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Authors

Haro, Greg J
Sheu, Bonnie
Marcus, Sivan G
et al.

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Perioperative Lung Resection Outcomes After Implementation of a Multidisciplinary, Evidence-based Thoracic ERAS Program

Greg J. Haro, MD, Bonnie Sheu, MD,* Sivan G. Marcus, BS,* Ankit Sarin, MD,† Lundy Campbell, MD,‡ David M. Jablons, MD,* and Johannes R. Kratz, MD*✉*

Objective: This prospective study evaluated perioperative lung resection outcomes after implementation of a multidisciplinary, evidence-based Thoracic Enhanced Recovery After Surgery (ERAS) Program in an academic, quaternary-care center.

Background: ERAS programs have the potential to improve outcomes, but have not been widely utilized in thoracic surgery.

Methods: In all, 295 patients underwent elective lung resection for pulmonary malignancy from 2015 to 2019 PRE (n = 169) and POST (n = 126) implementation of an ERAS program containing all major ERAS Society guidelines. Propensity score-matched analysis, based upon patient, tumor, and surgical characteristics, was utilized to evaluate outcomes.

Results: After ERAS implementation, there was increased minimally invasive surgery (PRE 39.6%→POST 62.7%), reduced intensive care unit utilization (PRE 70.4%→POST 21.4%), improved chest tube (PRE 24.3%→POST 54.8%) and urinary catheter (PRE 20.1%→POST 65.1%) removal by postoperative day 1, and increased ambulation ≥3× on postoperative day 1 (PRE 46.8%→POST 54.8%). Propensity score-matched analysis that accounted for minimally invasive surgery demonstrated that program implementation reduced length of stay by 1.2 days [95% confidence interval (CI) 0.3–2.0; PRE 4.4→POST 3.2), morbidity by 12.0% (95% CI 1.6%–22.5%; PRE 32.0%→POST 20.0%), opioid use by 19 oral morphine equivalents daily (95% CI 1–36; PRE 101→POST 82), and the direct costs of surgery and hospitalization by $3500 (95% CI $1100–5900; PRE $23,000→POST $19,500). Despite expedited discharge, readmission remained unchanged (PRE 6.3%→POST 6.6%; $P = 0.94$).

Conclusions: The Thoracic ERAS Program for lung resection reduced length of stay, morbidity, opioid use, and direct costs without change in readmission. This is the first external validation of the ERAS Society thoracic guidelines; adoption by other centers may show similar benefit.

Keywords: enhanced recovery after surgery, lung resection, perioperative outcomes, thoracic surgery

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Enhanced Recovery After Surgery (ERAS) programs were developed in an effort to improve perioperative outcomes.[1,2] The foundation of an ERAS program is a collaborative, multidisciplinary team that systematically integrates evidence-based perioperative care techniques, remedies hospital-specific system issues that may impair recovery, objectively assesses outcomes, and alters the program if needed. Staples of programs include standardization of patient education, medical risk evaluation, minimally invasive surgery, anesthesia techniques, postoperative line and pain management, early mobilization, and expedited discharge.

The ERAS programs in the abdominal surgical specialties have been formally adopted as the new standard of care as numerous studies have shown improved patient outcomes.[1–4] In thoracic surgery, ERAS has not been widely utilized, and only a few centers have published their experiences in lung resection.[5–11] These studies demonstrate that ERAS programs have the potential to improve outcomes; however, their findings are limited. Many of these studies do not contain a comparison group, do not measure program adherence, report crude outcomes without accounting for confounding, do not represent normal practice as they evaluate only thoracotomy or minimally invasive surgery, or were from centers outside the United States.

At the University of California, San Francisco (UCSF), the Thoracic ERAS Program was developed based upon the latest evidence and implemented in a multidisciplinary fashion for patients undergoing lung resection (Table 1). Of note, the ERAS Society recently endorsed program content guidelines for thoracic surgery, and there is no prior external validation (https://www.ncbi.nlm.nih.gov/pubmed/30304509).[12] Our Thoracic ERAS Program contains all major ERAS Society guidelines and has additional components that are specific to our center. This prospective study seeks to evaluate the effectiveness of these guidelines to improve perioperative outcomes for patients undergoing lung resection within our Thoracic ERAS Program.

METHODS

Study Design

This is a prospective, cohort study of 295 patients who underwent elective lobectomy or sublobar resection for primary lung cancer or pulmonary metastasis before (PRE n = 169) and after (POST n = 126) implementation of the Thoracic ERAS Program at UCSF from October, 2015 to March, 2019, which includes 2 years before and 1.5 years after implementation. The Thoracic ERAS Program (Table 1) for lung resection is multidisciplinary, evidence-based, addresses all facets of perioperative care, and contains all major ERAS Society guidelines.[12] The Thoracic ERAS Program was applied to all patients regardless of stage or number of lesions; however, the program was not utilized on patients with extended resections, such as chest wall resection. In addition, patients with length of stay ≥3 weeks were excluded before analysis (PRE n = 1, POST n = 1). The UCSF Institutional Review Board approved the study and informed consent was waived as de-identified data

From the *Department of Surgery, Division of Cardiothoracic Surgery, University of California, San Francisco, San Francisco, CA; †Department of Surgery, Division of General Surgery, University of California, San Francisco, San Francisco, CA; and ‡Department of Anesthesia and Perioperative Care, University of California, San Francisco, San Francisco, CA.

✉johannes.kratz@ucsf.edu.

Author contributions: G.J.H. designed the study, acquired, analyzed, and interpreted the data, drafted the manuscript, and gave final approval for submission. B.S. and S.M. acquired the data, critically revised the manuscript, and gave final approval for submission. A.S., L.C., and D.M.J. interpreted the data, critically revised the manuscript, and gave final approval for submission. J.R.K. designed the study, interpreted the data, critically revised the manuscript, and gave final approval for submission.

The authors report no conflicts of interest.

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TABLE 1. Thoracic ERAS Program

Measure	PRE	POST
Preoperative		
Patient education	Verbal	Written patient education—diagnosis, treatment modalities, and expectations for hospital/home with verbal teach-back
Surgery to-do list	N/A	Written to-do list—cardiac clearance, anesthesia evaluation, PFTs, D/C blood-thinning medications, smoking cessation
Intraoperative		
Analgesia	Epidural analgesia all patients	Preemptive acetaminophen and gabapentin, epidural analgesia for thoracotomy only, intercostal nerve block for MIS
Prophylaxis	SSI only	SSI—timing, re-dosing, normothermia; VTE—mechanical and chemoprophylaxis, re-dosing; PONV—high-risk patients
Ventilation	Not standardized	Lung protective—maintains SpO_2 >90% with lowest possible FiO_2
Fluids	Euvolemia	Goal-directed euvolemia
Surgery	Not standardized	MIS whenever feasible
Postoperative		
Length of stay	Not standardized	POD1—MIS sublobar resection; POD2—MIS lobectomy; POD3—thoracotomy
Hospital acuity	ICU	Hospital ward; ICU for hemodynamic or respiratory need
Analgesia	Acetaminophen, opioids	Multimodality analgesia—acetaminophen, gabapentin, NSAIDs, and minimization of opioids
Line management	Lines removed after D/C epidural	D/C urinary catheter POD1 and chest tube POD1 if <400 mL
Prophylaxis	Not standardized	Delirium nursing prevention measures—patients ≥65 years old; continuation of VTE; no atrial fibrillation prophylaxis
Diet	Not standardized	Clear liquid diet, advance as tolerated; bowel regimen
Rehabilitation	Not standardized	Ambulation day of surgery and ≥3x/d; food served only out of bed; physical, occupational, and respiratory therapy
Discharge details	Not standardized	Written discharge instructions—when to call clinic, follow-up expectations; prescribed medications delivered to bedside

The Thoracic ERAS Program, developed at the University of California, San Francisco, for patients undergoing lung resection, is multidisciplinary, evidence-based, addresses all facets of perioperative care, and contains all major ERAS Society guidelines.[12]

D/C indicates discontinuation; MIS, minimally invasive surgery; NSAIDs, nonsteroidal anti-inflammatory drugs; PFTs, pulmonary function tests; POD, postoperative day; PONV, postoperative nausea vomiting; SSI, surgical site infection; VTE, venous thromboembolism.

were prospectively collected by chart review (Protocol # 18−26431, Expiration 10/23/2019). This study was not supported by an external funding source.

Operative Technique

Open cases were approached through a standard muscle-sparing, posterolateral thoracotomy. Video-assisted thoracoscopic surgery (VATS) cases were approached though a 3-port technique for sublobar resection or 3-port technique plus a 5th intercostal space 4 to 8 cm utility incision for lobectomy. Robotic-assisted VATS (RA-VATS) cases were performed using a completely portal 4-arm technique with all ports placed in the 8th interspace. Rib spreading was not utilized in VATS or RA-VATS.

Outcomes

The primary outcome was length of stay, and the secondary outcomes were program adherence, overall morbidity, daily opioid use, direct costs, 30-day readmission, and 30-day mortality.

Overall morbidity was defined as the presence of 1 or more in-hospital postoperative complications comprising all organ systems (Supplementary Digital Content—Morbidity Definition, http://links.lww.com/SLA/B848). In addition, morbidity was subclassified into minor and major morbidity based upon Clavien-Dindo Class I to II or III to IV, respectively.[13]

Daily opioid use was defined as the total in-hospital oral morphine equivalent (OME) use divided by the length of stay if the length of stay was ≤7 days. Patients with hospitalizations >7 days were excluded from this analysis (excluded PRE n = 11; POST n = 3).

Direct costs represent the total direct costs incurred to the medical center in providing patient care associated with surgery and subsequent hospitalization, and includes, but not limited to, the operating room, operative supplies, room and board, doctors, nursing, therapy, pharmacy, laboratory assessment, and imaging. They do not represent indirect costs, such as building maintenance or administration, and they do not represent patient charges.

Statistical Methods

Descriptive statistics were used to assess baseline characteristics and crude perioperative outcomes PRE and POST. Outcomes were also evaluated in a subcohort of elderly patients defined as >73 years old (upper quartile). A propensity score-matched analysis was utilized to estimate the average treatment effect of the ERAS program.[14] Propensity scores were based upon the following covariates: age-adjusted Charlson comorbidity index,[15] sex, race, diagnosis (primary lung cancer or pulmonary metastasis), and procedure (lobectomy or sublobar resection). In additional analyses, propensity scores were also based upon minimally invasive surgery, preoperative opioid history, and epidural analgesia.

The propensity scores utilized had appropriate overlap and balance between the covariates PRE and POST (Supplementary Digital Content—Evaluation of Propensity Scores and Matching, http://links.lww.com/SLA/B848). Patients were then matched using their propensity score by nearest neighbor 1:1 matching with replacement and caliper 0.2. The adequacy of matching was verified by a balance of matching, which appropriately reduced the predictive value of the covariates. Overall, the propensity scores and matching did not violate any model assumptions.

Missing data were found to be missing at random, and no deletion or imputation methods were used. A predetermined 2-sided alpha of 0.05 was considered statistically significant. All analyses were performed in Stata 15.1 (StataCorp LP; College Station, TX) using the following packages: pscore; psmatch2; pstest; pbalchk; teffects; psmatch.

TABLE 2. Patient and Surgery Characteristics After Implementation of the Thoracic ERAS Program

Variables*	PRE (n = 169)	POST (n = 126)
Age	67 [59–73]	67 [59–72]
Male	74 (43.8)	39 (31.0)
Race		
White	117 (69.2)	88 (69.8)
Asian	38 (22.5)	21 (16.7)
Other	14 (8.3)	17 (13.5)
Charlson comorbidity index	4 [3–5]	4 [3–5]
Smoking history	101 (59.8)	78 (61.9)
FEV1% predicted	86 [72–100]	91 [80–107]
DLCO adjusted	80 [71–95]	72 [65–90]
Preoperative opioid use	33 (19.5)	20 (15.9)
Primary lung cancer	140 (82.8)	96 (76.2)
Stage 0–I	122 (87.1)	79 (82.2)
Stage II–III	17 (12.1)	16 (16.7)
Stage IV	1 (0.7)	1 (1.0)
Pulmonary metastasis	29 (17.2)	30 (23.8)
# Lesions	1 [1–3]	1 [1–3]
Neoadjuvant therapy	16 (9.5)	21 (16.7)
Prior thoracic surgery	16 (9.5)	9 (7.1)
Minimally invasive surgery	67 (39.6)	79 (62.7)
VATS	23 (34.3)	9 (11.4)
RA-VATS	44 (65.7)	70 (88.6)
Lobectomy	81 (47.9)	62 (49.2)
Minimally invasive surgery	15 (18.5)	26 (41.9)
Sublobar resection	88 (52.1)	64 (50.8)
Segmentectomy	13 (14.8)	23 (35.9)
Wedge resection	75 (85.2)	41 (64.1)

*Continuous Variables: median [interquartile range]; categorical variables: number (proportion).

DLCO indicates diffusion capacity of the lungs for carbon monoxide; FEV1, forced expiratory volume in the first second.

RESULTS

Patient and Surgery Characteristics

In all, 295 patients (PRE n = 169, POST n = 126) underwent elective lung resection for primary lung cancer or pulmonary metastasis from 2015 to 2019 (Table 2). In evaluation of baseline characteristics, there were no substantial differences between the groups, including age, sex, race, underlying comorbidity, and smoking history. Indication for surgery was primary lung cancer in 83% PRE and 76% POST, and >80% had early-stage disease. In those with pulmonary metastasis, the median number of lesions was 1 in both groups [interquartile range (IQR) 1–3, range 1–9]. In all patients, approximately half underwent lobectomy. In regard to operative technique, our center adopted RA-VATS 1 year before implementation of the ERAS program which was utilized in 78% of all minimally invasive cases.

Thoracic ERAS Program Adherence Measures

The Thoracic ERAS Program altered clinical practice patterns, and there was appropriate adherence to the program goals (Fig. 1). The proportion of minimally invasive surgery increased from 40% PRE to 63% POST implementation of the program. Whereas 70% PRE were admitted to the intensive care unit (ICU), only 21% POST met criteria for ICU admission and the remaining patients were directly admitted to the cardiovascular thoracic step-down unit that employs continuous cardiac and pulse oximetry monitoring, and also dedicated chest physiotherapists. Other notable changes include decreased utilization of epidural analgesia for minimally invasive surgery, accelerated chest tube and urinary catheter removal, and increased early mobilization of patients. Finally, patient recoveries were expedited as 20% PRE compared with 47% POST were discharged within the program goal.

Unadjusted Perioperative Outcomes

Before the Thoracic ERAS Program, the median length of stay was 4 days and after its implementation decreased to 3 days (Table 3). This 1-day reduction in length of stay was consistent across surgical procedure (lobectomy vs sublobar resection), technique (minimally invasive vs thoracotomy), and elderly patients (>73 years old/upper quartile).

Overall morbidity decreased from 36% PRE to 20% POST (Table 3). While major morbidity remained similar, minor morbidity decreased after program implementation (33% PRE→19% POST). Notably, a similar reduction in morbidity was found when stratifying patients by technique (thoracotomy vs minimally invasive) or age (elderly patients >73 years old/upper quartile). On further evaluation of minor morbidity, the most prevalent complications were pneumonia (14% PRE→9% POST), new-onset atrial fibrillation (9% PRE→5% POST), and delirium (5% PRE→2% POST).

After implementation of the Thoracic ERAS Program, the median daily opioid use decreased 19 OME from 88 OME PRE to 69 OME POST (Table 3). Of note, a 5-mg oxycodone tablet represents 7.5 OME, corresponding to 2.5 fewer oxycodone tablets used per day in POST versus PRE patients. On further evaluation, the largest reduction in opioid use was observed in patients undergoing minimally invasive surgery (74 PRE→46 POST) and in elderly patients undergoing lung resection (PRE 71→55 POST). Those who underwent thoracotomy had similar opioid use after the ERAS Program (108 PRE→108 POST).

The median overall direct costs of the entire hospital encounter including surgery were $17,700 POST compared with $21,000 PRE (Table 3). The largest cost reductions after implementation of the program were related to the ICU ($3800 PRE→$0 POST), hospital ward ($4400 PRE→$3700 POST), rehabilitation consultation ($1100 PRE→$400 POST), pharmacy ($4300 PRE→$3800 POST), imaging ($600 PRE→$300 POST), and laboratory studies ($1100 PRE→$900 POST). The costs of the operating room did increase with the expansion of minimally invasive surgery ($3100 PRE→$4100 POST); however, these costs were offset by the aforementioned savings. In subanalysis of minimally invasive surgery, there still was an associated cost reduction ($18,000 PRE→$16,200 POST), but it was not as substantial as the cost reduction associated with thoracotomy ($22,700 PRE→$19,100 POST). Interestingly, elderly patients contributed the most to these savings ($24,600 PRE→$19,600 POST).

Readmission within 30 days occurred in 5% PRE and 6% POST, and there were no considerable differences in readmission rates when stratified by surgical techniques or age. There were no deaths within 30 days in the entire cohort.

Propensity Score-matched Analysis of Perioperative Outcomes

A propensity score-matched analysis was utilized to obtain a more accurate evaluation of the outcomes by accounting for confounding variables—age, sex, race, comorbidity, diagnosis, and procedure (lobectomy vs sublobar resection) (Table 4; Supplementary Digital Content, http://links.lww.com/SLA/B848). After propensity score matching (Table 4), the estimated average treatment effect of the Thoracic ERAS Program was an absolute reduction in length of stay by 1.4 days [95% confidence interval (CI) 0.9, 1.9; $P < 0.01$) from 4.5 days to 3.1 days. Overall morbidity was estimated to occur in 36.0% PRE and 22.4% POST with an absolute reduction

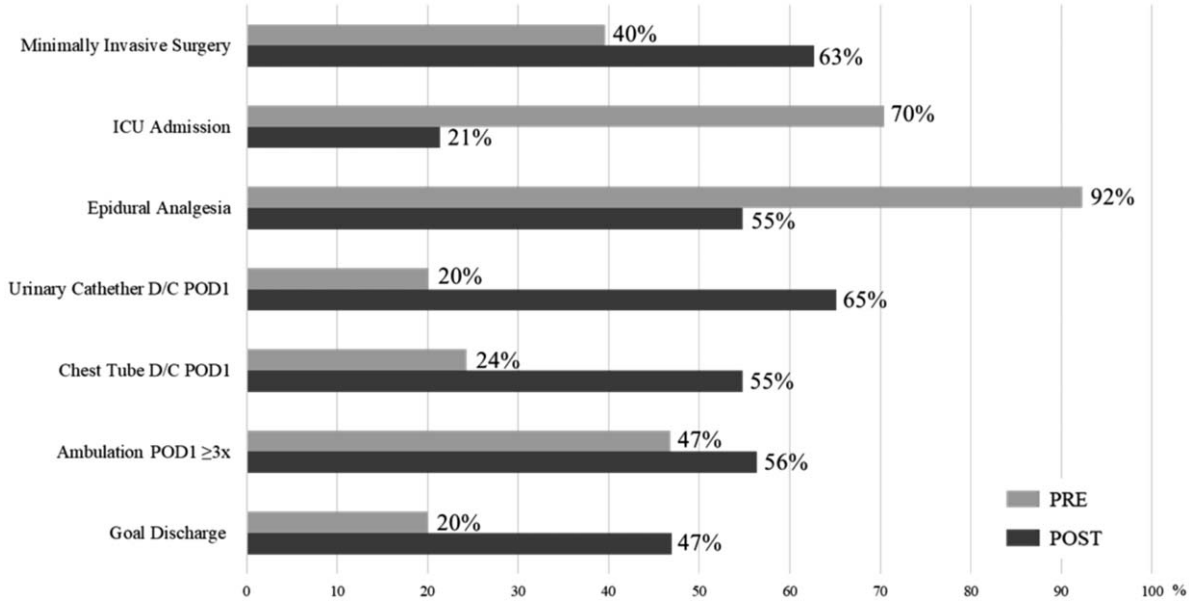

FIGURE 1. Thoracic ERAS Program Adherence. Core components of the Thoracic ERAS Program were measured to evaluate PRE and POST program adherence. The Thoracic ERAS Program altered clinical practice patterns, and there was appropriate adherence with increased minimally invasive surgery, line removal, ambulation, and goal discharge as well as reduced ICU admission and epidural analgesia for minimally invasive surgery. D/C indicates discontinue; ICU, intensive care unit; POD1, postoperative day 1.

TABLE 3. Unadjusted Perioperative Lung Resection Outcomes After Implementation of the Thoracic ERAS Program

Outcomes*	PRE (n = 169)	POST (n = 126)
Length of stay (d)	4.1 [3.0–5.1]	2.9 [1.9–3.8]
Lobectomy	4.3 [3.9–6.0]	3.4 [2.7–5.0]
Sublobar resection	3.3 [2.3–5.0]	2.0 [1.5–2.9]
Thoracotomy	4.3 [3.9–6.0]	3.3 [3.0–5.0]
Minimally invasive surgery	3.0 [2.1–4.2]	2.0 [1.8–3.1]
Elderly†	4.3 [3.3–6.0]	3.1 [2.2–4.9]
Overall morbidity‡	61 (36.1)	25 (19.8)
Minor (class I–II)	56 (33.1)	24 (19.1)
Major (class III–IV)	10 (5.9)	6 (4.8)
Thoracotomy	42 (41.2)	13 (27.7)
Minimally invasive surgery	19 (28.4)	12 (15.2)
Elderly†	19/35 (54.3)	10/25 (40.0)
Daily opioid use (OME)§	88 [52–139]	69 [34–109]
Thoracotomy	108 [71–160]	108 [62–153]
Minimally invasive surgery	74 [40–97]	46 [27–81]
Elderly†	71 [38–99]	55 [25–88]
Direct costs ($)	21,000 [17,200–26,200]	17,700 [13,900–22,100]
Thoracotomy	22,700 [18,600–27,300]	19,100 [16,100–24,400]
Minimally invasive surgery	18,000 [13,800–22,700]	16,200 [13,200–20,400]
Elderly†	24,600 [19,100–31,700]	19,600 [16,200–23,500]
30-d readmission	9 (5.3)	8 (6.4)
Thoracotomy	6 (66.7)	2 (25.0)
Minimally invasive surgery	3 (33.3)	6 (75.0)
Elderly†	3/35 (8.6)	0/25 (0.0)
30-d mortality	0 (0.0)	0 (0.0)

*Continuous variables: median [interquartile range]; categorical variables: number (proportion).

†Elderly: >73 years old (upper quartile).

‡Overall morbidity: 1 or more of the following: delirium, atrial fibrillation, myocardial infarction, atelectasis, pneumothorax, pleural effusion, respiratory failure, air leak, renal failure, venous thromboembolism, blood transfusion, pneumonia, surgical site infection, urinary tract infection, and sepsis of unknown origin; minor morbidity: Clavien Dindo Class I to II[13]; severe morbidity: Clavien Dindo Class III to IV.[13]

§Daily opioid use: total oral morphine equivalent (OME) per length of stay if length of stay <7 days.

of 13.6% (95% CI 2.1%, 25.1%; $P = 0.02$). The program was estimated to reduce the direct costs by $4000 (95% CI % $2000, $6000; $P < 0.01$) from $23,100 PRE to $19,100 POST. Despite reduction in length of stay, there was no difference in 30-day readmission after implementation of the program (PRE 5.1%→POST 7.5%; $P = 0.35$).

As minimally invasive surgery is a key component of the Thoracic ERAS Program, propensity scores that also accounted for minimally invasive surgery were generated to evaluate the effect of the program independent of surgical technique (Table 5). Overall, there was no substantial change in the findings. After accounting for minimally invasive surgery in propensity score-matched analysis, the ERAS Program was found to reduce length of stay by 1.2 days (95% CI 0.3–2.0; $P < 0.01$), morbidity by 12.0% (95% CI 1.6%–22.5%; $P = 0.02$), and the direct costs of surgery and hospitalization by $3500 (95% CI $1100–5900; $P < 0.01$) without a change in readmission (PRE 6.3%→POST 6.6%; $P = 0.94$).

Finally, we assessed daily opioid use by accounting for preoperative opioid history, minimally invasive surgery, and epidural analgesia in addition to the aforementioned patient characteristics (Table 6). The estimated average treatment effect of the program was an absolute reduction of 19 OME (95% CI 1, 36; $P = 0.04$) from PRE 101 OME to POST 82 OME. This estimated reduction corresponds to 2.5 fewer 5 mg oxycodone tablets per postoperative day.

DISCUSSION

The UCSF Thoracic ERAS Program improved perioperative outcomes for patients undergoing lung resection. Our study demonstrates the effectiveness of an evidence-based, multidisciplinary approach to ERAS implementation, and represents the first external validation of the ERAS Society thoracic guidelines.[12] We present our program and its results as a way to heighten exposure of ERAS in

TABLE 4. Propensity Score-matched Analysis Accounting for Age, Sex, Race, Charlson Comorbidity Index, Diagnosis, and Procedure.

Overall Thoracic ERAS Program				
Outcomes*	**PRE (n = 466)**	**POST (n = 492)**	**ATE (95% CI)**	***P***
Length of stay (d)	4.5	3.1	−1.4 (−1.9, −0.9)	<0.01
Overall morbidity	36.0%	22.4%	−13.6% (−25.1%, −2.1%)	0.02
Direct costs ($)	23,100	19,100	−4000 (−6000, −2000)	<0.01
30-d readmission	5.1%	7.5%	2.4% (−2.7, 7.6%)	0.35

*Propensity scores: age, sex, race, Charlson comorbidity index, diagnosis (primary lung cancer vs pulmonary metastasis), and procedure performed (lobectomy vs sublobar resection).
ATE indicates average treatment effect.

TABLE 5. Propensity Score-matched Analysis Additionally Accounting for Minimally Invasive Surgery

Accounting for Minimally Invasive Surgery				
Outcomes*	**PRE (n = 332)**	**POST (n = 339)**	**ATE (95% CI)**	***P***
Length of stay (d)	4.4	3.2	−1.2 (−1.7, −0.7)	<0.01
Overall morbidity	32.0%	20.0%	−12.0% (−22.5%, −1.6%)	0.02
Direct costs ($)	23,000	19,500	−3500 (−5900, −1100)	<0.01
Readmission	6.3%	6.6%	0.3% (−7.5%, 8.1%)	0.94

*Propensity scores: age, sex, race, Charlson comorbidity index, diagnosis (primary lung cancer vs pulmonary metastasis), procedure performed (lobectomy vs sublobar resection), and minimally invasive surgery.
ATE indicates average treatment effect.

thoracic surgery in an effort to improve care for our collective patients.

The Thoracic ERAS Program reduced length of stay by at least 1 day for all patients regardless of surgical technique or procedure. Importantly, in the setting of expedited hospitalizations, readmission remained unchanged and nominal. Moreover, as 47% were discharged within program goal, we expect to further reduce length of stay through continued management of patient expectations, and also utilizing the momentum gained from our significant cultural shift at the provider level. Of note, not all centers have found improved length of stay for patients undergoing minimally invasive surgery within their ERAS programs.[5,9] The discordance in findings is likely due to differences in the historical control, and also the ambitiousness of the program goals.

After implementation of the program, patients experienced fewer complications with an absolute reduction in overall morbidity by at least 12%. This finding was driven by reduction in minor morbidity and its most prevalent complications (pneumonia, atrial fibrillation, and delirium). Importantly, we found a reduction in overall morbidity for our elderly patients. A combination of the core components of the program likely contributed to these reductions, such as patient education of the importance of ambulation and breathing exercises, standardization of rehabilitation services, specialized delirium prevention measures, and increased utilization of minimally invasive surgery. We may see further reduction in morbidity with increased adherence to our analgesia, line management, and ambulation goals.

TABLE 6. Propensity Score-matched Analysis of Opiod Use Accounting for Age, Sex, Race, Charlson Comorbidity Index, Preoperative Opioid Use, Minimally Invasive Surgery, and the Use of Epidural Analgesia.

Daily Opioid Usage				
Outcomes	**PRE (n = 239)**	**POST (n = 249)**	**ATE (95% CI)**	***P***
Daily OME*	101	82	−19 (−36, −1)	0.04

*Propensity scores: age, sex, race, Charlson comorbidity index, preoperative opioid use, minimally invasive surgery, epidural analgesia; daily OME: total oral morphine equivalent (OME) per length of stay if length of stay <7 days.
ATE indicates average treatment effect.

In light of the ongoing opioid epidemic, a core component of the program was reduction in opioid use through utilization of multimodality analgesia. The Thoracic ERAS Program reduced opioid use by 19 oral morphine equivalents daily. This finding highlights the importance of patient expectations, alignment with nursing care, and opioid-sparing medications. We are currently conducting a randomized, triple-blinded clinical trial evaluating intercostal nerve blockade with liposomal versus standard bupivacaine, and we may further reduce opioid use by this approach.[16]

From a financial perspective, the Thoracic ERAS Program reduced direct costs by at least $3500 per patient. This corresponds to a program cost savings of at least $350,000 per 100 patients undergoing lung resection annually. Not unexpectedly, reduced length of stay and ICU utilization were the main drivers of cost savings, which offset the intraoperative costs associated with increased minimally invasive surgery. Further cost savings from the program may have been demonstrated by showing an improvement in available bed days and opportunity costs by freeing up hospital resources, but our study was limited in scope to direct costs only.

Our program was developed before the ERAS Society thoracic surgery formalization, but contains all of the major guidelines and 42 of the 45 individual content measures.[12] The 3 individual content measures that are different pertain to preoperative fasting and chest tube drainage systems. The ERAS Society recommends preoperative oral carbohydrate loading (Evidence Low, Recommendation Strong), fasting only 2 hours before anesthesia (Evidence High, Recommendation Strong), and use of chest tube digital drainage systems (Evidence Low, Recommendation Strong). The UCSF Thoracic

ERAS Program utilized fasting at midnight without carbohydrate loading and standard dry suction drainage systems. Nevertheless, this study represents an external validation of the ERAS Society major guidelines and that these additional components can be studied as we continue to evaluate our program.

This study does have limitations. A high proportion of our patients had stage I disease, and extended lung resections were excluded from this study. We suspect that other institutions may be experiencing similar upward trends in patients who present with stage I disease due to the steady increase in lung cancer screening adoption. In addition, although the propensity score-matched analysis helped reduce the bias of nonrandomization, there may still be unmeasured variables that could alter the findings. Furthermore, the Hawthorne effect could have played a role as patients and providers were aware of the program and its goals. Finally, some components of the program, such as patient education, do not have validated metrics that would aid their evaluation. Despite these limitations, this study represents the first external validation of the ERAS Society guidelines and demonstrates its safety and effectiveness for patients undergoing lung resection at a major, academic medical center in the United States.

CONCLUSIONS

Use of a multidisciplinary, evidence-based Thoracic ERAS Program improves perioperative outcomes for patients undergoing lung resection. Our study demonstrates the value of a thoughtfully planned program to reduce patient morbidity and healthcare costs. Adoption of such programs in the care of thoracic surgery patients should be encouraged.

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