions, and 30-day mortality. Secondary outcomes included common postoperative complications required for the Society for Thoracic Surgeons (STS) database.

Results: We observed an overall decrease in median LOS (4.0 *vs.* 3.0 days, P=0.030) and ICU admission status (15% *vs.* 7.6%, P=0.020) after implementation of our ERAS protocol. The difference in LOS was significantly lower for anatomic lung resections, but not non-anatomic resections. There was no difference in 30-day readmissions and a 0% mortality rate in both groups. Overall, there was a low complication rate that was similar between groups.

Conclusions: The implementation of an ERAS protocol led to decreased LOS and decreased ICU admission in patients undergoing minimally invasive lung resection. Process standardization optimizes performance by providers by decreasing decision fatigue and improving decision making, which may contribute to the improved outcomes observed in this study.

Keywords: Thoracic surgery; minimally invasive lung resection; enhanced recovery after surgery (ERAS); fast track; outcomes

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^ ORCID: 0000-0001-8374-1549.

Introduction

The benefits of an enhanced recovery after surgery (ERAS) protocol were first documented in colorectal surgery and have been increasingly adopted within additional surgical specialties (1,2). In the field of thoracic surgery, ERAS protocols have been shown to reduce length of stay (LOS) and patient complications with a subsequent reduction in cost of hospitalization (3-7). Improved postoperative analgesia and decreased postoperative opioid use have also been reported (8-10). However, there have been few studies that have examined the impact of ERAS protocols on minimally invasive lung resections alone (11,12). This is of particular interest given 82% of lobectomies for clinical stage 1 lung cancer are now performed via a video-assisted thoracic surgery (VATS) or robotic approach (13). Though there is likely a benefit to ERAS protocols in general thoracic surgery these protocols are not widely used nor are they standardized across different institutions (14).

In 2018, the ERAS Society along with the European Society of Thoracic Surgeons (ESTS) published a set of guidelines and recommendations for thoracic ERAS protocols (14). Within this document, there are 45 specific recommendations standardizing pre, peri, and postoperative care. Each recommendation is listed with a strength of recommendation. Strong preoperative recommendations include screening for nutritional status, smoking and alcohol cessation, correction of preexisting anemia, and thorough preoperative education and counseling. Strong perioperative recommendations include avoidance of pre-anesthesia sedatives, mechanical and pharmacological venous thromboembolism (VTE) prophylaxis, pre-incision antibiotics, euvolemic fluid management, and ventilatory lung protective strategies. Postoperatively, the guidelines strongly recommend resuming beta blockers for prevention of atrial fibrillation, early mobilization, combination antinausea medication, removal of unnecessary transurethral catheters, and prompt chest tube removal (14).

At our institution, we sought to implement a thoracic surgery ERAS protocol for patients undergoing minimally invasive lung resections. Our ERAS protocol included many of the recommendations from the ERAS society and ESTS with the goals of standardizing patient care between attending surgeons, simplifying care for residents and nursing staff, and ultimately improving patient care. We hypothesized that by standardizing our patient care with an ERAS protocol, this would lead to a reduced hospital LOS. We present this article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1500/rc).

Highlight box

Key findings

- In this study, we demonstrate a one-day reduction in length of stay (LOS) for patients undergoing minimally invasive lung resection after the implementation of a thoracic enhanced recovery after surgery (ERAS) protocol.

What is known and what is new?

- ERAS protocols in thoracic surgery have been shown to reduce LOS and complications. However, few studies exist examining the impact of these protocols on patients undergoing minimally invasive lung resection.
- In this study, we demonstrate a benefit of an ERAS protocol for patients undergoing minimally invasive lung resection.

What is the implication, and what should change now?

- As this study describes a benefit of an ERAS protocol for patients undergoing minimally invasive lung resection, other institutions should consider adopting a similar approach to the postoperative care of patients. Future studies should also seek to measure the impact of ERAS protocols on hospital staff.

Methods

This is a single-center retrospective cohort study of 442 patients that underwent minimally invasive (VATS or robotic) lung resection. The goal of the study was to evaluate the implementation of an ERAS protocol for minimally invasive lung resections. Residents and nursing staff were educated of the protocol and began implementing it on our start date of March 1st, 2019. There was 100% attending surgeon agreement and adoption of the protocol. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The institutional review board (IRB) at the UMass Chan Medical School reviewed and approved this study (No. H00019427). An informed consent waiver was obtained from the IRB due to the retrospective nature of this study.

Institutional thoracic ERAS protocol

The benefits of effective preoperative patient optimization in the setting of thoracic ERAS protocols have been well characterized (15). Therefore, our thoracic ERAS protocol begins with preoperative counseling by each surgeon once surgery is deemed necessary. There is no dedicated

preoperative physiotherapy evaluation or program, though the benefit of these programs for patients undergoing lung resection has been previously described (16). This is primarily due to fact that we function in a resource-limited hospital and community. However, patients are all counseled on smoking and alcohol cessation for 4 weeks prior to surgery and smoking cessation experts are offered to all active smokers. In patients who do elect to cease smoking, the 4-week requirement does not delay their surgery, especially given that it is rare for us to perform an operation within 4 weeks of booking. However, if the patients are unable to cease smoking, we do not let this delay their operation. Nutritional status is evaluated and if there is concern for malnutrition, albumin and prealbumin labs are ordered, as are nutritional supplements and referral to a nutritionist. Patients are screened for preoperative anemia and if hemoglobin is less than 8.0 g/dL, supplemental iron is considered. A screening for urinary retention symptoms is performed. Seven to 10 days prior to surgery, patients receive a phone call from a nurse practitioner to screen for evaluation of social concerns, as well as evaluation of who will drive the patient to the hospital and home. All patients are also evaluated by our anesthesia team prior to arriving at the hospital for surgery.

Our perioperative management is summarized in Tables S1-S3. There are three attending surgeons and 10 anesthesiologists and certified registered nurse anesthetists (CRNAs) who manage the perioperative care of our patients, all of whom follow the ERAS protocol. Patients are admitted the morning of their surgery, and are allowed to drink clear liquids until 2 hours before surgery. Gabapentin 300 mg and acetaminophen 975 mg are given the morning of surgery. Compression boots and subcutaneous heparin are given to all patients for VTE prophylaxis and antibiotics are administered 60 minutes prior to skin incision. All lung resections are performed under general anesthesia. Prior to the start of all lung resections, an arterial line, a large bore intravenous (IV) line, and a Foley catheter are placed. A double lumen endotracheal tube (ETT), based off patient sex and height, is used to facilitate lung isolation, and lung protective strategies are used throughout the duration of anesthesia. These are detailed in Table S1, under "Ventilation". Euvolemia is maintained throughout the operation and intraoperative fluid management is outlined in Table S1 under "Fluid management". Preoperative midazolam is avoided and the use of opiates is minimized after initial induction of anesthesia (Table S1, "Pain meds and sedation"). Postoperative prevention of nausea and vomiting is addressed with 4 mg dexamethasone after induction, and Zofran 4 mg prior to emergence from anesthesia.

Lung resections are performed through five small port incisions for both VATS and robotic operations. An intercostal nerve block is performed with liposomal bupivacaine at the start of every case. In patients with incomplete fissures, attempts are made to minimize fissure dissection. Mediastinal and hilar lymphadenectomies are performed for all cancer operations. Staples are used for division of parenchyma, vessels, and airway. With regards to intraoperative efforts to reduce air leaks, several steps can be taken. This includes lysis of all pleuro-parenchymal adhesions and takedown of the inferior pulmonary ligament, which we routinely practice (17). The Italian VATS group recommended the use of reinforced staple lines only in the case of severe emphysema, and pleural sealant when an intraoperative air leak is observed at the end of the case during lung inflation (17). In our practice, reinforced staple lines are very rarely used and the use of pleural sealant is variable and surgeon dependent. A single chest tube is placed at the conclusion of surgery.

A comprehensive overview of our postoperative patient care can be found in *Table 1*. On postoperative day (POD) 0, the chest tube is put to suction in the operating room (OR) and then transitioned to water seal in the post-anesthesia care unit (PACU). A chest X-ray is done in the PACU, and chest tube output is marked every four hours. Incentive spirometry is performed 10 times per hour and an Acapella device is given to all patients. For pain management, acetaminophen and gabapentin are given to all patients. Oxycodone is given to patients for moderate pain and hydromorphone is given to patients with severe pain. Patients are started on a clear liquid and advanced as tolerated. Nausea is treated with Zofran. Benadryl and melatonin can be given for insomnia but sedatives are avoided. All patients are placed on a bowel regimen consisting of colace, senna and Miralax as needed. Patients who smoke are given a nicotine patch.

On POD 1, patients are more aggressively mobilized, eat breakfast in a chair, and are walked two times per nursing shift. Supplemental oxygen is discontinued if oxygen saturation is above 88% on room air. Foley catheters are removed if renal function and hematocrit are stable, and urine output is satisfactory. Bladder scans are performed by the nursing staff and patients are intermittently catheterized if there is urinary retention. A portable chest X-ray is obtained on all patients. If patients do not have an air leak,

Table 1 Postoperative thoracic surgery ERAS pathway

ERAS component	Day of surgery	POD 1	POD 2
Vital signs and monitoring	Telemetry (ok to travel off telemetry)	Discontinue telemetry if stable	Discontinue telemetry if stable
	Continuous pulse oximetry	Discontinue continuous pulse oximetry if respiratory status stable Wean off oxygen if saturating >88% on room air	Discontinue continuous pulse oximetry if respiratory status stable
	Vital signs every 4 hours	Vital signs every 4 hours	Wean off oxygen if saturating >88% on room air
		Standing daily weight	Vital signs every 4 hours
			Standing daily weight
Nursing care and activity	Out of bed to chair when awake	Out of bed to chair for breakfast	Walk 2 times per shift
	Walk 2 times per shift	Walk 2 times per shift	Nurses change chest tube dressing as needed
		Nurses change chest tube dressing with dry sterile gauze (no Xeroform) as needed	Can shower with occlusive dressing over chest tube site
		Can shower with occlusive dressing over chest tube site	
IV fluids, Foley, diet	Lactated Ringer's solution at maintenance rate	Regular diet	Regular diet
	Advance diet as tolerated	Heparin-lock IV	
	Heparin-lock IV line when PO intake >250 cc	Discontinue Foley catheter	
	Foley catheter remains in place	Straight catheterization for bladder scan >600 cc or no void after 8 hours or symptomatic	
Labs and CXR, home meds	No post-op labs	Complete blood count and Chem-10	No labs
	CXR in PACU	Portable CXR	Portable CXR if chest tube still in place
		Home med reconciliation (half dose antihypertensives)	Home med reconciliation
Chest tube	Chest tube to suction in operating room	Chest tube to water seal	Chest tube to water seal
	Chest tube to water seal in PACU	Chest tube output marked every 4 hours	Chest tube output marked every 4 hours
	Chest tube output marked every 4 hours	Resident physicians strip chest tubes	Residents strip chest tubes
	Resident physicians strip chest tubes	Consider discontinuing chest tube if no air leak and low fluid output	Consider discontinuing chest tube if no air leak and low fluid output
		Post-pull CXR 2 hours after chest tube removal	Post-pull CXR two hours after removal

Table 1 (*continued*)

Table 1 (*continued*)

ERAS component	Day of surgery	POD 1	POD 2
Respiratory	Incentive spirometry 10 times per hour	Incentive spirometry 10 times per hour	Incentive spirometry 10 times per hour
	Acapella device	Acapella device	Acapella device
	Physiotherapy vest for high risk patients	Physiotherapy vest for high risk patients	Physiotherapy vest for high risk patients
	Duoneb and albuterol per respiratory protocol	Duoneb and albuterol per respiratory protocol	Duoneb and albuterol per respiratory protocol
Pain control and sleep	Tylenol 975 mg by PO TID	Tylenol 975 mg PO TID	Tylenol 975 mg PO TID
	Gabapentin 100 mg TID	Toradol 15 mg IV every 6 hours	Ibuprofen 400 mg with meals
	Toradol 15 mg IV every 6 hours (attending decision)	Gabapentin 300 mg TID unless somnolence or contraindicated	Gabapentin 300 mg TID unless somnolence or contraindicated
	Oxycodone 2.5, 5, or 10 mg every 3 hours as needed-base dosing off pain	Oxycodone 2.5–5 mg every three hours as needed	Oxycodone 2.5–5 mg every 3 hours as needed
	Dilaudid 0.4 or 0.8 mg every 2 hours as needed for severe pain	Benadryl 25–50 mg PO as needed for itching/sleep	Benadryl 25–50 mg PO as needed for itching/sleep
	Benadryl 25–50 mg by mouth as needed for itching/sleep	Melatonin 3 mg as needed for sleep	Melatonin 3 mg as needed for sleep
	Melatonin 3 mg as needed for sleep	IV narcotics only for breakthrough pain, no standing orders	IV narcotics only for breakthrough pain, no standing orders
Prophylaxis	Nicotine patch if smoker	Nicotine patch if smoker	Nicotine patch if smoker
	Venodyne boots	Venodyne boots	Venodyne boots
	No lovenox or subcutaneous heparin	Prophylactic subcutaneous lovenox	Prophylactic subcutaneous lovenox
	Colace 100 mg BID/senna 17.2 mg at bedtime	Colace 100 mg BID/senna 17.2 mg at bedtime	Colace 100 mg BID/senna 17.2 mg at bedtime
	Miralax as needed	Miralax as needed	Miralax as needed
	Zofran 4 mg IV/PO every 8 hours as needed for nausea	Zofran 4 mg IV/PO every 8 hours as needed for nausea	Zofran 4 mg IV/PO every 8 hours as needed for nausea
			Milk of magnesia daily if no BM
			POD4: lactulose every 6 hours if no BM
			POD6: dulcolax suppository if no BM
Consults and discharge	–	Physical therapy consult for age >60 or ECOG ≥1	Discharge planning
		Smoking cessation for current smokers	
		Consider nutrition evaluation if malnourished	
		Consider VNA services	
		Discharge planning	

ERAS, enhanced recovery after surgery; POD, postoperative day; IV, intravenous; PO, oral; CXR, chest X-ray; PACU, post-anesthesia care unit; TID, three times daily; BID, two times daily; BM, bowel movement; ECOG, Eastern Cooperative Oncology Group; VNA, Vising Nurse Association.

there is low chest tube output (F.L. <300, M.W.M. <400, K.U. <500), and chest X-ray is satisfactory, chest tubes are removed on POD 1. If the chest tube is removed, a chest X-ray is obtained two hours after removal. Beta blockers are resumed for patients with atrial fibrillation at half the normal dose. A complete blood count and comprehensive metabolic panel are checked. Chest physiotherapy is ordered for all patients. For pain management, IV narcotics are used for breakthrough severe pain and standing orders for these medications are discontinued. Physical therapy consult is placed for all patients over 65 and those who are deemed frail. Discharge planning begins and potential barriers to discharge are identified. Some patients are discharged on POD 1.

On POD 2, patients are advanced as tolerated through ERAS checkpoints that were not accomplished on POD 1. No labs are drawn unless clinically indicated and chest X-ray is only obtained if a chest tube is still in place. A more aggressive bowel regimen is implemented if patients still have not had return to normal bowel function. Discharge planning is continued and when ready, patients are discharged. Our standard discharge criteria for patients are as follows: their chest tube has been removed, they are on room air, they are able to ambulate independently, and their pain is well controlled on oral medication. Depending on patient status, we will selectively discharge patients with chest tubes, home oxygen, or Foley catheters. However, by and large, there was no systematic change in our discharge criteria following implementation of our ERAS protocol.

Data collection

Outcome data was collected for patients undergoing minimally invasive (VATS and robotic) lung resections between January 1st, 2015 and October 26th, 2021 using our institutional Society for Thoracic Surgeons (STS) database. The ERAS protocol was implemented at our institution on March 1st, 2019. Following this date, all patients undergoing minimally invasive lung resection at our institution were started on the ERAS protocol. Patients were retrospectively grouped as pre-ERAS or post-ERAS based on their date of operation. Patients were then further subdivided into groups determined by operation type: anatomic and non-anatomic lung resections. The anatomic group included lobectomies, segmentectomies, and bilobectomies. The non-anatomic group included wedge resections.

Baseline characteristics were recorded for all patients including sex, race, ethnicity, age, body mass index (BMI), preoperative FEV1, smoking history, preexisting cardiovascular or pulmonary disease, procedure type, and procedure lobe (*Table 2*, Table S4). Primary outcomes included LOS in days (median and mean), complications, intensive care unit (ICU) admission status, 30-day hospital readmission, and 30-day mortality. LOS was calculated as the number of days from the patient's surgery until their discharge. Secondary outcomes included discharge and postoperative complications, as reported in the institutional STS database. Notable discharge outcomes included the proportion of patients discharged alive, and the proportions of patients discharged with a chest tube, foley catheter, or new home oxygen requirement. Notable postoperative complications included the occurrence of prolonged air leak (>5 days), pneumonia, pneumothorax requiring chest tube reinsertion, acute respiratory distress syndrome, respiratory failure, atrial arrythmia, ventricular arrythmia, deep vein thrombosis, myocardial infarction, urinary tract infection, urinary retention, and sepsis. A comprehensive list of all secondary outcomes as reported in the institutional STS database can be found in Table S5.

Statistical analysis

Baseline characteristics and patient outcomes were compared using Chi-squared tests or Fisher's exact test for categorical variables. Fisher's exact test was used when the expected value of any cell was less than five. *T*-tests or Mann-Whitney *U* tests were used for continuous variables. Data that were missing from the institutional STS database were excluded from statistical analysis. Results were considered significant when a P value of less than 0.05 was observed. All analyses were conducted in SAS version 9.4.

Results

Following data extraction, there were 193 patients identified in the pre-ERAS group and 249 patients in the post-ERAS group. Baseline characteristics were compared for each group (*Table 2*). There were no differences observed with respect to sex, race, ethnicity, age, or BMI. A significant difference was observed with respect to the American Society of Anesthesiologists (ASA) classification between the pre- and post-ERAS groups (class III: 78% *vs.* 87%, respectively, P=0.008). However, there was no significant difference observed with functional status [independent, partially dependent, or totally dependent (P=0.16)]. The prevalence of cancer was statically different in the pre-

Table 2 Baseline cohort characteristics

Patient variable	Pre-ERAS (n=193)	Post-ERAS (n=249)	P value
Male sex	72 [37]	96 [39]	0.79
Race			0.33
Asian	6 [3.1]	4 [1.6]	
Black	3 [1.6]	9 [3.6]	
Other	3 [1.6]	7 [2.8]	
White	180 [94]	229 [92]	
Hispanic or Latino ethnicity	9 [4.7]	13 [5.2]	0.80
Age (years)	65 [10]	66 [10]	0.45
BMI (kg/m^2)	28 [5.7]	29 [7.3]	0.53
Preoperative FEV1 (% predicted)	84.9 [19.7]	83.3 [19.0]	0.42
Zubrod ECOG score			0.07
0	122 [63]	175 [71]	
1	60 [31]	68 [27]	
2	11 [5.7]	5 [2.0]	
Functional status[†]			0.16
Independent	45 [94]	231 [93]	
Partially dependent	2 [4.2]	17 [6.9]	
Totally dependent	1 [2.1]	0	
Hypertension	130 [67]	148 [59]	0.09
Congestive heart failure	3 [1.6]	5 [2.0]	0.27
Coronary artery disease	42 [22]	43 [17]	0.23
Pulmonary hypertension	6 [3.1]	5 [2.0]	0.54
Diabetes	34 [18]	39 [16]	0.58
Cigarette smoking			0.97
Current	56 [29]	70 [28]	
Former	107 [55]	141 [57]	
Never	30 [16]	38 [15]	
ASA classification			0.030
II	32 [17]	25 [10]	
III	150 [78]	217 [87]	
IV	11 [5.7]	7 [2.8]	
Disease category			0.008
Non-cancer	17 [8.8]	43 [18]	
Cancer	176 [91]	202 [82]	

Table 2 (*continued*)

Table 2 (*continued*)

Patient variable	Pre-ERAS (n=193)	Post-ERAS (n=249)	P value
Procedure			0.014
Lobectomy	127 [66]	140 [56]	
Segmentectomy	5 [2.6]	22 [8.8]	
Bilobectomy	1 [0.5]	4 [1.6]	
Wedge resection	60 [31]	83 [33]	
Procedure group			0.62
Anatomic	133 [69]	166 [67]	
Non-anatomic	60 [31]	83 [33]	
Primary lobe[‡]			0.28
Upper	83 [54]	113 [58]	
Middle	9 [5.8]	17 [8.7]	
Lower	63 [41]	65 [33]	
Operative approach			<0.001
VATS	175 [91]	136 [55]	
Robotic	18 [9.3]	113 [45]	

Data are presented as number of patients with corresponding percentage [%] or mean [standard deviation]. [†], there are 146 missing for this variable, which is why the numbers do not sum to the column totals. The numbers and percentages are correct as they are based on the data that are available. [‡], lobe data not collected for benign or metastatic disease. There were 38 (20%) unspecified lung resections in the pre-ERAS group and 54 (22%) in the ERAS group. ERAS, enhanced recovery after surgery; BMI, body mass index; FEV1, forced expiratory volume in one second; ECOG, Eastern Cooperative Oncology Group; ASA, American Society of Anesthesiologists; VATS, video-assisted thoracic surgery.

ERAS group (91% *vs.* 82%, P=0.008), however during the time period for post-ERAS, our institution began collecting data for benign lung disease, so the overall percentage of reported cancer cases was reduced. No significant difference in smoking status or preoperative FEV1 was observed between the two groups. There was no significant difference in the distribution of primary procedure lobe between groups (P=0.28). Due to an increase in availably of robotic console time, there was a higher proportion of robotic lung resections performed in the ERAS group (45% *vs.* 9.3%, P<0.001). Evaluation of LOS between these two groups revealed similar overall median and mean LOS (Table S6).

Primary outcomes for this study included LOS, postoperative events, ICU admission status, 30-day hospital readmission, and 30-day mortality (*Table 3*). After implementation of an ERAS protocol, we observed a significant reduction in median LOS after minimally invasive lung resection (4.0 *vs.* 3.0 days, P=0.030). There was also a significant decrease in the ICU admission status following surgery (15% *vs.* 7.6%, P=0.020). There were no significant differences in the pre- and post-ERAS groups with respect to postoperative events (31% *vs.* 35%, P=0.44), 30-day readmission (7.8% *vs.* 9.6%, P=0.72), or 30-day mortality (0% for both groups). Of note, the mean LOS was not significantly different between groups. There was one significant outlier in the data with a LOS of 119 days following a wedge resection due to immigration issues. However, both with and without this outlier, the distribution of the LOS data was non-normal with a rightward skew. Given this non-normal distribution, we opted to compare medians due to the ability to compare distributions between the groups.

We then further subdivided the groups by anatomic lung resections (lobectomy, segmentectomy, bilobectomy) (*Table 4*) and non-anatomic lung resections (wedge resections) (*Table 5*). In the non-anatomic lung resection group, there was no significant difference in either median or mean LOS between the pre- and post-ERAS

Table 3 Primary outcomes for all lung resections

All lung resections	Pre-ERAS (n=193)	Post-ERAS (n=249)	P value
Length of stay (days)	4.0 (3.0, 6.0)	3.0 (2.0, 5.0)	0.030
Length of stay (days)	5.0 (3.8)	4.9 (8.0)	0.78
Postoperative events occurred	60 [31]	86 [35]	0.44
ICU admission status	28 [15]	19 [7.6]	0.020
30-day hospital readmission	15 [7.8]	24 [9.6]	0.72
30-day mortality	0	0	–

Data represented as either median (interquartile range), mean (standard deviation) or number of patients with corresponding percentage [%]. ERAS, enhanced recovery after surgery; ICU, intensive care unit.

Table 4 Primary outcomes: anatomic resections

Outcome measure	Pre-ERAS (n=133)	Post-ERAS (n=166)	P value
Length of stay (days)	4.0 (4.0, 7.0)	4.0 (3.0, 6.0)	0.018
Length of stay (days)	5.8 (4.0)	5.0 (3.5)	0.08
Postoperative events occurred	50 [38]	64 [39]	0.87
ICU admission status	24 [18]	15 [9.0]	0.022
30-day hospital readmission	13 [9.8]	20 [12]	0.77
30-day mortality	0	0	–

Data represented as either median (interquartile range), mean (standard deviation) or number of patients with corresponding percentage [%]. ERAS, enhanced recovery after surgery; ICU, intensive care unit.

Table 5 Primary outcomes: non-anatomic resections

Outcome measure	Pre-ERAS (n=60)	Post-ERAS (n=83)	P value
Length of stay (days)	2.0 (2.0, 4.0)	3.0 (2.0, 4.0)	0.86
Length of stay (days)	3.4 [2.7]	4.6 [13]	0.41
Postoperative events occurred	10 [17]	22 [27]	0.16
ICU admission status	4 [6.7]	4 [4.8]	0.64
30-day hospital readmission	2 [3.3]	4 [4.8]	0.66
30-day mortality	0	0	–

Data represented as either median (interquartile range), mean [standard deviation] or number of patients with corresponding percentage [%]. ERAS, enhanced recovery after surgery; ICU, intensive care unit.

groups. In the anatomic lung resection group (lobectomy, segmentectomy, and bilobectomy), there was reduction in mean LOS that was trending towards significance in (5.8 *vs.* 5.0, P=0.08). Despite the median LOS being the same for pre- and post-ERAS anatomic lung resections, there was a statistically significant difference between the groups. This is attributable to the different distributions of the two groups (pre-ERAS: IQR, 4.0–7.0; post-ERAS: IQR, 3.0–6.0). There was also a significant decrease in ICU admission status between the pre- and post-ERAS groups for anatomic lung resections (18% *vs.* 9.0%, P=0.022).

Notable secondary outcomes are found in *Table 6*. All patients were discharged alive from the hospital in both groups. A higher proportion of patients were discharged from

Table 6 Secondary outcomes

Variables	Pre-ERAS (n=193)	Post-ERAS (n=249)	P value
Discharge outcomes			
Discharged alive	193 [100]	249 [100]	–
Discharged with chest tube	2 [1.0]	10 [4.0]	0.06
Discharged with Foley catheter	1 [0.5]	3 [1.2]	0.64
Discharged with home oxygen	2 [4.2]	24 [9.6]	0.28
Pulmonary complications			
Air leak >5 days	19 [9.8]	22 [8.8]	0.72
Pneumonia	4 [2.1]	4 [1.6]	0.73
Pneumothorax (requiring chest tube reinsertion)	10 [5.2]	4 [1.6]	0.033
Acute respiratory distress syndrome	1 [0.5]	1 [0.4]	0.99
Respiratory failure	2 [1.0]	6 [2.4]	0.48
Cardiovascular complications			
Atrial arrhythmia requiring treatment	7 [3.6]	13 [5.2]	0.42
Ventricular arrhythmia requiring treatment	3 [1.6]	2 [0.8]	0.66
DVT requiring treatment	0	2 [0.8]	0.51
Myocardial infarction	0	0	–
Other complications			
Urinary tract infection	1 [0.5]	6 [2.4]	0.14
Urinary retention	18 [9.3]	31 [12]	0.30
Sepsis	1 [0.5]	0	0.44

All data presented as number of patients with corresponding percentage [%]. ERAS, enhanced recovery after surgery; DVT, deep vein thrombosis.

the hospital with a chest tube in the ERAS group, though this difference was not statistically significant (pre-ERAS 1.0%, post-ERAS 4.0%, P=0.06). To verify the increased proportion of patients discharged home with a chest tube was not impacting our LOS data, we performed an analysis excluding all 12 patients discharged with a chest tube. In this analysis, we observed a median (IQR) LOS of 4 (3, 6) days in the non-ERAS group and 3 (2, 5) days in the ERAS group (P=0.008). No difference was observed with rate of discharge with a Foley catheter (P=0.64) or new oxygen requirement (P=0.28). Regarding pulmonary complications, there was a significant decrease in postoperative pneumothorax requiring chest tube reinsertion in the ERAS group (pre-ERAS 5.2%, post-ERAS 1.6%, P=0.033). There were no differences in occurrence of prolonged air leak (P=0.72), pneumonia (P=0.73), acute respiratory distress syndrome (P=0.99), or respiratory failure (P=0.48).

Discussion

In this study, we describe the implementation and results of a thoracic surgery ERAS protocol. This protocol was designed to comprehensively optimize the pre, peri, and postoperative periods of patients undergoing minimally invasive lung resection. Following the start of our ERAS pathway, we observed an overall significant one-day reduction in median LOS. We also observed a significant decrease in ICU admission rates. We did not observe any differences in 30-day hospital readmission (7.8% *vs.* 9.6%) or mortality rates (0% in both groups).

Common reasons for patients requiring ICU level care after minimally invasive thoracic surgery include arrythmias, pressor and oxygen requirements, and pain control; components of the ERAS pathway were included to prevent these issues. In pre-ERAS period, admission to

ICU was 15%. This was a result of managing some patients in the PACU overnight, which is considered an ICU level of care admission. As part of the implementation of the ERAS program, we met with floor and PACU nursing and a concerted effort was made to decrease number of patients managed in the PACU and send more patients directly to the floor. This change likely resulted in a substantial reduction of cost to both hospital and patient, though cost was not analyzed in this study. However, decreased total hospital costs have been previously demonstrated as a benefit of an ERAS protocol (8).

Though this reduced ICU admission rate was due to implementation of a hospital policy rather than a change in patients' clinical condition, it is still an important finding and discussion point of this study, Thoracic ERAS protocols attempt to implement best practices in a standardized fashion. Current data supports that preventative ICU level care after thoracic surgery does not benefit patients in the absence of immediate complications (18,19). When we began routinely send patients to the floor instead of the PACU for observation overnight, there was no significant difference in complication rates and our overall LOS was reduced. Therefore, other hospitals considering implementing thoracic ERAS protocols should feel comfortable sending patients without immediate complications directly to the floor who may previously have been candidates for overnight PACU admission. In future studies, an even more appropriate of ICU utilization may be unanticipated ICU admission despite initial postoperative monitoring on the floor. However, this variable was not available to us in our institutional STS database.

In the secondary outcomes of this study, we observed a trend-level increase in proportion of patients in the ERAS group who were discharged home with a chest tube. At our institution, we send patients home with a chest tube if they have a prolonged air leak. However, there was no difference in prolonged air leak between the two groups. We hypothesize this difference in proportion of patients discharged home with a chest tube is secondary to a change in practice during the COVID-19 pandemic, during which there was a drive to discharge patients home quickly, both to free up hospital beds and to prevent post-lung resection COVID infection. When all patients who were discharged home with a chest tube were excluded from analysis, the decrease in LOS remained significant. Therefore, the decrease in LOS after ERAS implementation is unrelated to discharging more patients home with chest tubes. Notably, we observed a decreased incidence of pneumothorax after chest tube removal requiring chest tube reinsertion in the ERAS group which likely reflects a more conservative approach to chest tube management in the ERAS group as there was no difference observed with rates of prolonged air leak.

The findings from our own institutional experience with an ERAS program are consistent with previous studies that demonstrate improved outcomes in patients undergoing thoracic surgery. Table S7 summarizes previous ERAS studies. Notably, in our ERAS study we observed a benefit to patients undergoing minimally invasive lung resections. This differs from previous studies that showed patients undergoing minimally invasive thoracic surgery experienced either less of a benefit from ERAS protocols, or no benefit at all (5,12). This statistically significant reduction in LOS after minimally invasive lung resection is also notable since the overall LOS in our pre-ERAS group was relatively low when compared to the studies cited in Table S7. Thus, our study demonstrates that use of a comprehensive ERAS pathway benefits patients undergoing minimally invasive lung resection. This is an important finding, given that the vast majority of lung resections are now performed using a VATS or robotic approach (13).

When examining our minimally invasive lung resections, we observed a significant decrease in LOS for the anatomic resections, but not for non-anatomic resections. The majority of the studies presented in Table S7 excluded non-anatomic resections or did not specifically analyze differences in anatomic and non-anatomic resections with respect to the benefits gained from ERAS. Lee *et al.* did include a variable for sub-lobar resection, but did not observe any difference in LOS between the pre- and post-ERAS groups (20). In our study, we also did not observe any benefit in our primary outcomes with respect to non-anatomic resections. However, patients undergoing minimally invasive wedge resection have a similar pre- and post-operative pathway as those patients undergoing segmentectomy and lobectomy, and therefore benefit in a similar manner from an ERAS protocol. Of note, within the non-anatomic (wedge) resection group, we included patients undergoing lung resection for lung nodule or lung cancer, patients with interstitial lung disease needing tissue diagnosis, and patients undergoing blebectomy for primary spontaneous pneumothorax. This heterogeneity in patient population may explain the absence of difference in LOS.

Since ERAS pathways were first described, there have been numerous studies across surgical disciplines reporting the clinical benefits of these pathways. This study adds to

the current body of literature, as noted above. What is not clear is why patients benefit from ERAS pathways. It is reasonable to hypothesize that if numerous "best practices" in clinical care are aggregated and implemented, then patients should overall do better. We certainly agree that this may explain some of the benefits observed. However, we believe a greater contribution to improved clinical outcomes with ERAS pathways is process standardization and facilitated decision making, which decrease errors and improve quality of care.

Process standardization can be defined as "the specification and communication of a process at a level of detail sufficient to permit consistent and verifiable implementation by different users at different times and in different settings" (21). This is particularly relevant in surgical fields where a substantial number of healthcare professionals are required to work together to assist patients in their preparation and eventual recovery from surgery. Failure to standardize processes can be detrimental, and in healthcare, non-standardized patterns of care have been shown to lead to less favorable clinical outcomes and reduced safety (21). Similarly, lower compliance with an ERAS protocol has been associated with increased morbidity in patients undergoing lung resections (4). There is value in repeatedly and consistently performing a process the same way, and ERAS protocols facilitate this.

We also believe that ERAS protocols are useful in reducing decision fatigue. Decision fatigue is, essentially, a decreased willingness to cognitively engage with a problem when presented with an increasing number of decisions (22). The way that decision fatigue manifests is situationally dependent, but it generally results in the decision-maker taking a "path of least resistance" (22). Consider the countless number of postoperative decisions that are required in the absence of an ERAS protocol. Decisions are required for chest tube management, foley catheter removal, resumption of home medications, and many others. Without an ERAS protocol, decisions about when to remove a foley catheter may detract focus and time from decisions regarding when to remove a chest tube or next steps in a patient who has new hypoxia or hypotension. According to the concept of decision fatigue, there are a finite number of decisions one can make before reverting to heuristics and choosing a decision requiring the least cognitive effort. This inevitably defers decision making and extends patient stays. However, in the presence of an ERAS protocol, decisions such as when to remove a foley catheter are made prior to the patient even arriving on the floor after surgery. We hypothesize that this also allows for better care of patients who require a higher level of care. Because staff resources, cognitive effort and attention are not being used on smaller decisions, decision-making capacity among caregivers can be redistributed to patients who need additional (and more cognitively demanding) attention.

Reducing decision fatigue and improving process standardization may help to explain why ERAS protocols can reduce patients' hospital LOS, even when complication rates remain unchanged. In our study, we observed a one-day reduction in LOS, but the only difference in postoperative complications was a decrease in occurrence of postoperative pneumothorax requiring chest tube reinsertion. Similar findings (reduced LOS with similar postoperative complications) have been reported in other institutions who implemented a thoracic ERAS protocol (8,10,11). Though LOS is frequently used as a surrogate measure for improvements in clinical outcomes, it may not be the most effective way to capture the benefits of ERAS protocols when factors such as improved patient workflow and days alive and out of hospital may also be significantly improved (23,24). Future studies examining hospital workflow and better patient-centered outcomes may help to further elucidate the benefits of enhanced recovery pathways.

Limitations of this study include the retrospective nature as well the results deriving from a single center and small number of providers. Due to the retrospective design, preoperative patient demographics differed between groups. There was an increase in the percentage of robotic lung resections in the ERAS group, due to an increase in robotic console availability. Though robotic lung resections may lead to shorter LOS, we did not observe any difference in LOS when comparing our robotic and VATS lung resections (25). There was also an increase in sublobar lung resections performed, indicative of current changes in surgical practice and the ongoing discourse surrounding lobar versus sublobar resection for early stage lung cancer (26). This could have introduced bias into our study that we were not able to control for. In addition to the increase in robotic and sublobar lung resections, there was a lower proportion of lung resections performed for cancer. Though cancer patients may be more fragile than their non-cancer counterparts, there was a higher proportion of patients with an ASA score of II in the ERAS group. Therefore, we do not believe that there were overall healthier patients in our ERAS cohort. Finally, our data collection was limited by a change in reporting for

the institutional STS database and a change in the hospital electronic medical record system. Because of this, not all data were available for the pre-ERAS group.

Conclusions

An ERAS protocol benefited patients undergoing minimally invasive anatomic lung resection. In these patients, reductions in LOS and ICU admission rates were observed following the implementation of an ERAS protocol. Process standardization optimizes performance by care providers by decreasing decision fatigue and improving decision making, which may contribute to the improved outcomes observed in this study. Future work should focus on evaluating patient workflow and more patient-centered outcome measures. Additionally, future studies should investigate the experience of providers utilizing ERAS protocols, as subjectively there was an increase in provider satisfaction with an ERAS pathway.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1500/rc

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The institutional review board (IRB) at the UMass Chan Medical School reviewed and approved this study (No. H00019427). An informed consent waiver was obtained from the IRB due to the retrospective nature of this study.

References

1. Varadhan KK, Neal KR, Dejong CH, et al. The enhanced recovery after surgery (ERAS) pathway for patients undergoing major elective open colorectal surgery: a meta-analysis of randomized controlled trials. Clin Nutr 2010;29:434-40.
2. Ljungqvist O, Scott M, Fearon KC. Enhanced Recovery After Surgery: A Review. JAMA Surg 2017;152:292-8.
3. Li S, Zhou K, Che G, et al. Enhanced recovery programs in lung cancer surgery: systematic review and meta-analysis of randomized controlled trials. Cancer Manag Res 2017;9:657-70.
4. Rogers LJ, Bleetman D, Messenger DE, et al. The impact of enhanced recovery after surgery (ERAS) protocol compliance on morbidity from resection for primary lung cancer. J Thorac Cardiovasc Surg 2018;155:1843-52.
5. Van Haren RM, Mehran RJ, Mena GE, et al. Enhanced Recovery Decreases Pulmonary and Cardiac Complications After Thoracotomy for Lung Cancer. Ann Thorac Surg 2018;106:272-9.
6. Li R, Wang K, Qu C, et al. The effect of the enhanced recovery after surgery program on lung cancer surgery: a systematic review and meta-analysis. J Thorac Dis 2021;13:3566-86.
7. Madani A, Fiore JF Jr, Wang Y, et al. An enhanced recovery pathway reduces duration of stay and complications after open pulmonary lobectomy. Surgery 2015;158:899-908; discussion 908-10.
8. Martin LW, Sarosiek BM, Harrison MA, et al. Implementing a Thoracic Enhanced Recovery Program: Lessons Learned in the First Year. Ann Thorac Surg

2018;105:1597-604.
9. Strobel RJ, Krebs ED, Cunningham M, et al. Enhanced Recovery Protocol Associated With Decreased 3-Month Opioid Use After Thoracic Surgery. Ann Thorac Surg 2023;115:241-7.
10. Turner KM, Delman AM, Griffith A, et al. The Impact of Enhanced Recovery After Surgery on Persistent Opioid Use Following Pulmonary Resection. Ann Thorac Surg 2023;115:249-55.
11. Tahiri M, Goudie E, Jouquan A, et al. Enhanced recovery after video-assisted thoracoscopic surgery lobectomy: a prospective, historically controlled, propensity-matched clinical study. Can J Surg 2020;63:E233-40.
12. Brunelli A, Thomas C, Dinesh P, et al. Enhanced recovery pathway versus standard care in patients undergoing video-assisted thoracoscopic lobectomy. J Thorac Cardiovasc Surg 2017;154:2084-90.
13. Servais EL, Towe CW, Farjah F, et al. The Society of Thoracic Surgeons General Thoracic Surgery Database: 2021 Update on Outcomes and Research. Ann Thorac Surg 2021;112:693-700.
14. Batchelor TJP, Rasburn NJ, Abdelnour-Berchtold E, et al. Guidelines for enhanced recovery after lung surgery: recommendations of the Enhanced Recovery After Surgery (ERAS®) Society and the European Society of Thoracic Surgeons (ESTS). Eur J Cardiothorac Surg 2019;55:91-115.
15. D'Andrilli A, Rendina EA. Enhanced recovery after surgery (ERAS) and fast-track in video-assisted thoracic surgery (VATS) lobectomy: preoperative optimisation and care-plans. J Vis Surg 2018;4:4.
16. Bertani A, Ferrari P, Terzo D, et al. A comprehensive protocol for physiokinesis therapy and enhanced recovery after surgery in patients undergoing video-assisted thoracoscopic surgery lobectomy. J Thorac Dis 2018;10:S499-511.
17. Gonfiotti A, Viggiano D, Voltolini L, et al. Enhanced recovery after surgery and video-assisted thoracic surgery lobectomy: the Italian VATS Group surgical protocol. J Thorac Dis 2018;10:S564-70.
18. Pinheiro L, Santoro IL, Faresin SM. Who Needs to Be Allocated in ICU after Thoracic Surgery? An Observational Study. Can Respir J 2016;2016:3981506.
19. Fontana V, Coureau M, Grigoriu B, et al. The role of the intensive care unit after thoracic surgery. Rev Mal Respir 2022;39:40-54.
20. Lee A, Seyednejad N, Lawati YA, et al. Evolution of Process and Outcome Measures during an Enhanced Recovery after Thoracic Surgery Program. J Chest Surg 2022;55:118-25.
21. Leotsakos A, Zheng H, Croteau R, et al. Standardization in patient safety: the WHO High 5s project. Int J Qual Health Care 2014;26:109-16.
22. Persson E, Barrafrem K, Meunier A, et al. The effect of decision fatigue on surgeons' clinical decision making. Health Econ 2019;28:1194-203.
23. Bertolaccini L, Brunelli A. Devising the guidelines: the techniques of uniportal video-assisted thoracic surgery-postoperative management and enhanced recovery after surgery. J Thorac Dis 2019;11:S2069-72.
24. Huang L, Frandsen MN, Kehlet H, et al. Days alive and out of hospital after enhanced recovery video-assisted thoracoscopic surgery lobectomy. Eur J Cardiothorac Surg 2022;62:ezac148.
25. Emmert A, Straube C, Buentzel J, et al. Robotic versus thoracoscopic lung resection: A systematic review and meta-analysis. Medicine (Baltimore) 2017;96:e7633.
26. Divisi D, De Vico A, Zaccagna G, et al. Lobectomy versus sublobar resection in patients with non-small cell lung cancer: a systematic review. J Thorac Dis 2020;12:3357-62.

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