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ORIGINAL SCIENTIFIC REPORT

Enhanced Recovery After Surgery Protocol Minimizes Intensive Care Unit Utilization and Improves Outcomes Following Pulmonary Resection

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Abstract

Background Enhanced recovery after surgery (ERAS) protocols have been associated with improved postoperative outcomes but require further validation in thoracic surgery. This study evaluated outcomes of patients undergoing pulmonary resection before and after implementation of an ERAS protocol.

Methods Electronic medical records were queried for all patients undergoing pulmonary resection between April 2017 and April 2019. Patients were grouped into pre- and post-ERAS cohorts based on dates of operation. The ERAS protocol prioritized early mobilization, limited invasive monitoring, euvolemia, and non-narcotic analgesia. Primary outcome measures included intensive care unit (ICU) utilization, postoperative pain metrics, and perioperative morbidity. Regression analyses were performed to identify predictors of morbidity. Subgroup analyses were performed by pulmonary risk profile and surgical approach.

Results A total of 64 pre- and 67 post-ERAS patients were included in the study. ERAS implementation was associated with reduced postoperative ICU admission (pre: 65.6% vs. post: 19.4%, $p < 0.0001$), shorter ICU median length of stay (LOS) (pre: 1 vs. post: 0, $p < 0.0001$), and decreased opioid usage measured by median morphine milligram equivalents (pre: 40.5 vs. post: 20.0, $p < 0.0001$). Post-ERAS patients also reported lower visual analog scale (VAS) pain scores on postoperative days (POD) 1 and 2 (pre: 6.3/5.6 vs. post: 5.3/4.2, $p = 0.04/0.01$) as well as average VAS pain score over POD0-2 (pre: 6.2 vs. post: 5.2, $p = 0.005$).

Conclusions Implementation of an ERAS protocol for pulmonary resection, which dictated reduced ICU admissions, did not increase major postoperative morbidity. Additionally, ERAS-enrolled patients reported improved postoperative pain control despite decreased opioid utilization.

Introduction

The first iteration of an enhanced recovery after surgery (ERAS) protocol led to decreased intensive care unit (ICU) and overall length of stay (LOS), employing many facets of

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modern protocols, such as preoperative patient and family education, early extubation, and early mobilization [1]. Early protocols utilizing ERAS verbiage focused on colorectal surgery but were quickly implemented across surgical disciplines [2, 3]. While specifics of the protocols differ across specialties and institutions, the goal is to create a multidisciplinary, evidence-based approach to optimizing perioperative patient care and improving outcomes [4–6]. This includes an emphasis on minimally invasive surgery (MIS), non-narcotic analgesia, and early mobilization.

Similar protocols have been advantageous for patients undergoing pulmonary resection, utilizing techniques such as shortened preoperative fasting periods, thoracic epidural or subarachnoid analgesia, and intercostal nerve blockades [7–10]. Numerous clinical benefits have been reported following protocol implementation, including but not limited to decreased postoperative pulmonary complications, shortened LOS, and reduced opioid usage [7–9]. In addition to improving postoperative outcomes, ERAS protocols have also been shown to significantly reduce hospital costs [8, 11]. ERAS protocols remain largely institution-specific in the USA, with variability in outcomes when implemented for thoracic surgery [12]. Consequently, further research is required to support the development of consensus ERAS guidelines in thoracic surgery and further optimize perioperative care.

The objective of this study was to evaluate outcomes of patients undergoing pulmonary resection before and after implementation of an ERAS protocol at a single academic institution. We hypothesized that employing an ERAS protocol would lead to decreased resource utilization, including ICU admissions, as well as improved postoperative pain management with reduced opioid requirements.

Materials and methods

Electronic medical records were queried for all patients undergoing anatomic lung resection between April 2017 and April 2019. The institutional ERAS protocol was rolled out at the midpoint of the study in April 2018. Patients were organized into pre- and post-ERAS groups based on date of operation. All post-ERAS patients were enrolled in the ERAS protocol. There was no transitional period after introduction of the institutional ERAS protocol, and all surgeons immediately and unanimously participated in its use. Exclusion criteria included incomplete data sets, extended resections (pneumonectomy), or non-resectional operations. Consistent with modalities presented in previous literature, the ERAS protocol prioritized early mobility, limited invasive monitoring, euvolemia, and non-narcotic analgesia, including intraoperative regional blocks instead of thoracic epidurals [7–9, 11, 12]. For minimally invasive approaches, regional blocks were administered at the start of the operation, typically extending one level superior to the highest port site and one level inferior to the lowest port site. The complete institutional protocol is described in Online Resource 1.

Descriptive statistics were performed for demographic variables. Primary outcome measures included ICU utilization, perioperative pain metrics, and perioperative complications. Logistic and linear regression analyses were performed to compare groups. Beta estimates for morphine milligram equivalent (MME) usage were calculated as square root values to account for linearity assumption violations. A mediation analysis was performed to characterize the potential influence of pain score modulation on the relationship between ERAS protocol implementation and MME usage. Cohorts were further divided based on pulmonary risk profile and approach (MIS vs. open). Patients were considered increased risk if they had a postoperative predicted forced expiratory volume in 1 second or a postoperative predicted diffusing capacity of the lungs for carbon monoxide $< 50\%$. MIS included robotic or video-assisted thoracic surgery (VATS) approaches. All VATS and robotic anatomic lung resections were performed without rib-spreading. Robotic approaches employed closed port techniques with CO2 insufflation, while VATS approaches employed open port techniques without insufflation. Between 1 and 4 port sites were used during robotic and VATS anatomic lung resections at the discretion of the operating surgeon. Staging in this study was performed in accordance with the contemporaneous edition of the American Joint Committee on Cancer staging manual [13, 14]. Significance level for two-sided tests was defined as $p < 0.05$. All statistical analyses were performed with SAS v9.4 (SAS Institute Inc., Cary, NC).

Results

A total of 64 pre-ERAS and 67 post-ERAS patients met inclusion criteria and comprised the final cohorts. Groups were well balanced with respect to demographic and preoperative variables (Table 1). Median ages of the pre- and post-ERAS cohorts were 64.5 (26–89) years and 64.0 (21–86) years, respectively ($p = 0.91$). There were no significant differences between cohorts regarding sex, ethnicity, or body mass index. Groups were also well balanced with respect to comorbidities, including Charlson Comorbidity Scores. No significant differences were found in preoperative pulmonary function, American Society of Anesthesiologists classification, surgery type, or operative approach.

Perioperative outcomes

There were no significant differences in blood transfusions, intraoperative fluid balance, or invasive line use between pre- and post-ERAS groups (Table 1). The post-ERAS group experienced reduced postoperative ICU admissions (65.6% vs. 19.4%, $p < 0.0001$) and median ICU LOS (1 vs. 0 days, $p < 0.0001$). There were no significant differences in chest tube duration, ventilator duration, prolonged air leak, hospital LOS, or readmissions < 30 days.

Risk stratified outcomes

Patients were stratified into standard and increased-risk cohorts based on pulmonary function test results. There were 7/64 and 9/67 increased-risk patients in the pre- and post-ERAS cohorts, respectively. Compared to the standard-risk pre-ERAS reference group, both standard-risk and increased-risk post-ERAS groups experienced significantly decreased postoperative ICU admissions (post-ERAS standard-risk: OR 0.14, 95% CI [0.06, 0.34], $p < 0.0001$; post-ERAS increased-risk: OR 0.20, 95% CI [0.05, 0.84], $p = 0.03$) (Fig. 1). No significant differences were observed with respect to new-onset atrial fibrillation or LOS when stratifying by risk.

Surgical approach

When grouped by surgical approach, post-ERAS patients who underwent either MIS (OR 0.06, $p < 0.0001$) or open surgery (OR 0.36, $p = 0.04$) had significantly lower odds of ICU admission compared to pre-ERAS MIS patients (Table 2). Irrespective of ERAS, patients who underwent open surgery had increased chest tube duration (pre-ERAS: IRR 2.33, $p < 0.0001$; post-ERAS: IRR 2.30, $p < 0.0001$) and longer LOS (pre-ERAS: IRR 1.70, $p < 0.0001$; post-ERAS: IRR 1.69, $p < 0.0001$) relative to the pre-ERAS MIS group. No significant difference in either outcome was noted between pre- and post-ERAS MIS cohorts.

Opioid use

VAS pain scores were improved for the post-ERAS cohort compared to the pre-ERAS cohort. This included time-point-specific VAS scores on POD1 and POD2 as well as average VAS scores over POD0-2 (Table 3). Median pain medication usage in MME was reduced in post-ERAS as compared to pre-ERAS patients [40.5 (0–191.6) vs. 20.0 (0–193), $p < 0.0001$]. Stratifying by surgical approach revealed significantly improved daily VAS pain scores for the post-ERAS MIS cohort relative to the pre-ERAS MIS reference cohort (POD0: OR 0.77, $p = 0.005$; POD1: OR 0.77, $p = 0.005$; POD2: OR 0.68, $p = 0.002$) (Table 4). When compared against the pre-ERAS MIS reference cohort, average VAS pain scores over POD0-2 differed only for post-ERAS MIS patients (β −1.49, standard error 0.45, $p = 0.001$) (Fig. 2a). When compared instead with a pre-ERAS open surgery reference cohort, post-ERAS MIS patients remained the only group with significantly different average VAS pain scores over POD0-2 (β −1.82, standard error 0.59, $p = 0.002$) (Fig. 2b). Opioid usage was lower in both post-ERAS cohorts relative to the pre-ERAS MIS reference cohort [post-ERAS MIS: β −3.12, standard error 0.59, $p < 0.0001$; post-ERAS open: β −1.71, standard error 0.64, $p = 0.008$].

Mediation analysis demonstrated that ERAS protocol implementation had a total effect of β −2.19 on MME consumption (standard error 0.46, $p < 0.0001$). Average VAS pain scores over POD0-2 accounted for 42.4% of the total mediation ($p = 0.0002$); the remaining 57.7% represents unknown pathways through which the ERAS protocol reduced MME consumption (β −1.26, standard error 0.37, $p = 0.0005$). Every unit increase in average VAS pain score over POD0-2 for any given patient led to a mean increase of 0.87 ($p < 0.0001$) in MME usage, whereas ERAS protocol implementation contributed a mean reduction of −1.06 ($p = 0.004$) in average VAS pain score. A summary of the mediation analysis is presented in Online Resource 2.

Discussion

This study demonstrates that implementation of our ERAS protocol for patients undergoing pulmonary resection is associated with decreased ICU utilization, improved pain control, and reduced opioid consumption. In the absence of consensus guidelines, these findings offer critical evidence to characterize the advantages of ERAS in thoracic surgery using clinical algorithms consistent with current medical literature. Furthermore, the benefit of reduced resource utilization with ERAS protocol implementation is especially poignant in this era of increased ICU needs during the COVID-19 pandemic. These results are consistent with previously studied non-thoracic ERAS protocols as well as the largest published series of thoracic ERAS patients by Van Haren and colleagues.[9] In our study, the pre-ERAS MIS cohort was primarily used as the reference group, given prior studies demonstrating the efficacy of VATS with respect to perioperative outcome metrics; the authors believe this design minimizes the potential to overestimate the benefits of ERAS protocol implementation [15]. For example, patients who underwent open surgery—with or without ERAS implementation—had an increased LOS compared to pre-ERAS MIS patients, whereas LOS was similar between pre-ERAS and post-ERAS MIS patients

Table 1 Demographics and perioperative characteristics

	Pre-ERAS (n = 64)	(%)	Post-ERAS (n = 67)	(%)	p value
Age (years)					
Median (Range)	64.5 (26–89)		64.0 (21–86)		0.91
Sex					0.20
Male	32	50.0	41	61.2	
Female	32	50.0	26	38.8	
BMI					
Average	27.8		26.8		0.32
< 30	48	75.0	56	83.6	0.08
≥ 30	16	25.0	11	16.4	
Ethnicity					0.17
Caucasian	36	56.3	38	56.8	
African American	1	1.6	7	10.5	
Asian	18	28.1	14	20.9	
Other	9	14.1	8	11.9	
ASA					0.35
II	10	15.6	11	16.4	
III	52	81.3	56	83.6	
IV	2	3.1	0	0.0	
Diagnosis					0.43
Primary lung cancer	34	47.2	43	64.2	
Pathologic Stage					
IA	12	35.3	10	23.3	
IB	9	26.5	10	23.3	
IIA	2	5.9	6	14.0	
IIB	3	8.8	7	16.3	
IIIA	6	17.7	4	9.3	
IIIB	1	2.9	3	7.0	
IVA	1	2.9	2	4.7	
IVB	0	0.0	1	2.3	
Cancer metastatic to lung					
Primary Site					
Colorectal	10	34.5	11	47.8	
Soft Tissue Sarcoma	7	24.1	0	0.0	
Renal	4	13.8	2	8.7	
Other	8	27.8	10	43.5	
Benign	1	1.6	1	1.5	
Treatment					
Systemic therapy before chest surgery					0.62
No	40	62.5	39	58.2	
Yes	24	37.5	28	41.8	
Radiation before chest surgery					0.96
No	51	76.7	53	79.1	
Yes	9	14.1	9	13.4	
Yes, to chest	4	6.3	5	7.5	
Procedure					0.49
Single wedge resection	17	26.6	12	17.9	
Multiple wedge resection	9	14.1	11	16.4	
Lobectomy $\pm$ wedge	38	59.4	44	65.7	

Table 1 continued

	Pre-ERAS (n = 64)	(%)	Post-ERAS (n = 67)	(%)	p value
Approach					0.07
Open surgery	18	28.1	27	40.3	
Minimally Invasive Surgery	46	71.9	40	59.7	
Comorbidiies					
Average Charlson Score	4.8		4.5		0.41
Cardiac disease	5	7.8	1	1.5	
Peripheral vascular disease	4	6.3	3	4.5	
CVA/TIA	2	3.1	2	3.0	
Dementia	0	0.0	1	1.5	
Chronic Pulmonary Disease	10	15.6	17	25.4	
Rheumatologic Disease	1	1.6	4	6.0	
Liver Disease	3	4.7	4	6.0	
Diabetes Mellitus	19	29.7	21	31.4	
Renal disease	0	0.0	1	1.5	
Metastatic tumor	32	50.0	27	40.3	
Hematologic Malignancy	0	0.0	2	3.0	
Preoperative pulmonary function					
FEV1 postoperative % predicted					
Median (Range)	77 (38–131)		78 (35–105)		0.67
DLCO post-operative % predicted					
Median (Range)	70 (40–113)		69 (36–109)		0.37
Intraoperative outcomes					
Arterial line	53	82.8	60	89.6	0.36
Central line	13	20.3	8	11.9	0.18
Estimated blood loss (mL)					
Median (Range)	50 (1–400)		50 (0–800)		0.03
Fluid Balance					
Median (Range)	940 (-850–4000)		870 (150–3850)		0.38
Patients requiring transfusion	3	4.7	5	7.5	0.52
Blood transfusion	Median (Range)	0 (0–2)	0 (0–41)		NA
Post operative outcomes					
Hospital LOS (days)					
Median (Range)	3.3 (1.2–21.3)		2.5 (1.3–13.3)		0.37
Postoperative ICU admission	42	65.6	13	19.4	< 0.0001
ICU LOS (days)					
Median (Range)	1 (0–4)		0 (0–34)		<0.0001
Readmission within 30 days	3	4.7	6	9.0	0.49
ICU readmission within 30 days	0	0.0	1	1.5	0.99
Death within 30 days	0	0.0	0	0.0	NA
Major postoperative complications [a]	3	4.7	2	3.0	0.68
Pulnonary					
Chest tube duration (days)					
Median (Range)	2 (1–47)		2 (1–48)		0.44
Air leak > 5 days	3	4.7	6	9.0	0.49
Discharged with chest tube	4	6.3	4	6.0	0.99
Reintubation	0	0	1	1.5	0.99
Ventilator duration (days)					
Median (Range)	0 (0)		2 (0–40)		0.34

Table 1 continued

	Pre-ERAS (n = 64)	(%)	Post-ERAS (n = 67)	(%)	p value
Pneumonia	2	3.1	1	1.5	0.61
ARDS	0	0.0	1	1.5	0.99
Tracheostomy	0	0.0	1	1.5	0.99
Atelectasis requiring bronchoscopy	0	0.0	2	3.0	0.50
Pleural effusion requiring drainage	1	1.6	0	0.0	0.99
PTX requiring chest tube reinsertion	1	1.6	3	4.5	0.62
Respiratory arrest	0	0.0	1	1.5	0.99
Empyema	1	1.6	1	1.5	0.99
Discharged with newly required O2	0	0.0	1	1.5	0.99
Cardiac	7	10.9	5	7.5	
Atrial fibrillation	7	10.9	4	6.0	0.36
Cardiac arrest	0	0.0	1	1.5	0.99
Heme	2	3.1	3	4.5	
Pulmonary embolism	1	1.6	0	0	0.99
Patients requiring transfusion	1	1.6		3	0.62
pRBC transfusion (units)					
Median (Range)	0 (0–1)		0 (0–41)		NA
Gastrointestinal [b]	1	1.6	3	4.5	0.62
Genitourinary [c]	5	7.8	8	11.9	0.56
Wound[d]	1	1.6	1	1.5	0.99
Neurologic [e]	1	1.6	0	0	0.99

[a]Clavien–Dindo Grade 3–5

[b]Including ileus, diarrhea, small bowel obstruction

[c]Including acute kidney injury, urinary retention, urinary tract infection

[d]Including surgical site infection

[e]Including delirium, cerebrovascular accident/transient ischemic attack

ARDS = acute respiratory distress syndrome; ASA = American Society of Anesthesiologists Classification; BMI = body mass index; CVA/TIA = cerebrovascular accident/transient ischemic attack; DLCO = diffusing capacity of the lungs for carbon monoxide; FEV1 = forced expiratory volume, 1 second; ICU = intensive care unit; LOS = length of stay; NA = not applicable; pRBC = packed red blood cells; PTX = pneumothorax

(Table 2). However, post-ERAS MIS patients benefitted from reduced ICU admissions relative to pre-ERAS MIS patients. Further, irrespective of surgical approach, the likelihood of ICU admission was significantly reduced in all post-ERAS patients relative to pre-ERAS MIS patients. As previously noted, although Van Haren et al. demonstrated reduced ICU admissions for ERAS patients, there is a paucity of data validating these results following ERAS implementation [9, 16]. Our findings suggest that open operations do not negate the reduction in odds of ICU admission following ERAS implementation. This may represent the cohort experiencing the greatest magnitude of benefit, as the advantages of ERAS for patients undergoing MIS may be subject to diminishing returns. As opposed to endpoints such as morbidity or pain metrics, decreased ICU utilization may indeed serve to reflect changes in physician-directed care, but the present study indicates that this reduction can be achieved safely through ERAS protocol implementation. Similar to a recent study by Khoury et al., our results did not demonstrate a decrease in hospital LOS following ERAS implementation as reported by previous studies, suggesting that LOS may not be the ideal metric for defining ERAS protocol success [6, 8–10].

Patients in the post-ERAS cohort experienced clear advantages over the pre-ERAS cohort with respect to postoperative pain control. These benefits were detected in VAS pain scores on POD1, POD2, and overall (Table 3). Although decreased VAS pain scores were observed in the post-ERAS MIS cohort relative to the pre-ERAS MIS cohort, no differences in VAS pain scores were detected between pre-ERAS MIS and post-ERAS open patients either overall or on any individual postoperative day

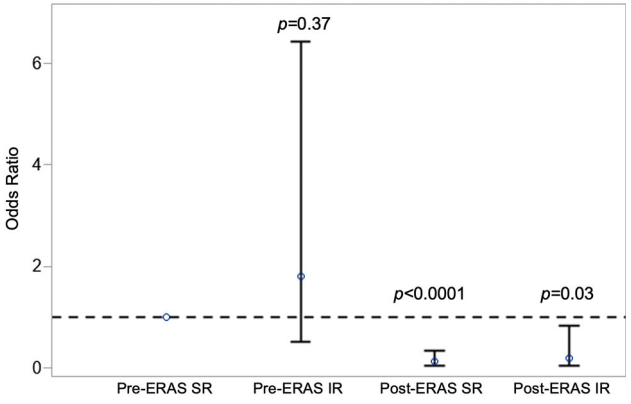

Fig. 1 Postoperative ICU admission by protocol and risk level. Abbreviations: SR = standard risk; IR = increased risk

(Table 4, Fig. 2a). This would support the utility of open operations, when appropriate, under ERAS protocol with the expectation that postoperative pain control would be equivalent to a non-ERAS MIS operation. Our findings are consistent with prior studies comparing thoracotomy and VATS, where no differences in pain scores were observed on POD 1–3 when enrolled on an ERAS protocol [17].

In addition to reductions in self-reported pain, the post-ERAS cohort also benefitted from decreased opioid consumption (Table 3). This finding is consistent with reports of decreased opioid use with enhanced recovery programs in previous literature [8, 18]. Interestingly, post-ERAS open surgery patients used fewer opioids than the pre-ERAS MIS reference group, despite our observation that the two cohorts did not differ significantly with respect to VAS pain scores. This finding may reflect disparate opioid requirements originating from differences in postoperative pain between the pre-ERAS MIS and post-ERAS open cohorts. Maintaining equivalent pain control, as noted by similar VAS pain scores despite a 50% reduction in overall opioid utilization, would support broad implementation of ERAS even in the absence of effect on standard perioperative metrics such as LOS and re-admission. This may be the most valuable effect noted, as patients undergoing chest surgery for cancer are particularly vulnerable to long-term opioid dependence [19, 20]. Although we did not specifically compare post-ERAS MIS with post-ERAS open patients, similar pain scores and MME usage have been reported between ERAS patients receiving VATS and open surgery [17].

It is also possible that differences in opioid usage were driven by pathways other than pain. Mediation analysis demonstrated that only 42.4% of the impact of ERAS protocol implementation on opioid consumption occurred via reductions in average VAS pain score. While pain reduction constituted an undoubtedly substantial contribution, the remaining 57.7% influence in this relationship could be accounted for by several different factors, including but not limited to early mobilization, improved overall patient satisfaction, and perception of a better patient–physician relationship. However, these pathways were not examined in the present study. These observations are reflective of the well-described nature of ERAS protocols as multifaceted models with synergistic components

Table 2 Postoperative outcomes stratified by protocol, risk level, and approach

	Protocol and approach	Measure of Assoc. [95% CI]	*p* value
Length of stay (days)			
	Pre-ERAS MIS	*Reference (IRR)*	*Reference*
	Pre-ERAS Open	1.70 [1.31, 2.20]	<0.0001
	Post-ERAS MIS	0.75 [0.55, 1.01]	0.06
	Post-ERAS Open	1.69 [1.30, 2.20]	<0.0001
Chest tube duration (days)			
	Pre-ERAS MIS	*Reference (IRR)*	*Reference*
	Pre-ERAS Open	2.33 [1.78, 3.04]	<0.0001
	Post-ERAS MIS	1.00 [0.76, 1.31]	0.98
	Post-ERAS Open	2.30 [1.81, 2.93]	<0.0001
Postoperative ICU admission			
	Pre-ERAS MIS	*Reference (OR)*	*Reference*
	Pre-ERAS Open	2.25 [0.64, 7.93]	0.21
	Post-ERAS MIS	0.06 [0.02, 0.21]	<0.0001
	Post-ERAS Open	0.36 [0.14, 0.95]	0.04

95% CI = 95% confidence interval; IRR = incidence rate ratio; Measure of Assoc. = measure of association; MIS = minimally invasive surgery; OR = odds ratio

Table 3 Opioid usage and average pain score

	Pre-ERAS	Post-ERAS	*p* value
Pain medication use (MME)			
Median (Range)	40.5 (0–191.6)	20.0 (0–193)	<0.0001
Average pain scores			
VAS POD0	6.7	5.9	0.1
VAS POD1	6.3	5.3	0.04
VAS POD2	5.6	4.2	0.01
VAS POD0-2	6.2	5.2	0.005

MME = Morphine milligram equivalents; POD = postoperative day; VAS = visual analog scale

Table 4 Postoperative pain by protocol and surgical approach

	Protocol and approach	IRR (95% CI)	*p* value
VAS POD 0			
	Pre-ERAS MIS	*Reference*	*Reference*
	Pre-ERAS Open	0.99 [0.80, 1.23]	0.94
	Post-ERAS MIS	0.77 [0.65, 0.92]	0.005
	Post-ERAS Open	1.01 [0.85, 1.21]	0.90
VAS POD 1			
	Pre-ERAS MIS	*Reference*	*Reference*
	Pre-ERAS Open	0.99 [0.80, 1.23]	0.94
	Post-ERAS MIS	0.77 [0.64, 0.93]	0.005
	Post-ERAS Open	0.93 [0.77, 1.13]	0.47
VAS POD 2			
	Pre-ERAS MIS	*Reference*	*Reference*
	Pre-ERAS Open	1.22 [0.96, 1.54]	0.11
	Post-ERAS MIS	0.68 [0.53, 0.87]	0.002
	Post-ERAS Open	0.92 [0.74, 1.15]	0.48

95% CI = 95% confidence interval; IRR = incidence rate ratio; MIS = minimally invasive surgery; POD = postoperative day; VAS = visual analog scale

that enhance recovery through a cascade of improved perioperative outcomes [3]. As such, it can be difficult to characterize the total value of ERAS protocol implementation, let alone fully assess the contribution of each individual component. For example, postoperative pain is a critically important factor that our institutional ERAS protocol seeks to address through multiple avenues, but it represents just one element of a patient's perioperative experience.

This study has several limitations, including those inherent to retrospective designs. Certain true disparities in perioperative outcomes, such as hospital LOS, between pre-ERAS and post-ERAS cohorts may not have been detected due to small sample size. Sample size limitations precluded a subgroup analysis of patients who experienced an ICU LOS > 1 day, which may have otherwise provided valuable insight into the impacts of our institutional ERAS protocol. In comparing opioid usage between cohorts stratified by protocol and surgical approach, the square root of MME was identified as the relevant variable due to a linearity assumption violation. While this modified the terminology used to describe our results, introduction of this proxy (i.e., rather than MME, directly) did not alter the core finding: Decreased opioid consumption was observed in both the post-ERAS MIS and post-ERAS open cohorts relative to the pre-ERAS MIS reference group. The costs associated with each patient's hospital stay were not specifically investigated, and comments pertaining to the potential financial advantages of ERAS protocol implementation in this study are therefore limited to inference only. However, the decrease in ICU utilization alone is likely to account for cost reductions easily offsetting the cost of protocol implementation. Martin et al. estimated cost-savings of $5,299 and $15,861 with ERAS implementation for each patient undergoing VATS and thoracotomy, respectively [8]. In their investigation of the economic implications of enhanced recovery pathways, Paci and colleagues similarly described significant cost reductions with respect to both ICU and pharmacy utilization [11].

Conclusions

This study demonstrates that our institutional ERAS protocol, which dictates reduced postoperative ICU admissions, offers significant benefits for pulmonary resection patients, including improved VAS pain scores and decreased opioid consumption. Nearly half the reduction in opioid usage observed in ERAS patients is attributable to amelioration of postoperative pain, but the remainder of this impact occurs through undescribed pathways. In addition to patient-centered benefits, ERAS protocols may present opportunities for significant reductions in perioperative healthcare costs, thereby providing a supplementary financial advantage for healthcare providers and institutions. Continued research efforts are necessary to further characterize the utility of ERAS protocol implementation in thoracic surgery and ultimately contribute to the development of consensus guidelines in the USA.

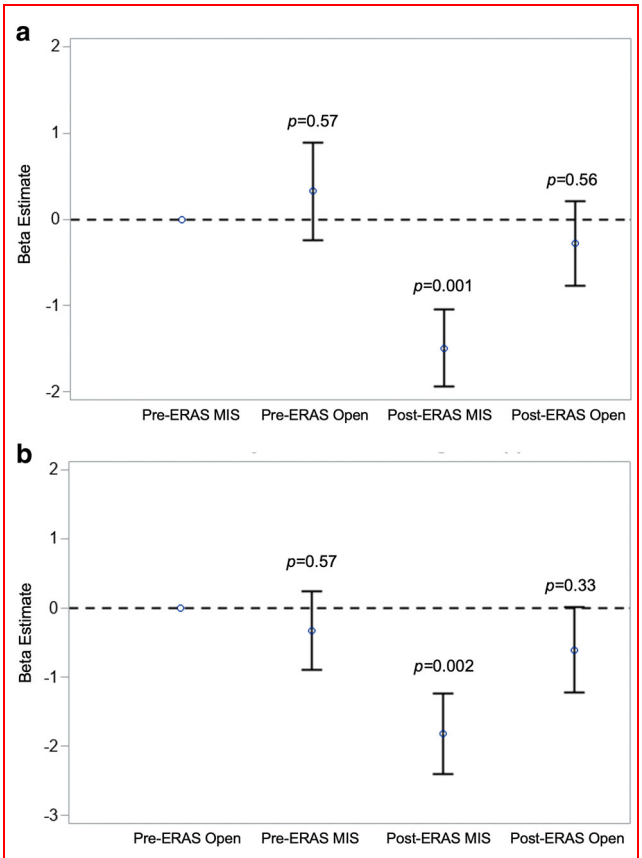

Fig. 2 Average pain score by protocol and surgical approach. Abbreviations: MIS = minimally invasive surgery

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00268-021-06259-1.

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Declaration

Conflict of interest The authors have no conflicts of interest to disclose.

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