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Original Research Article

Evaluation of Enhanced Recovery after Surgery (ERAS) Protocol in Thoracic Lobectomy: Effects on Pulmonary Complications and Length of Hospital Stay

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Abstract

Background: Thoracic lobectomy remains the gold standard surgical treatment for early-stage non-small cell lung cancer (NSCLC). However, postoperative pulmonary complications (PPCs) continue to represent a major source of morbidity, prolonged hospitalization, and increased healthcare expenditure. Enhanced Recovery after Surgery (ERAS) protocols have demonstrated efficacy across multiple surgical disciplines, yet their systematic application in thoracic lobectomy remains incompletely characterized.

Methods: A prospective comparative study was conducted at a tertiary thoracic surgery center. A total of 216 patients undergoing elective lobectomy for NSCLC were enrolled: 112 patients managed under the ERAS protocol and 104 patients under conventional care. Primary outcomes included PPC incidence and LOS. Secondary outcomes included 30-day readmission, mortality, chest tube duration, and pain scores.

Results: The ERAS group demonstrated a significantly lower PPC rate (15.2% vs. 29.8%; $p = 0.009$) and shorter mean LOS (5.3 ± 1.8 vs. 8.1 ± 2.6 days; $p < 0.001$) compared to conventional care. Chest tube duration was reduced (2.8 ± 1.1 vs. 4.2 ± 1.7 days; $p < 0.001$). No significant differences in 30-day readmission rates (7.1% vs. 5.8%; $p = 0.680$) or mortality (0.9% vs. 1.0%; $p = 1.000$) were observed between groups.

Conclusion: Implementation of an ERAS protocol in thoracic lobectomy significantly reduces postoperative pulmonary complications and hospital length of stay without increasing readmission or mortality rates, supporting its adoption as a standard perioperative care framework in thoracic surgery.

Keywords: Enhanced Recovery After Surgery; ERAS; thoracic lobectomy; postoperative pulmonary complications; length of hospital stay; lung cancer surgery; perioperative care.

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Introduction

Lung cancer remains the leading cause of cancer-related mortality worldwide, with non-small cell lung cancer (NSCLC) accounting for approximately 85% of all diagnosed cases [1]. For patients presenting with early-stage resectable disease, anatomic lobectomy—with or without mediastinal lymph node dissection—constitutes the definitive curative intervention and is associated with superior oncologic outcomes compared to sublobar resection [2]. Despite advances in minimally invasive surgical techniques, including video-assisted thoracoscopic surgery (VATS) and robotic-assisted approaches, postoperative pulmonary complications (PPCs) remain the most prevalent and consequential adverse events following lobectomy, occurring in 15–40% of patients and contributing disproportionately to prolonged hospitalization, intensive care utilization, and perioperative mortality [3]. The Enhanced Recovery After Surgery (ERAS) paradigm, originally developed by Kehlet and Wilmore for colorectal surgery, represents a multimodal, evidence-based approach to perioperative care designed to attenuate the surgical stress response, preserve organ function, and accelerate physiological recovery [4]. ERAS protocols typically integrate preoperative patient education and optimization, minimization of fasting intervals, multimodal opioid-sparing analgesia, goal-directed fluid therapy, early mobilization, and standardized criteria for drain removal and discharge [5]. The implementation of ERAS pathways has

consistently demonstrated significant reductions in complication rates, hospital length of stay (LOS), and healthcare costs across abdominal, orthopedic, urologic, and gynecologic surgical specialties [6].

The translation of ERAS principles to thoracic surgery has gained considerable momentum over the past decade. The ERAS Society and the European Society of Thoracic Surgeons published consensus guidelines for perioperative care in lung surgery in 2019, comprising 45 individual recommendations spanning the preoperative, intraoperative, and postoperative phases [7]. However, compared to the extensive literature supporting ERAS in abdominal surgery, the evidence base in thoracic lobectomy remains comparatively limited. Several retrospective analyses and small prospective studies have suggested beneficial effects of ERAS implementation on LOS and selected complications [8], but heterogeneity in protocol composition, patient populations, and outcome definitions has precluded definitive conclusions [9].

A specific gap exists regarding the impact of comprehensive ERAS protocols on PPCs as a primary outcome measure in lobectomy patients. While individual components—such as thoracic epidural analgesia, early chest tube removal, and structured mobilization—have been studied in isolation [10], few investigations have evaluated the synergistic effect of the complete ERAS bundle on pulmonary-specific outcomes. Furthermore, concerns persist regarding whether accelerated recovery pathways might inadvertently increase readmission rates or mask complications that would otherwise be identified during prolonged inpatient observation [11].

The present study aimed to evaluate the impact of a comprehensive, protocol-driven ERAS pathway on the incidence of postoperative pulmonary complications and length of hospital stay following thoracic lobectomy for NSCLC, compared with conventional perioperative management, while simultaneously assessing safety endpoints including 30-day readmission and mortality.

Materials and Methods

Study Design and Setting: This prospective, non-randomized comparative study was conducted in the Department of Thoracic Surgery at a university-affiliated tertiary referral center.

Study Population: Adults aged 18–80 years undergoing elective anatomic lobectomy (via VATS or open thoracotomy) for histologically confirmed or strongly suspected NSCLC (clinical stages I–IIIA) were eligible for inclusion. Exclusion criteria included pneumonectomy or bilobectomy, emergent surgery, American Society of Anesthesiologists (ASA) physical status classification ≥ IV, severe chronic obstructive pulmonary disease with forced expiratory volume in one second (FEV_1) < 40% predicted, prior ipsilateral thoracic surgery, concurrent cardiac surgery, neoadjuvant chemoradiation within four weeks of surgery, and inability to participate in rehabilitation due to cognitive or severe musculoskeletal impairment.

ERAS Protocol Components: The ERAS protocol was developed based on the ERAS Society/ESTS guidelines and comprised the following standardized elements: (1) preoperative counseling and stoma-free education sessions; (2) carbohydrate loading two hours preoperatively; (3) avoidance of prolonged fasting (clear fluids until two hours, solids until six hours before anesthesia); (4) antimicrobial prophylaxis with a single dose of cefazolin; (5) lung-protective ventilation with low tidal volumes (6–8 mL/kg ideal body weight); (6) goal-directed intraoperative fluid management using stroke volume variation monitoring; (7) multimodal analgesia including paravertebral block or intercostal nerve blockade, acetaminophen, non-steroidal anti-inflammatory drugs, and gabapentinoids, with minimization of systemic opioids; (8) postoperative nausea and vomiting prophylaxis; (9) early chest tube removal based on standardized criteria (output < 200 mL/24 hours, no air leak, fully expanded lung on chest radiograph); (10) structured early mobilization commencing within four hours postoperatively; (11) early oral nutrition within six hours of surgery; and (12) predefined discharge criteria including adequate oral analgesia, independent mobilization, absence of complications requiring inpatient management, and satisfactory chest radiograph.

Conventional Care: Patients in the conventional care group received standard perioperative management at the discretion of the attending surgical and anesthesia teams, without a structured protocol. This typically included epidural or patient-controlled intravenous opioid analgesia, ad libitum fluid administration, physician-determined chest tube removal, and empirical mobilization timelines.

Outcome Measures: The primary outcomes were (1) the incidence of PPCs within 30 days and (2) total hospital LOS. PPCs were defined using the Melbourne Group Scale classification and included pneumonia, atelectasis requiring bronchoscopic intervention, acute respiratory distress syndrome (ARDS), air leak persisting beyond five days, empyema, and respiratory failure necessitating reintubation or mechanical ventilation exceeding 48 hours. Secondary outcomes comprised chest tube duration, postoperative pain scores (numerical rating scale, 0–10) at 24 and 72 hours, 30-day unplanned readmission, 30-day mortality, and intensive care unit (ICU) admission rate.

Data Collection: Clinical data were prospectively collected using a standardized case report form and included patient demographics, comorbidity burden (Charlson Comorbidity Index), pulmonary function test results, ASA classification, surgical approach, operative time, pathologic staging, and all outcome variables.

Statistical Analysis: Sample size calculation was performed a priori based on the hypothesis that the ERAS protocol would reduce PPC incidence from 30% to 15%, requiring 97 patients per group (α = 0.05, power = 80%). Accounting for a 10% attrition rate, 108 patients per group were targeted.

Data were analyzed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean ± SD and compared using the independent-samples t-test or Mann-Whitney U test as appropriate. Categorical variables were expressed as frequencies and percentages and compared using the chi-square test or Fisher's exact test. Multivariable logistic regression was performed to adjust for potential confounders. Statistical significance was defined as $p < 0.05$.

Results

Patient Demographics and Baseline Characteristics: A total of 216 patients were enrolled: 112 in the ERAS group and 104 in the conventional care group. Baseline demographic and clinical characteristics were comparable between groups. The mean age was 62.7 ± 9.3 years in the ERAS group and 63.4 ± 10.1 years in the conventional care group ($p = 0.588$). The proportion of male patients was 58.9% and 61.5%, respectively ($p = 0.695$). No significant differences were observed in ASA classification, Charlson Comorbidity Index, preoperative FEV_1 percent predicted, smoking status, surgical approach (VATS vs. thoracotomy), or pathologic stage (Table 1).

Table 1: Baseline Demographic and Clinical Characteristics (N = 216)

Characteristic	ERAS Group (n = 112)	Conventional Group (n = 104)	p-value
Age (years), mean ± SD	62.7 ± 9.3	63.4 ± 10.1	0.588
Male sex, n (%)	66 (58.9)	64 (61.5)	0.695
BMI (kg/m²), mean ± SD	25.4 ± 3.8	25.9 ± 4.1	0.352
Current/former smoker, n (%)	74 (66.1)	72 (69.2)	0.613
ASA class III, n (%)	38 (33.9)	36 (34.6)	0.916
CCI, mean ± SD	3.2 ± 1.6	3.4 ± 1.8	0.394
FEV_1 % predicted, mean ± SD	78.6 ± 14.2	76.9 ± 15.8	0.408
VATS approach, n (%)	76 (67.9)	68 (65.4)	0.698
Pathologic stage I, n (%)	58 (51.8)	52 (50.0)	0.795
Pathologic stage II, n (%)	34 (30.4)	30 (28.8)	0.810
Pathologic stage IIIA, n (%)	20 (17.9)	22 (21.2)	0.542
Operative time (min), mean ± SD	158.4 ± 42.7	162.1 ± 45.3	0.537

BMI = body mass index; ASA = American Society of Anesthesiologists; CCI = Charlson Comorbidity Index; FEV_1 = forced expiratory volume in one second; VATS = video-assisted thoracoscopic surgery.

Primary Outcomes: The incidence of PPCs was significantly lower in the ERAS group compared to the conventional care group (15.2% vs. 29.8%; OR = 0.42; 95% CI: 0.22–0.80; $p = 0.009$). Pneumonia (5.4% vs. 12.5%; $p = 0.068$) and clinically significant atelectasis (4.5% vs. 10.6%; $p = 0.085$) were the most common individual PPCs, both showing trends favoring the ERAS group. Prolonged air leak was significantly less frequent in the ERAS group (2.7% vs. 9.6%; $p = 0.032$). The mean hospital LOS was significantly shorter in the ERAS group (5.3 ± 1.8 vs. 8.1 ± 2.6 days; $p < 0.001$) (Table 2).

Table 2: Primary and Secondary Outcomes by Study Group

Outcome	ERAS Group (n = 112)	Conventional Group (n = 104)	p-value
Primary Outcomes			
Overall PPC incidence, n (%)	17 (15.2)	31 (29.8)	0.009
Pneumonia, n (%)	6 (5.4)	13 (12.5)	0.068
Atelectasis (requiring intervention), n (%)	5 (4.5)	11 (10.6)	0.085
Prolonged air leak (>5 days), n (%)	3 (2.7)	10 (9.6)	0.032
ARDS, n (%)	1 (0.9)	2 (1.9)	0.607
Reintubation/mechanical ventilation, n (%)	2 (1.8)	4 (3.8)	0.430
Empyema, n (%)	0 (0.0)	1 (1.0)	0.481
Hospital LOS (days), mean ± SD	5.3 ± 1.8	8.1 ± 2.6	< 0.001

Secondary Outcomes			
Chest tube duration (days), mean ± SD	2.8 ± 1.1	4.2 ± 1.7	< 0.001
ICU admission, n (%)	8 (7.1)	16 (15.4)	0.052
30-day readmission, n (%)	8 (7.1)	6 (5.8)	0.680
30-day mortality, n (%)	1 (0.9)	1 (1.0)	1.000

PPC = postoperative pulmonary complication; ARDS = acute respiratory distress syndrome; LOS = length of stay; ICU = intensive care unit.

Pain Scores and Analgesic Outcomes: Postoperative pain scores were significantly lower in the ERAS group at both 24 hours (3.4 ± 1.6 vs. 5.2 ± 2.1; p < 0.001) and 72 hours (2.1 ± 1.2 vs. 3.8 ± 1.7; p < 0.001). Cumulative intravenous morphine equivalent consumption during the first 72 postoperative hours was significantly reduced in the ERAS group (Table 3).

Table 3: Postoperative Pain Scores and Opioid Consumption

Variable	ERAS Group (n = 112)	Conventional Group (n = 104)	p-value
NRS pain score at 24 h, mean ± SD	3.4 ± 1.6	5.2 ± 2.1	< 0.001
NRS pain score at 72 h, mean ± SD	2.1 ± 1.2	3.8 ± 1.7	< 0.001
IV morphine equivalents 0–72 h (mg), mean ± SD	22.4 ± 11.3	48.7 ± 18.6	< 0.001
Time to first ambulation (h), mean ± SD	6.2 ± 2.8	18.4 ± 8.6	< 0.001
Time to oral intake (h), mean ± SD	5.8 ± 2.3	14.6 ± 6.4	< 0.001

NRS = numerical rating scale; IV = intravenous.

Multivariable Analysis: Multivariable logistic regression adjusting for age, sex, ASA class, CCI, FEV_1 percent predicted, smoking status, and surgical approach confirmed that ERAS protocol implementation was independently associated with reduced PPC risk (adjusted OR = 0.39; 95% CI: 0.19–0.78; p = 0.008).

Discussion

The present study demonstrates that implementation of a comprehensive ERAS protocol in patients undergoing thoracic lobectomy for NSCLC is associated with a clinically and statistically significant reduction in postoperative pulmonary complications and hospital length of stay, without a concomitant increase in readmission or mortality rates. These findings add to the growing body of evidence supporting the systematic adoption of ERAS principles in thoracic surgical practice.

The observed 49% relative reduction in PPC incidence (15.2% vs. 29.8%) in the ERAS group is particularly noteworthy, as PPCs represent the predominant driver of morbidity, resource utilization, and failure-to-rescue events following pulmonary resection [12]. Our findings align with those reported by Brunelli et al., who demonstrated that standardized fast-track protocols reduced pulmonary complications following anatomic lung resections [13], and extend earlier work by Muehling et al. showing that structured perioperative pathways improved respiratory outcomes after thoracotomy [14]. The magnitude of PPC reduction observed in our study exceeds that reported in some prior investigations, which may reflect the comprehensiveness of our multimodal protocol and the high baseline complication rate in the conventional care cohort.

The significant reduction in hospital LOS from 8.1 to 5.3 days (a 34.6% decrease) is consistent with findings from multiple ERAS implementations in thoracic surgery. Gonzalez et al. reported a median LOS reduction of 2 days following ERAS implementation in their lobectomy program [15], while Batchelor et al. demonstrated similar improvements in a mixed thoracic surgical population [16]. Importantly, the reduction in LOS observed in our study was not associated with increased 30-day readmission (7.1% vs. 5.8%; p = 0.680), addressing a persistent concern raised by critics of accelerated recovery pathways who hypothesize that premature discharge may precipitate avoidable readmissions [17]. The readmission rate in our ERAS cohort falls within the range of 4–12% reported in large thoracic surgery databases and does not suggest premature discharge practices [18].

The substantial reduction in opioid consumption (54% decrease in intravenous morphine equivalents) observed in the ERAS group is a critical finding with implications extending beyond analgesic efficacy. Excessive perioperative opioid administration is independently associated with respiratory depression, impaired cough reflex, atelectasis, and delayed mobilization—all established risk factors for PPCs [19]. The multimodal, opioid-sparing analgesic strategy employed in our ERAS protocol—combining regional anesthetic techniques with non-opioid systemic agents—likely contributed mechanistically to the observed reduction in

pulmonary complications by preserving respiratory mechanics and facilitating early ambulation. This interpretation is supported by the significantly earlier time to first ambulation (6.2 vs. 18.4 hours) and earlier resumption of oral intake in the ERAS group.

The earlier chest tube removal observed in the ERAS group (2.8 vs. 4.2 days) merits specific discussion. Prolonged chest tube drainage is recognized as an independent predictor of increased LOS, patient discomfort, restricted mobility, and pleural space complications [20]. The implementation of standardized, criteria-based chest tube removal protocols—rather than empirical physician-determined timing—likely contributed to the earlier drain removal and lower incidence of prolonged air leak in the ERAS cohort. This finding is concordant with recommendations from the ERAS Society/ESTS guidelines emphasizing protocol-driven chest tube management [7].

The trend toward reduced ICU admission in the ERAS group (7.1% vs. 15.4%; $p = 0.052$), while not reaching statistical significance, carries potential implications for resource allocation and cost containment. Rogers et al. demonstrated that ERAS implementation in thoracic surgery was associated with significant cost reductions, primarily driven by decreased ICU utilization and shortened hospitalization [21]. Future studies with larger sample sizes may be powered to detect statistically significant differences in this outcome.

Several limitations must be acknowledged. First, the non-randomized, sequential cohort design introduces the possibility of temporal confounding and performance bias, as surgical teams may have evolved their practices independently of the protocol.

However, the stable surgical team composition and consistent operative techniques throughout the study period mitigate this concern. Second, the single-center design limits external generalizability. Third, the sample size, while adequate for the primary outcome, was insufficient to detect differences in low-frequency events such as mortality and ARDS. Fourth, compliance with individual ERAS protocol elements was not systematically audited; variations in adherence may have attenuated the observed treatment effect, and future investigations should incorporate compliance monitoring as recommended by the ERAS Society [22]. Finally, longer-term outcomes including quality of life, chronic pain, and oncologic endpoints were not assessed and warrant investigation in subsequent studies. Our findings align with a recent meta-analysis by Li et al. that synthesized evidence from 14 studies encompassing 3,478 patients and concluded that ERAS protocols significantly reduce LOS and complications following thoracic surgery [23]. However, the heterogeneity of included studies and varying protocol compositions underscore the need for standardized, high-quality prospective trials to definitively establish the optimal ERAS bundle for thoracic lobectomy.

Conclusion

This study demonstrates that implementation of a comprehensive Enhanced Recovery After Surgery protocol in thoracic lobectomy for non-small cell lung cancer significantly reduces the incidence of postoperative pulmonary complications by nearly 50% and shortens hospital length of stay by approximately three days compared to conventional perioperative management. These benefits are achieved through synergistic multimodal interventions—including opioid-sparing analgesia, early mobilization, protocol-driven chest tube management, and goal-directed fluid therapy—without any demonstrable increase in 30-day readmission or mortality. The findings support the systematic adoption of ERAS protocols as a standard of perioperative care in thoracic surgery programs and highlight the importance of institutional commitment to structured, evidence-based recovery pathways to optimize patient outcomes and healthcare resource utilization.

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