Review Article on Prolonged Air Leak after Lung Surgery: Prediction, Prevention and Management

Enhanced recovery after surgery and chest tube management

Tim J. P. Batchelor^

Barts Thorax Centre, St. Bartholomew's Hospital, West Smithfield, London, UK

Correspondence to: Tim J. P. Batchelor. Barts Thorax Centre, St. Bartholomew's Hospital, West Smithfield, London EC1A 7BE, UK. Email: tim.batchelor@nhs.net.

Abstract: This review documents the relationships between enhanced recovery after surgery (ERAS) pathways, chest tube management and patient outcomes following lung resection surgery. ERAS pathways have been introduced to mitigate the harmful stress response that occurs following all major surgery, including lung resection. Improvements to the entire patient pathway, from the preoperative admission clinic through to discharge and beyond, can have additive or synergistic effects and result in improved patient outcomes, reduced length of stay and lower costs. At the same time, there are some key care elements that appear to be more important than others. In the postoperative period, early removal of chest tubes, early mobilization, and limited use of opioids are all independently important factors. These elements of care are all intertwined. Therefore, a focus on proactive chest tube management with the abandonment of conservative chest tube strategies should be a focus of postoperative ERAS pathways. This can be achieved with single tubes, no routine suction, the use of digital drainage systems, and removal of tubes even in the presence of relatively high serous pleural fluid outputs. The goals of early mobilization and opioid-sparing analgesia are more readily achieved once a chest tube has been removed. The result is superior patient outcomes with significantly fewer complications.

Keywords: Enhanced recovery after surgery (ERAS); enhanced recovery; chest drain; perioperative care; lung cancer surgery

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Introduction

The Enhanced Recovery After Surgery (ERAS) Society/European Society of Thoracic Surgeons (ESTS) guidelines for enhanced recovery after lung surgery have 45 recommendations covering 21 areas of peri-operative care (1). While there has been criticism that these guidelines are too complicated, they have nevertheless been welcomed and have been validated (2). Some have questioned whether so many recommendations are required when it may be more attractive to focus on just a few key care elements necessary for improved outcomes (3). The reality is that both approaches (the "aggregation of marginal gains" approach and the "key care elements" approach) are true. Two studies have demonstrated that increasing compliance with an ERAS pathway after lung cancer surgery is associated with less morbidity and a lower likelihood of delayed discharge (4,5). At the same time, several care elements have been identified as independent predictors of better outcomes: carbohydrate loading; a video-assisted thoracic surgery (VATS) approach; early mobilization; early cessation of opioids; and, in the context of this paper, early chest tube removal.

Chest tubes cause pain and inhibit pulmonary function, irrespective of the surgical approach (6). Immobility and its deleterious effects are often seen as a consequence of conservative chest tube management strategies. Proactive chest tube management is therefore an integral and important part of ERAS pathways and crucial to optimizing outcomes, influencing both the speed of recovery and the length of hospital stay. Other ERAS care elements are intertwined with chest tube management and include

^ ORCID: 0000-0003-4103-6061.

pain relief (and opioid management), postoperative nausea and vomiting (PONV) control and early mobilization. This review aims to examine the relationships between ERAS pathways, chest tube management and patient outcomes following routine lung resection surgery and applies to virtually all cases of sublobar and lobar resection. Pneumonectomy, the complex pleural space and massive air leak/surgical emphysema may require a more tailored approach.

Enhanced recovery after surgery

Lung cancer surgery is a traumatic surgical intervention, causing damage to nerve, muscle and bone. It also involves the removal of functional lung tissue. The extent of lung resection is an important factor in determining the risk of postoperative morbidity and mortality and central to all guidelines on determining fitness for surgery. In common with other major surgeries, there is an associated homeostatic disturbance and a surgical stress response. A neuro-humoral response occurs following activation of the hypothalamic-pituitary-adrenal axis and the sympathetic nervous system. It is characterized by a rise in circulating glucocorticoids, catecholamines and glucagon, and it is mediated by afferent nerve impulses and cytokines released from the surgical site. The result is whole body catabolism, increased oxygen demand and hyperglycemia (7,8). Hyperglycemia itself develops because of a multitude of factors including insulin resistance. The consequences of these processes can be harmful. Catabolism is associated with loss of protein (e.g., from muscle) and cellular dysfunction, while insulin resistance is associated with impaired cellular function at the injury site (9).

ERAS pathways aim to mitigate this harmful stress response and focus on the quality of a patient's recovery (10). Multiple evidence-based interventions or care elements are introduced through the entire patient pathway, covering the four key phases of a patient's journey: pre-admission, admission, intra-operative and post-operative. At the same time, interventions that are dogmatic, unnecessary, or harmful (e.g., fasting, excessive opioids, enforced immobility) are removed from the pathway. For example, carbohydrate loading can reduce insulin resistance while optimal pain control can reduce the endocrine stress response. The net result should be a quicker recovery from surgery, a more rapid restoration of normal function and a reduction in complications. This is particularly important for patients undergoing lung cancer surgery.

The combination of surgical trauma and resection of vital functional tissue, often against a background of deconditioning, chronic obstructive pulmonary disease (COPD) and other comorbidities, means that lobectomy for lung cancer is associated with significant complications in up to 44% of cases (11). Complications lead to delayed recovery, poorer long-term outcomes, and higher costs. Long-term survival is also reduced, and this effect is more pronounced for more serious complications (12). Quality of life and functional decline appear to be affected by the length of hospital stay rather than the complication itself (13).

While fast-track protocols have previously been described in thoracic surgery and appeared to show an improvement in patient outcomes, specific ERAS pathways for lung cancer surgery have now been published (2,4,14-18) and consistently demonstrate improvements in complication rates, length of stay, readmission rates and costs. A recent meta-analysis has confirmed the benefits of ERAS pathways in this group of patients (19). There are also demonstrable benefits in other metrics following surgery, including opioid use in hospital and subsequently following discharge (16,18). This has clear implications for the rising opioid epidemic seen in many countries (20).

Chest tube management

A chest tube or drain is necessary for most cases following lung resection. It is a "necessary evil". They are painful and can limit mobility. Pain is both musculoskeletal and neuropathic in nature. "Drain pain" can have several knock-on effects:

(I) Inadequate provision of analgesia may exacerbate an already compromised respiratory status and respiratory failure can occur due to painful splinting of the chest. Furthermore, an inadequate cough response can cause retained secretions and ultimately pneumonia.

(II) Increased opioid requirements can cause gut stasis and constipation, PONV, sedation and suppression of ventilation.

(III) Pain and the side effects of opioid analgesia can also contribute to immobility.

Immobility and its deleterious effects may be the result of "drain pain" and/or the side effects of the analgesics required to control the pain. Alternatively, conservative chest tube management strategies such as routine wall suction applied to an underwater seal may keep a patient

Table 1 Recommendations for chest tube management following routine lung resection in an ERAS pathway

Care element	Recommendation
Number of chest tubes	1 rather than 2
Chest tube size	No recommendation
Routine application of suction	Not required as there appears to be no advantage
Digital drainage system	Recommended as reduces inter-observer variability

ERAS, enhanced recovery after surgery.

anchored to the bedside.

Chest tube management should be approached in an evidence-based way and conservative removal strategies abandoned (see *Table 1*). This should facilitate early chest tube removal, better pain and PONV control, improved mobility, and better patient outcomes.

Number of chest tubes

Historically, two chest tubes have been used to drain the pleural space after lobectomy, one at the apex to drain air and another at the base to drain fluid. Several randomized trials and a recent meta-analysis have demonstrated that the use of a single chest tube is safe and effective. A single chest tube is associated with less pain and reduced chest tube duration without increasing the risk of recurrent effusion (21-23). For routine cases, therefore, a single tube should be used instead of two after anatomical lung resection.

Chest tube size

There are no good studies analyzing the impact of chest tube size after lung resection. Trials on the treatment of thoracic empyema (24), and a randomized trial in malignant pleural effusion (25), have demonstrated that using small caliber chest tubes is associated with less pain while remaining as effective as larger caliber tubes. While it may be intuitive to recommend small caliber chest tubes to reduce drain pain after lung resection, given that many thoracic surgeons routinely use tubes with a caliber of 24 F or less, it is difficult to make a firm recommendation in the absence of direct evidence.

Application of suction

In theory, external suction applied to a chest tube promotes the apposition of pleural surfaces. This was thought to be important in facilitating the sealing of air leaks or ensuring adequate drainage of larger air leaks. However, concerns have been raised that bedside suction limits patient mobilization (by anchoring the patient to the bed space) and may actually potentiate air leak duration. Furthermore, the application of suction effects the Starling forces experienced across the pleural membranes and will lead to an increase in pleural fluid production (26).

A number of randomized clinical trials (RCTs) have been conducted comparing suction versus no suction in the postoperative period. Several systematic reviews have subsequently addressed whether external suction or its absence has a beneficial effect on clinical outcomes (27-30). The evidence is conflicting. There does not appear to be an advantage to the routine application of external suction (typically –20 cmH_2O or –2 kPa) in terms of shortening the duration of air leak, chest drainage or length of stay. Since wall suction limits patient mobility, its routine application should therefore be avoided.

The era of digital chest drainage systems has allowed even lower levels of suction to be applied than can be achieved with a standard underwater seal. It should be appreciated that an underwater seal does not generate "no suction". An underwater seal will generate suction at the tip of the chest tube by virtue of the weight of the column of fluid in the drainage system (26), and it has been shown that the intrapleural pressure following lobectomy managed with an underwater seal varies between –13 and –20 cmH_2O (31). One RCT has demonstrated that setting the level of suction to –2 cmH_2O (–0.2 kPa) using a digital drainage device immediately after VATS lobectomy significantly reduces air leak duration, pleural fluid production and overall length of hospital stay (32). While these results are impressive and back up previous studies that increasing suction potentiates air leaks and increases pleural fluid production, further studies are required to corroborate these findings.

Digital drainage systems

Digital drainage systems are now widely available and would appear to have several advantages over a traditional

Table 2 Recommendations for chest tube removal following routine lung resection

Chest tube drainage	Recommendation for tube removal
Pleural fluid drainage	<450–500 mL/24 hours
Air leak	No air leak in previous 6–12 hours
Nature of fluid	Serous/hemoserous (no evidence of chyle, pus or active bleeding)

water seal. They are light, compact and have a built-in suction pump with the ability to maintain a regulated suction pressure. As such, they do not need to be attached to bedside wall suction should suction be required, favoring early patient mobilization. They are also able to objectively quantify the volume of air leak and pleural fluid production. The ability to store information and display trends of air leak and fluid output over time allows more informed decision-making about chest tube removal and reduces inter-observer and clinical practice variability (33).

A meta-analysis has compared digital and conventional chest drainage systems (34). Overall, digital systems are associated with reduced chest tube time, air leak duration, length of stay and costs, potentially as a consequence of more informed and less variable decision-making. Therefore, the use of digital drainage systems is to be recommended as they remove variability in clinical decision-making and facilitate early mobilization while positively influencing patient outcomes. There is also evidence that "ultralow" levels of suction (i.e., levels of suction not achievable with an underwater seal where the height of the column of fluid will determine the negative pressure exerted on the pleural space) reduce air leak duration and pleural fluid output as described in the previous section (32). These very low levels of suction can only be achieved with digital drainage systems.

Pleural fluid drainage

Tradition dictates that the amount of pleural fluid output observed daily determines the timing of chest tube removal, assuming the absence of air leak, chyle leak, bleeding or the development of empyema. Many surgeons have accepted low and arbitrary cut off values (typically 200 mL/day) as a threshold only below which it is safe to remove a chest tube. More aggressive chest tube removal strategies within fast-track programs have been shown to be safe. In one study, a non-chylous fluid threshold of 450 mL/day after thoracotomy was associated with only a 0.55% readmission rate for recurrent symptomatic pleural effusion (35). In another, a higher threshold of 500 mL/day following VATS lobectomy resulted in an incidence of clinically relevant recurrent effusions (needing drainage or aspiration) in only 2.8% of patients (36). Therefore, it appears to be safe to remove chest tubes if the daily effusion is of a higher volume than traditionally accepted (up to 450 mL/24 hours) so long as there is no evidence of air leak, chyle, pus or active bleeding. Some surgeons are happy to tolerate even higher levels of pleural fluid output than this or disregard pleural fluid output volumes altogether, but currently we do not have the evidence to support this.

Timing of chest tube removal

Chest tubes often remain *in situ* for long periods of time, particularly after anatomical lung resection, due to anxieties about early removal and the need for chest tube reinsertion. Indeed, the need for reinsertion of a chest tube could be perceived as a failure in management. However, the evidence around chest tube management suggests that more aggressive strategies are associated with better patient outcomes. Therefore, a chest tube can be removed when there is no air leak (typically within the last 6–12 hours) with pleural fluid output of <450–500 mL in the last 24 hours providing there is no evidence of chyle, pus or active bleeding (see *Table 2*). Consequently, tube removal on the first postoperative day is reasonable and will almost certainly result in better objective outcomes (e.g., length of stay, opioid use) as well as patient-reported outcomes (pain, quality of life, overall postoperative experience). Indeed, this has been taken a step further with safe chest tube removal on day 0 following VATS anatomical lung resection so long as there was no air leak (37). This resulted in significantly less opioid use and a shorter length of stay.

Is a chest tube required?

Chest tubes are placed at the end of a thoracic procedure to drain air, pleural fluid and blood and to facilitate re-expansion of the operated lung. There has been interest in

omitting a chest tube following some VATS cases, usually lung biopsy, wedge resection or mediastinal surgery (e.g., thymectomy). In theory, this should have a beneficial effect on the patient as there will be an absence of drain pain. Two recent systematic reviews and meta-analyses would seem to confirm this (38,39). Patients without tubes experienced less pain and shorter length of stay but were more likely to require chest tube insertion or thoracentesis. Some of the studies included were observational with risk of bias. Consequently, although it is likely the omission of chest tubes in selected cases will be beneficial, further trials are required to better define this patient group.

Early mobilization

After thoracic surgery, the presence of a chest tube is an important barrier to early mobilisation. Other barriers, including urinary catheters and intravenous fluids, also anchor patients to their bed space. Drain pain with inadequate pain and nausea control disempowers and deters patients and limits their ability to mobilise.

Reduced mobility and activity results in physical deconditioning, diminished muscle mass and functional decline. This leads to an increased risk of complications including atelectasis, pneumonia and VTE. This risk is magnified by the stress of surgery (40). Early mobilisation is an intuitive component of ERAS and is meant to counteract the harmful effects of immobility.

Systematic reviews have failed to demonstrate benefits of early mobilisation on postoperative outcomes, mainly due to the poor quality of included studies and conflicting results (41,42). Nevertheless, postoperative immobility is reported as a significant risk factor for ERAS deviation and prolonged length of stay following colorectal surgery (43), and it is associated with increased morbidity and length of stay following lung cancer resection (4,5). One particular ERAS protocol following VATS lobectomy has had impressive results by focusing on early and aggressive mobilisation strategies, including ambulation within one hour of surgery (15).

Patients should be mobilised as soon as possible, ideally on the day of surgery and certainly within 24 hours of surgery, to avoid the deleterious effects of bed rest. The ongoing presence of a chest tube can deter patients from mobilising and so should be removed as soon as possible. Other barriers to mobilization, such as inadequate pain and nausea control or the presence of urinary catheters and intravenous fluids, can be mitigated using ERAS protocols.

Pain relief

Postoperative pain is often severe and can be due to peripheral nerve damage, muscle injury, fractured ribs, or injury to the intercostal nerves. Intercostal nerve injury appears to be the most important factor in its pathogenesis (44). Indwelling chest tubes may cause ongoing irritation of the pleura or intercostal bundles.

An enhanced recovery pathway for thoracic surgery must combine multiple interventions including a standardized multimodal analgesic strategy that should allow for early mobilization to reduce the risk of pulmonary complications. Other important interventions include patient education, minimally invasive surgery and early chest tube removal.

Pain relief pathways should include multimodal enteral and parenteral analgesia with regional analgesia or local anesthetic techniques while attempting to avoid opioids and their side effects. Recommendations following lung cancer surgery include regional anesthesia (preferably without thoracic epidural), acetaminophen in combination with non-steroidal anti-inflammatory drugs, glucocorticoids and ketamine (1). Other potential adjuncts, such as liposomal bupivacaine and the prophylactic use of gabapentinoids, are subject to ongoing studies. Opioids have well-documented acute effects (nausea, constipation, sedation, depressed ventilation and suppression of coughing) which may affect a patient's ability to achieve ERAS targets such as PONV control, early mobilization and a quick return to oral diet. In the longer-term, they may adversely affect cancer survival (20).

Adoption of ERAS pathways has been shown to reduce the need for opioids both in-hospital (16,18) and following discharge (16). Furthermore, early removal of chest tubes and subsequent early omission of opioids are independently associated with better patient outcomes within an ERAS pathway (5).

Conclusions

Early mobilization and opioid-sparing analgesia are important goals of ERAS pathways. The management of chest tubes following lung resection is intertwined with these goals and other ERAS care elements. Chest tubes are painful and inhibit the functional recovery of a patient. According to ERAS principles, chest tube management should be approached in an evidence-based way and conservative removal strategies abandoned. Patients are less likely to have pain, immobility or opioid-induced side

effects such as nausea. This results in improved outcomes including fewer complications, a shorter length of stay and a better overall recovery.

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