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# Enhanced Recovery after Thoracotomy in the Intensive Care Unit: Current Evidence, Clinical Strategies, and Future Perspectives

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**ABSTRACT**

Enhanced Recovery After Surgery (ERAS) has emerged as an important perioperative framework for improving outcomes after thoracotomy, particularly in patients requiring intensive postoperative care. This review examines current evidence and practical strategies for applying ERAS principles in the intensive care unit after thoracic surgery. Key components include preoperative optimization through patient education, pulmonary assessment, smoking cessation, nutritional support, and anesthetic planning; intraoperative measures such as appropriate surgical technique selection, goal-directed fluid therapy, targeted anesthesia, multimodal analgesia, and tissue-sparing practice; and postoperative ICU management focused on hemodynamic monitoring, ventilatory support, pain control, chest tube care, mobilization, respiratory physiotherapy, and early nutritional intervention. Collectively, these measures aim to reduce pulmonary complications, shorten ICU and hospital stay, improve functional recovery, and enhance quality of life. The review also highlights important barriers to implementation, including protocol variability, limited resources, and the complexity of critically ill thoracic patients. Overall, ERAS provides a structured and multidisciplinary approach that aligns perioperative care with modern goals of safety, efficiency, and patient-centered recovery after thoracotomy.

## Introduction

Thoracic surgery remains a cornerstone in the management of a wide spectrum of pulmonary, mediastinal, pleural, and esophageal diseases, including malignancies, traumatic injuries, and complex infectious processes. Among thoracic surgical approaches, thoracotomy is still required in many patients despite the increasing use of minimally invasive techniques, particularly when extensive exposure, anatomical complexity, or urgent intervention is necessary. However, thoracotomy is widely recognized as one of the most physiologically stressful surgical procedures because it combines major tissue disruption, significant postoperative pain, and substantial cardiopulmonary strain.

These challenges even more pronounced in critically ill patients admitted to the intensive care unit (ICU), where preexisting comorbidities, impaired respiratory reserve, and perioperative instability may amplify postoperative morbidity and delay recovery (1).

The postoperative course after thoracotomy complicated by severe pain and respiratory dysfunction. Inadequately controlled pain can impair deep breathing, suppress effective coughing, and reduce early mobilization, thereby increasing the risk of atelectasis, secretion retention, pneumonia, and respiratory failure.

In addition to pulmonary complications, thoracotomy may contribute to hemodynamic stress, sleep disruption, prolonged need for ventilator support, and delayed return of gastrointestinal and physical function. These complications often translate into longer ICU and hospital stays, increased readmission rates, and greater use of

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healthcare resources. As a result, the burden of thoracotomy extends beyond the immediate surgical event and influences both short-term recovery and long-term quality of life, particularly in vulnerable ICU populations (2).

In response to these challenges, the concept of Enhanced Recovery After Surgery (ERAS) has emerged as a structured, evidence-based model of perioperative care designed to reduce surgical stress and accelerate functional recovery. ERAS programs integrate multiple coordinated interventions across the preoperative, intraoperative, and postoperative phases of care. Core elements commonly include patient education, nutritional optimization, shortened fasting, multimodal analgesia, opioid-sparing pain control, protective ventilation strategies, early chest physiotherapy, prompt mobilization, and early enteral nutrition when feasible. Rather than relying on a single intervention, ERAS pathways seek to standardize best practices and improve outcomes through multidisciplinary collaboration among surgeons, anesthesiologists, intensivists, nurses, physiotherapists, and nutrition teams (3).

In thoracic surgery, ERAS pathways have gained increasing attention because they directly address the major drivers of postoperative morbidity. Contemporary thoracic ERAS protocols emphasize regional analgesic techniques, careful fluid management, avoidance of unnecessary drains and catheters, early removal of invasive devices, and aggressive prevention of pulmonary complications. For patients requiring thoracotomy and postoperative ICU care, these measures may be especially valuable because they target the mechanisms that prolong critical illness, such as persistent pain, immobilization, impaired ventilation, and metabolic stress. Although implementation varies across institutions, emerging evidence suggests that ERAS-based thoracic care can shorten hospital stay, reduce complication rates, and improve patient-centered recovery without compromising safety. Nevertheless, important uncertainties remain regarding protocol adherence, ICU-specific adaptations, and the management of high-risk subgroups (4).

Given the growing relevance of ERAS in modern thoracic perioperative medicine, a focused evaluation of its role in thoracotomy patients admitted to the ICU warranted. This article aims to summarize the current evidence, outline practical clinical strategies, and discuss future directions for ERAS implementation in this high-acuity population. By examining how standardized recovery pathways can be adapted to the unique physiological and organizational demands of ICU care, the review seeks to clarify their potential to improve outcomes, optimize resource use, and support a more efficient and patient-centered model of thoracic surgical recovery (5).

**Core Principles of ERAS in Thoracic Surgery**

Enhanced Recovery After Surgery (ERAS) is a patient-centered, evidence-based perioperative care model developed to attenuate the physiological stress of surgery and support faster, safer recovery. Rather than focusing solely on the technical success of an operation, ERAS emphasizes the entire surgical journey, integrating preoperative preparation, intraoperative optimization, and postoperative rehabilitation into a coordinated pathway. The central premise is that many traditional perioperative practices such as prolonged fasting, excessive opioid use, delayed feeding, and unnecessary immobilization can intensify the surgical stress response and delay functional recovery. In contrast, ERAS protocols aim to preserve organ function, reduce complications, and promote an earlier return to baseline activity through standardized, multidisciplinary care (6).

The biological rationale for ERAS lies in its effort to blunt the neuroendocrine and inflammatory consequences of surgical trauma. Major surgery activates catabolic hormonal pathways, increases insulin resistance, alters fluid balance, impairs pulmonary mechanics, and disrupts normal gastrointestinal and musculoskeletal function. If these responses are not actively mitigated, patients may experience prolonged weakness, respiratory compromise, delayed mobilization, and extended hospitalization. ERAS therefore seeks to reduce the magnitude of this physiological disturbance through measures such as minimizing fasting times, optimizing nutrition, ensuring effective multimodal analgesia, avoiding unnecessary fluid overload, and encouraging early ambulation. The goal is not simply earlier discharge, but the preservation of physiological stability and restoration of functional independence as efficiently as possible (7).

The ERAS concept was initially developed in colorectal surgery in the late 1990s and early 2000s, when investigators began to challenge long-standing perioperative conventions and replace them with evidence-driven practices. Over time, the approach evolved into a broader international movement supported by specialty societies and multidisciplinary expert groups. As data accumulated, ERAS principles were adapted for multiple surgical fields, including gynecology, urology, hepatobiliary surgery, and cardiothoracic procedures. In thoracic surgery, the application of ERAS gained momentum as clinicians recognized that pulmonary complications, severe postoperative pain, and delayed mobilization were common barriers to recovery. Thoracic procedures, especially lung resection and open thoracotomy, offered a particularly relevant setting for ERAS because postoperative outcomes depend heavily on respiratory mechanics, physical activity, and coordinated perioperative support (8).

In the context of thoracic and lung surgery, ERAS principles have been tailored to address procedure-specific risks while maintaining the broader philosophy of recovery optimization. Preoperatively, this includes patient counseling, smoking cessation, nutritional assessment, respiratory prehabilitation, and careful evaluation of comorbid conditions. Intraoperatively, ERAS pathways often prioritize minimally invasive techniques when feasible, lung-protective ventilation, normothermia, balanced fluid therapy, and regional anesthesia strategies that reduce opioid requirements. Postoperatively, special emphasis is placed on early chest physiotherapy, effective secretion clearance, mobilization, prompt oral intake, and rational management of drains and catheters. These interventions are especially relevant after thoracic operations because even modest impairments in ventilation or pain control can quickly translate into atelectasis, pneumonia, or prolonged dependence on intensive monitoring and respiratory support (9).

A defining feature of ERAS is that it functions as a comprehensive pathway rather than an isolated checklist of interventions. Its success depends on consistent implementation, interdisciplinary communication, and institutional commitment to protocolized care. Surgeons, anesthesiologists, intensivists, nurses, physiotherapists, nutrition specialists, and pain teams all contribute to achieving the shared objective of reducing postoperative morbidity while preserving patient comfort and safety. In thoracic surgery, where recovery is highly sensitive to pulmonary performance and pain burden, this collaborative model is particularly valuable. Accordingly, ERAS has become an increasingly important framework for improving perioperative quality, standardizing best practice, and aligning thoracic surgical care with modern principles of efficiency, safety, and functional recovery (10).

**Preoperative Optimization**

Preoperative optimization is a fundamental component of Enhanced Recovery after Surgery (ERAS) pathways in thoracic surgery because it directly shapes postoperative resilience and influences the risk of pulmonary, infectious, and functional complications. Patients undergoing thoracic procedures, particularly thoracotomy and major lung resection, often present with limited respiratory reserve, smoking-related disease, malignancy-associated frailty, or nutritional impairment. For this reason, preparation before surgery should be viewed not as a routine administrative step, but as an active therapeutic phase. The purpose of preoperative optimization is to identify modifiable risks, improve physiological readiness, and align perioperative planning with the patient's clinical profile and expected postoperative needs. In well-structured thoracic ERAS programs, this phase establishes the foundation for safer recovery and efficient use of intensive care and hospital resources (11).

Patient education is one of the most practical and effective elements of preoperative care. Clear counseling regarding the surgical procedure, expected pain trajectory, breathing exercises, chest physiotherapy, early mobilization, nutritional goals, and discharge planning can reduce anxiety while improving adherence to recovery protocols. Informed patients are better able to participate in coughing exercises, incentive spirometry, and postoperative ambulation, all of which are particularly important after thoracic surgery. Education also helps establish realistic expectations regarding drains, temporary functional limitations, and the need for active participation in recovery. When communication is individualized and delivered through a multidisciplinary framework, it contributes not only to patient satisfaction but also to improved engagement with ERAS targets after surgery (12).

Assessment of pulmonary function is another essential step before thoracic surgery. Because respiratory complications remain a major cause of postoperative morbidity, objective evaluation of lung capacity and reserve is critical for operative planning and risk stratification. Pulmonary function testing, diffusion capacity assessment, and, when indicated, exercise-based evaluation can guide the anticipated extent of resection and the need for postoperative respiratory support. Beyond risk estimation, this assessment creates an opportunity to initiate prehabilitation strategies, including inspiratory muscle training, breathing instruction, and pulmonary rehabilitation in selected patients. Even short-term respiratory conditioning may improve postoperative ventilation, secretion clearance, and exercise tolerance, thereby supporting smoother recovery after surgery (13).

Smoking cessation is among the most impactful preoperative interventions in thoracic surgical patients. Continued smoking is associated with impaired mucociliary clearance, increased airway reactivity, reduced tissue oxygenation, and a higher incidence of pulmonary and wound complications. It may also compromise cardiovascular stability and delay healing. Encouraging cessation before surgery is therefore a core ERAS recommendation, and even a limited abstinence period may offer measurable benefit. Effective preoperative smoking intervention should combine counseling with pharmacologic support when appropriate, rather than relying solely on brief advice. Integrating cessation support into the surgical pathway underscores the preventive nature of ERAS and reinforces the broader goal of improving both perioperative and long-term health outcomes (14).

Nutritional optimization is equally important, particularly in patients with cancer, chronic disease, or weight loss before thoracic surgery. Malnutrition can impair immune function, reduce muscle strength, delay wound healing, and prolong recovery. Preoperative screening for nutritional risk should therefore be routine, with targeted intervention for patients showing evidence of sarcopenia, frailty, or inadequate intake. Oral nutritional supplementation, protein support, and individualized dietary counseling may help improve metabolic readiness before surgery. At the same time, prevention of infection and thoughtful anesthetic planning are critical aspects of optimization. Appropriate antimicrobial prophylaxis, skin preparation, and attention to modifiable infectious risks combined with pre-anesthetic assessment focused on airway management, comorbidity review, and multimodal pain planning. Early coordination of regional anesthesia and opioid-sparing strategies can improve postoperative analgesia and facilitate breathing, mobilization, and adherence to ERAS goals after thoracic intervention (15) (figure 1).

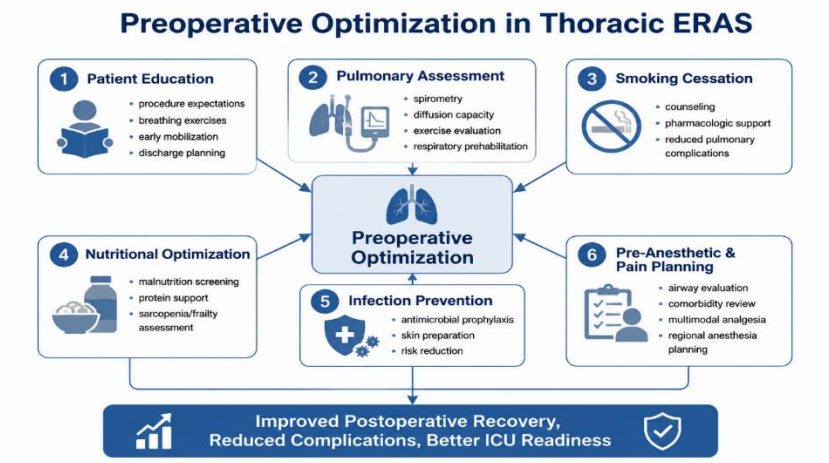


**Figure 1.** Multi-dimensional Framework of Preoperative Optimization in Thoracic ERAS

**Intraoperative Strategies**

Intraoperative management is a central pillar of Enhanced Recovery After Surgery (ERAS) in thoracic surgery because events during the operation have a direct impact on postoperative pulmonary function, pain burden, hemodynamic stability, and overall recovery trajectory. Thoracic procedures impose substantial physiological stress through surgical trauma, one-lung ventilation, fluid shifts, and inflammatory activation. As a result, intraoperative decision-making must extend beyond technical completion of the operation and focus equally on preserving organ function and minimizing avoidable injury. ERAS-aligned intraoperative care emphasizes precision, physiologic balance, and coordination between the surgical and anesthesia teams in order to reduce complications and accelerate functional recovery after thoracotomy or lung resection (16).

Selection of the most appropriate surgical technique is one of the earliest intraoperative determinants of outcome. Whenever oncologically and technically feasible, minimally invasive approaches such as video-assisted thoracoscopic surgery or robotic-assisted thoracic surgery are favored because they are associated with less chest wall trauma, reduced postoperative pain, earlier mobilization, and shorter hospital stay compared with open thoracotomy. Nevertheless, the principle is not simply to choose the least invasive method, but to select the approach that offers the best balance of safety, completeness of resection, and physiological preservation for the individual patient. Even when thoracotomy is required, careful incision planning, muscle-sparing techniques, and gentle rib retraction can help reduce tissue injury and postoperative respiratory compromise (17).

Precise fluid management is another essential element of intraoperative ERAS practice in thoracic surgery. Both fluid overload and excessive restriction may be harmful in this population. Liberal fluid administration can contribute to pulmonary edema, impaired gas exchange, and cardiopulmonary stress, particularly in the setting of one-lung ventilation and reduced lymphatic reserve after lung resection. Conversely, inadequate perfusion may increase the risk of tissue hypoxia, renal dysfunction, and hemodynamic instability. For this reason, contemporary thoracic anesthesia favors individualized, goal-directed fluid therapy based on dynamic hemodynamic assessment and close monitoring of perfusion endpoints. The aim is to maintain adequate circulating volume while avoiding unnecessary interstitial accumulation, thereby supporting oxygenation and reducing postoperative pulmonary morbidity (18).

Targeted anesthesia is equally important in maintaining physiological stability throughout thoracic surgery. ERAS protocols support anesthetic strategies that facilitate rapid emergence, early

extubation, and predictable recovery while minimizing cardiopulmonary depression. Balanced anesthesia using short-acting agents allows titration according to surgical stimulus and patient response, reducing prolonged sedation and facilitating early postoperative assessment. During thoracic procedures, anesthesia teams must also optimize oxygenation and ventilation during one-lung ventilation, preserve normothermia, prevent nausea and vomiting, and limit unnecessary use of long-acting medications. These measures are especially relevant in thoracic patients, in whom delayed awakening, impaired cough, and residual respiratory depression may significantly hinder early mobilization and pulmonary hygiene after surgery (19).

Multimodal analgesia is a core intraoperative ERAS strategy because effective pain control is inseparable from respiratory recovery. Severe pain after thoracotomy can suppress deep breathing, impair coughing, and increase the risk of atelectasis and pneumonia. Accordingly, analgesic plans should combine different pharmacological and regional techniques to reduce reliance on systemic opioids. Depending on the procedure and patient profile, thoracic epidural analgesia, paravertebral block, erector spinae plane block, and local anesthetic infiltration may be integrated with non-opioid agents such as acetaminophen and nonsteroidal anti-inflammatory drugs when appropriate. This multimodal approach improves comfort while limiting opioid-related adverse effects such as nausea, sedation, ileus, and respiratory depression, all of which can delay postoperative recovery (20).

Reduction of tissue injury remains the unifying principle behind all intraoperative ERAS interventions. Gentle tissue handling, meticulous hemostasis, avoidance of unnecessary dissection, protection of intercostal nerves, and efficient operative conduct can decrease inflammatory burden and preserve postoperative function. In thoracic surgery, minimizing trauma is particularly important because even limited additional pain or pulmonary insult may have disproportionate consequences for breathing mechanics and ICU needs. Therefore, intraoperative ERAS is best understood as a strategy of cumulative protection: each decision that limits physiological disturbance contributes to better pain control, fewer pulmonary complications, shorter hospitalization, and a smoother return to baseline activity (21) (figure 2).

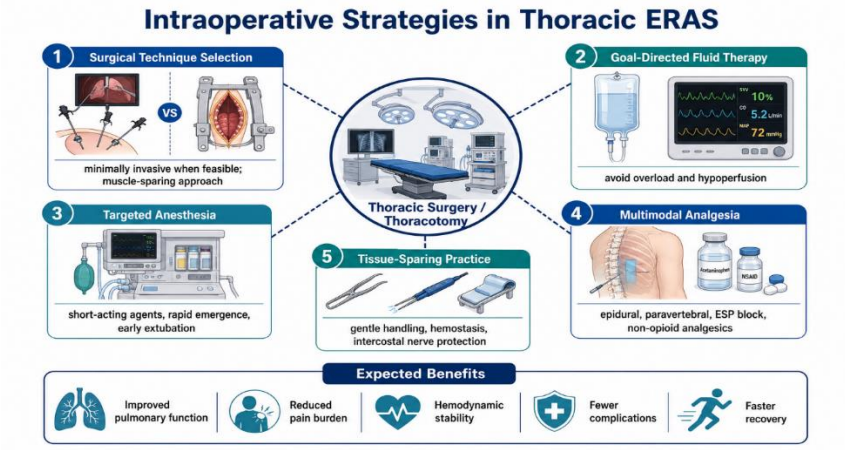


**Figure 2.** Comprehensive Intraoperative Management Framework within Thoracic ERAS

**Post-Thoracotomy ICU Care**

Management of patients in the intensive care unit after thoracotomy is a critical determinant of postoperative outcome because these individuals are especially vulnerable to respiratory compromise, hemodynamic instability, pain-related dysfunction, and early surgical complications. Thoracotomy is associated with substantial physiological stress, including altered pulmonary mechanics, inflammatory activation, fluid shifts, and impaired cough due to pain. The ICU phase therefore requires vigilant monitoring and proactive intervention aimed at preserving oxygen delivery, preventing avoidable complications, and supporting recovery of respiratory and functional capacity. Within an ERAS framework, postoperative intensive care is not limited to surveillance; it is an organized extension of perioperative optimization in which timely, protocol-driven management can reduce morbidity, shorten hospital stay, and improve overall recovery after major thoracic surgery (22).

Hemodynamic monitoring is one of the first priorities in the immediate postoperative period. Patients recovering from thoracotomy may experience hypotension, bleeding, arrhythmias, vasodilation, or reduced venous return related to anesthesia, fluid shifts, or intrathoracic pressure changes. Close observation of blood pressure, heart rate, urine output, serum lactate, and peripheral perfusion is essential for early detection of instability. In selected high-risk patients, invasive monitoring may be required to evaluate preload,

cardiac performance, and response to therapy. The objective is to maintain adequate organ perfusion while avoiding both under-resuscitation and excessive fluid administration, since pulmonary resection and thoracic trauma increase susceptibility to edema and impaired gas exchange. Hemodynamic care must therefore remain dynamic, individualized, and closely integrated with respiratory management in the ICU setting (23).

Mechanical ventilation strategy also plays a central role in post-thoracotomy care. Some patients intubated early, whereas others require continued ventilatory support because of residual anesthetic effects, limited respiratory reserve, or perioperative complications. In either case, lung-protective principles are essential. Tidal volumes should remain appropriately low, airway pressures be carefully controlled, and positive end-expiratory pressure adjusted to optimize oxygenation without causing over distension or hemodynamic compromise. Early liberation from mechanical ventilation is desirable when clinically feasible because prolonged intubation increases the risk of pneumonia, secretion retention, diaphragmatic dysfunction, and delayed mobilization. Extubation readiness evaluated systematically, with careful attention to gas exchange, mental status, cough effectiveness, and pain control (24).

Prevention of pulmonary complications is a major ICU objective after thoracotomy because atelectasis, pneumonia, mucus plugging, and respiratory failure remain common causes of prolonged recovery. Effective prevention requires a bundle approach that includes chest physiotherapy, incentive spirometry when appropriate, assisted coughing, early mobilization, secretion management, and maintenance of adequate analgesia. Nursing and physiotherapy teams play an especially important role in promoting lung expansion and airway clearance. Positioning strategies, humidification, and prompt recognition of deteriorating oxygenation can further reduce progression to major pulmonary events. Since thoracotomy patients often have preexisting lung disease or limited reserve, even modest declines in respiratory function should be addressed early and aggressively in order to avoid escalation to noninvasive or invasive ventilatory support (25).

Pain control is inseparable from respiratory recovery in the ICU after thoracotomy. Severe postoperative pain impairs deep inspiration, suppresses cough, restricts mobilization, and contributes directly to pulmonary complications. Multimodal analgesia should therefore continue after surgery using a combination of regional and systemic techniques tailored to the patient's condition. Thoracic epidural analgesia, paravertebral blockade, or newer fascial plane blocks may provide effective pain relief while reducing opioid exposure. Non-opioid adjuncts can further improve comfort and limit sedation, nausea, and respiratory depression. At the same time, chest tube management and fluid-electrolyte control require close attention. Chest drains monitored for air leak, bleeding, drainage volume, and proper function, as they provide crucial information about pulmonary re-expansion and postoperative complications. Fluid and electrolyte therapy should remain conservative but adequate, with frequent reassessment to avoid both hypovolemia and fluid overload. Maintaining this balance is essential for tissue perfusion, cardiac rhythm stability, and optimal respiratory mechanics during the early postoperative period (26) (figure 3).

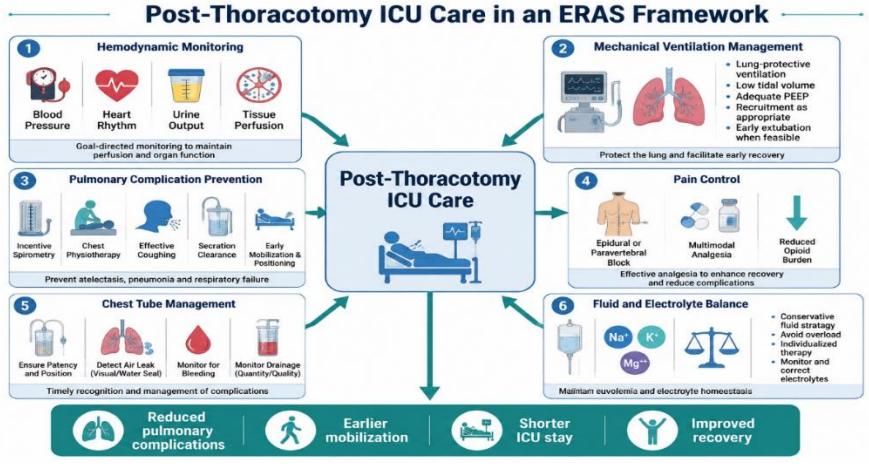


**Figure 3.** Integrated Postoperative Care Model in the ICU for Thoracotomy Patients

**Pain Control and Early Mobilization**

Pain management is a cornerstone of Enhanced Recovery after Surgery (ERAS) in thoracic surgery because post-thoracotomy pain is often severe enough to impair ventilation, suppress cough, and delay mobilization. Unlike pain after many other surgical procedures, thoracotomy pain directly affects respiratory mechanics by limiting chest wall expansion and promoting shallow breathing. This can lead to secretion retention, atelectasis, hypoxemia, and pneumonia if not addressed promptly and effectively. Within the ERAS

framework, analgesia therefore not viewed solely as a comfort measure, but as a therapeutic intervention essential for preserving pulmonary function and enabling active postoperative recovery. The objective is to provide reliable pain relief while minimizing opioid-related adverse effects that may compromise alertness, respiratory drive, gastrointestinal function, and early ambulation (27).

Thoracic epidural analgesia historically regarded as one of the most effective methods for pain control after thoracotomy. By providing segmental blockade of thoracic nociceptive pathways, epidural analgesia can produce superior relief during both rest and coughing, thereby facilitating deep breathing and more effective airway clearance. Its value is particularly evident in patients undergoing open thoracotomy, where chest wall trauma is substantial and pain intensity may be profound. Effective epidural analgesia may reduce pulmonary complications by allowing patients to participate more fully in physiotherapy and early mobilization. However, its use requires careful patient selection and monitoring because hypotension, urinary retention, and technical failure may limit its applicability in some clinical settings. Even so, it remains a key option within thoracic ERAS protocols when appropriately integrated into perioperative care (28).

Paravertebral block has emerged as an important alternative to thoracic epidural analgesia, especially in patients for whom epidural placement is undesirable or technically challenging. By delivering local anesthetic adjacent to the thoracic vertebral column, this technique provides unilateral segmental analgesia that can effectively reduce pain after thoracotomy while often causing less hypotension than epidural blockade. In contemporary thoracic practice, paravertebral block is valued for its ability to support coughing, breathing exercises, and mobilization without the same degree of sympathetic blockade seen with epidural techniques. Depending on institutional expertise and patient factors, it used as a single-injection block or as a continuous catheter-based strategy. Its increasing adoption reflects the broader ERAS principle of tailoring analgesic interventions to maximize functional recovery while minimizing treatment-related burden (29).

Multimodal analgesia complements regional techniques by combining different classes of analgesic agents and methods in order to improve pain control through multiple mechanisms while reducing dependence on systemic opioids. This approach may include acetaminophen, nonsteroidal anti-inflammatory drugs when appropriate, regional blocks, local anesthetic infiltration, and judicious opioid rescue therapy. In some settings, adjunctive agents are also used to enhance analgesia and limit sensitization. The importance of multimodal therapy in thoracic ERAS lies in its ability to preserve patient wakefulness, reduce nausea and sedation, and facilitate participation in breathing exercises and ambulation. When pain controlled without excessive opioid exposure, patients are more likely to breathe deeply, clear secretions effectively, and tolerate activity in the early postoperative period, all of which contribute to fewer pulmonary complications and faster recovery (30).

Early mobilization and respiratory physiotherapy are inseparable from effective analgesia and together form a major pillar of thoracic ERAS care. Once pain is adequately controlled, patients should be encouraged to sit upright, stand, and begin walking as early as clinically feasible. Early movement improves ventilation-perfusion matching, enhances secretion clearance, stimulates circulation, and reduces the risk of venous thromboembolism and muscle deconditioning. At the same time, respiratory physiotherapy including deep breathing exercises, supported coughing, inspiratory training, and structured pulmonary rehabilitation techniques helps re-expand dependent lung regions and lowers the risk of atelectasis after thoracotomy. These interventions are particularly important in thoracic patients, who often have reduced preoperative pulmonary reserve and are vulnerable to rapid respiratory decline. In the ERAS model, the combination of optimized analgesia, targeted physiotherapy, and early ambulation transforms postoperative care from passive observation into active recovery support, leading to shorter hospitalization and improved functional outcomes (31).

**Mobilization, Nutrition, and Complication Prevention**

Early mobilization and respiratory physiotherapy are essential components of Enhanced Recovery After Surgery (ERAS) after thoracotomy because they directly target the pulmonary dysfunction that commonly follows major chest surgery. Thoracotomy causes pain, splinting, reduced inspiratory capacity, and impaired cough, all of which predispose patients to secretion retention and collapse of dependent lung regions. For this reason, postoperative recovery must include structured interventions that restore ventilation and physical activity as early as possible. Respiratory physiotherapy through deep breathing exercises, supported coughing, inspiratory expansion techniques, and airway clearance strategies helps maintain alveolar recruitment and improves mucus elimination. When these measures are combined with upright positioning and early ambulation, the risk of postoperative pulmonary complications can be significantly reduced. Mobilization also counteracts muscle deconditioning and supports a faster return to baseline function, making it one of the most practical and effective elements of ERAS-based care in the ICU and surgical ward (32).

Breathing exercises and supervised physiotherapy are particularly important in reducing the incidence of atelectasis after thoracotomy. Following surgery, patients often avoid deep inspiration because of pain and chest wall restriction, resulting in hypoventilation and progressive loss of lung volume. Targeted respiratory exercises can reverse this process by promoting sustained lung expansion and improving inspiratory muscle performance. Walking early after surgery further enhances diaphragmatic movement, improves ventilation-perfusion matching, and stimulates more effective coughing and secretion clearance. In addition, ambulation reduces the harmful effects of prolonged bed rest, including reduced functional capacity, venous stasis, and increased dependence on supportive care. Within the ERAS framework, early mobilization is not an optional rehabilitation step but a priority intervention that should begin as soon as hemodynamic and respiratory conditions allow (33).

Nutritional support in the ICU is another major determinant of recovery after thoracotomy. Major thoracic surgery induces a catabolic stress response that increases energy expenditure, accelerates protein breakdown, and contributes to loss of skeletal muscle mass if nutritional needs not addressed early. Timely nutritional therapy helps preserve immune competence, supports wound healing, and maintains respiratory muscle strength, all of which are particularly relevant in critically ill postoperative patients. Current ERAS-based critical care practice favors early nutritional assessment and prompt initiation of feeding when clinically feasible. Caloric delivery individualized according to metabolic demand, while protein provision should be sufficient to limit lean body mass loss and support recovery. This is especially important in patients with malignancy, preexisting malnutrition, or prolonged ICU stays, as these factors amplify postoperative nutritional vulnerability (34).

Enteral nutrition is generally preferred over parenteral nutrition in postoperative thoracic ICU patients because it helps preserve gastrointestinal integrity, supports gut-associated immune function, and is associated with fewer infectious complications when the gastrointestinal tract is usable. Early enteral feeding also aligns with ERAS principles by reducing the adverse consequences of prolonged fasting and promoting more physiological recovery. Parenteral nutrition remains an important option when enteral feeding is contraindicated, poorly tolerated, or insufficient to meet nutritional targets, but it usually considered a secondary strategy rather than the first-line approach. Careful monitoring of tolerance, glucose balance, and electrolyte status is essential regardless of the route selected. The aim is to provide adequate nutritional support without causing aspiration risk, overfeeding, or metabolic complications that could compromise respiratory or systemic recovery (35).

Prevention of post-thoracotomy complications requires the integration of all these measures into a coherent ICU pathway. Pneumonia and atelectasis reduced through effective pain control, lung expansion therapy, secretion management, and early mobilization. Acute respiratory failure prevented by close monitoring, timely respiratory support, and avoidance of fluid overload. Thromboembolism prophylaxis should combine pharmacologic prevention, when not contraindicated, with mobilization and mechanical measures as appropriate. Surgical site infection risk lowered through meticulous wound care, glycemic control, and adherence to perioperative infection-prevention practices. In ERAS-guided thoracic care, complication prevention not based on isolated interventions but on a coordinated strategy that preserves respiratory function, supports metabolism, and promotes active recovery from the earliest postoperative stage (36).

**Clinical Outcomes and Implementation Challenges**

Enhanced Recovery after Surgery (ERAS) pathways have increasingly demonstrated meaningful clinical benefits in patients undergoing thoracotomy, particularly when perioperative elements applied consistently across preoperative, intraoperative, and postoperative phases. One of the most frequently reported outcomes is reduction in length of stay, including shorter intensive care utilization and earlier transfer to lower-acuity settings. These improvements attributed to better pain control, earlier mobilization, fewer pulmonary complications, and efficient progression through postoperative milestones. In thoracotomy patients, whose recovery often delayed by severe pain and respiratory dysfunction, ERAS can help transform postoperative care from a reactive model to a proactive one. As a result, patients may achieve earlier extubation, improved functional recovery, and predictable discharge planning without compromising safety (37).

A major advantage of ERAS in thoracic surgery is its association with reduced postoperative morbidity. Studies have shown that structured recovery pathways may lower the incidence of pulmonary complications, decrease the burden of opioid-related adverse effects, and reduce the frequency of delayed mobilization and nutritional deterioration. Because thoracotomy patients are particularly vulnerable to pneumonia, atelectasis, and respiratory failure, the cumulative effect of optimized analgesia, respiratory physiotherapy, conservative fluid management, and early ambulation is highly relevant. These strategies also contribute to better preservation of physiological reserve during the immediate postoperative period. Importantly, improved outcomes are rarely due to a single intervention; rather, they emerge from

coordinated implementation of multiple evidence-based practices that reinforce one another throughout recovery (38).

Beyond traditional clinical endpoints, ERAS may also improve patient-centered outcomes such as perceived recovery, physical independence, and postoperative quality of life. Thoracotomy often followed by prolonged fatigue, pain-related limitation, and delayed return to normal daily activity. By reducing the intensity of postoperative dysfunction and encouraging earlier restoration of movement, nutrition, and self-care, ERAS pathways may enhance both short-term experience and medium-term functional outcomes. Better symptom control and earlier engagement in rehabilitation can help patients regain confidence and autonomy sooner after surgery. Although quality-of-life measurement varies across studies, the overall trend suggests that recovery pathways emphasizing comfort, education, and active rehabilitation provide benefits that extend beyond simple hospital metrics (39).

Economic impact is another important dimension of ERAS implementation. Reduced ICU stay, fewer complications, earlier ambulation, and shorter overall hospitalization can translate into lower treatment costs and efficient use of healthcare resources. These effects are especially relevant in thoracic surgery, where intensive monitoring, postoperative respiratory support, and complication management can be resource-intensive. In addition, improved coordination of care may decrease unnecessary variation in practice and enhance workflow efficiency among surgical, anesthetic, nursing, and rehabilitation teams. From a systems perspective, ERAS offers not only a strategy for improving outcomes but also a framework for promoting value-based perioperative care in high-acuity surgical populations (40).

Despite these advantages, implementation of ERAS in the ICU after thoracotomy remains challenging. One major limitation is variability in protocol design and adherence across institutions. Differences in surgical technique, anesthetic practice, local staffing, and postoperative monitoring capacity can make standardization difficult. Resource limitations further complicate implementation, particularly in settings with limited access to specialized pain services, physiotherapy, nutritional support, or structured multidisciplinary pathways. In addition, critically ill thoracic patients often present with complex comorbidities, severe respiratory compromise, or postoperative instability that may limit the feasibility of certain ERAS elements such as very early mobilization or rapid advancement of feeding. These realities do not negate the value of ERAS, but they highlight the need for flexible, context-sensitive application. Future progress will depend on protocol refinement, stronger implementation strategies, and adaptation of ERAS principles to the needs of high-risk ICU populations while preserving the core goal of safer, faster, and more functional recovery after thoracotomy (41).

## Conclusion

ERAS has become a valuable framework for improving recovery after thoracotomy in the ICU. By integrating preoperative optimization, precise intraoperative management, effective analgesia, early mobilization, respiratory support, and nutritional care, ERAS can reduce complications and accelerate functional recovery. Although implementation remains challenging in critically ill patients, a multidisciplinary and protocol-driven approach offers substantial potential to improve both clinical outcomes and quality of care.

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## Conflicts of interest

The authors declare that they have no competing interests.

## Disclosure Statement

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## Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

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