Review Article

Optimizing postoperative care protocols in thoracic surgery: best evidence and new technology

Daniel G. French, Michael Dilena, Simon LaPlante, Farid Shamji, Sudhir Sundaresan, James Villeneuve, Andrew Seely, Donna Maziak, Sebastien Gilbert

Division of Thoracic Surgery, University of Ottawa, The Ottawa Hospital—General Campus, Ottawa, ON, Canada

Contributions: (I) Conception and design: DG French, S Gilbert; (II) Administrative support: DG French, S Gilbert; (III) Provision of study materials or patients: DG French, S LaPlante, M Dilena, S Gilbert; (IV) Collection and assembly of data: All authors; (V) Data analysis and interpretation: DG French, S LaPlante, M Dilena, S Gilbert; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Sebastien Gilbert, MD. Associate Professor of Surgery, Chief of Division of Thoracic Surgery, The Ottawa Hospital, General Campus Suite 6363, 501 Smyth Road, Ottawa, ON, K1H 8L6, Canada. Email: sgilbert@toh.on.ca.

Abstract: Postoperative clinical pathways have been shown to improve postoperative care and decrease length of stay in hospital. In thoracic surgery there is a need to develop chest tube management pathways. This paper considers four aspects of chest tube management: (I) appraising the role of chest X-rays in the management of lung resection patients with chest drains; (II) selecting of a fluid output threshold below which chest tubes can be removed safely; (III) deciding whether suction should be applied to chest tubes; (IV) and selecting the safest method for chest tube removal. There is evidence that routine use of chest X-rays does not influence the management of chest tubes. There is a lack of consensus on the highest fluid output threshold below which chest tubes can be safely removed. The optimal use of negative intra-pleural pressure has not yet been established despite multiple randomized controlled trials and meta-analyses. When attempting to improve efficiency in the management of chest tubes, evidence in support of drain removal without a trial of water seal should be considered. Inconsistencies in the interpretation of air leaks and in chest tube management are likely contributors to the conflicting results found in the literature. New digital pleural drainage systems, which provide a more objective air leak assessment and can record air leak trend over time, will likely contribute to the development of new evidence-based guidelines. Technology should be combined with continued efforts to standardize care, create clinical pathways, and analyze their impact on postoperative outcomes.

Keywords: Thoracic surgery clinical pathways; chest drain protocol; digital pleural drains; chest tube management

Submitted Oct 08, 2015. Accepted for publication Oct 10, 2015.
doi: 10.3978/j.issn.2072-1439.2015.10.67
View this article at: http://dx.doi.org/10.3978/j.issn.2072-1439.2015.10.67

Introduction

Postoperative clinical pathways reduce length of hospital stay and increase patient satisfaction without increasing adverse events (1-7). Colorectal surgeons lead the way by implementing clinical pathways focusing on early resumption of oral diet and ambulation, which was countercurrent to previously established practice. Similar success with postoperative clinical pathways has been achieved in head and neck surgery with decreased pulmonary complications and shorter length of stay (2). A survey of Canadian cardiac surgery intensive care units found 26 of 28 institutions used clinical pathways (8). There have also been efforts to standardized and streamline the care of patients who undergo lung resection (3-7). More recently, interest in optimizing the care of lung resection patients has been rekindled by the introduction of digital pleural drainage technology into clinical practice.

Clinical pathways

Postoperative clinical pathways have been the backbone of fast-track programs in thoracic surgery. Investigators from Europe reported on the implementation of a fast-track pulmonary resection which included early feeding and ambulation, multimodal analgesia and early removal of chest tubes (3). Although they did not find a significant difference in length of stay, they reported a higher level of patient satisfaction. In Asia, investigators have succeeded in decreasing post-operative delirium, decreasing hospital stay, and lowering health care costs through preoperative identification of high risk patients and successful implementation of pulmonary resection care pathways (4,5,9). Improvements have also been achieved in North American centers using a similar approach (6).

Our institutional pathways and protocols are primarily aimed at standardization of postoperative feeding, blood work, pain management, respiratory care, and allied health team involvement, such as, physiotherapy, respiratory therapy and social work to decrease length of stay. These general aspects of post-surgical care probably enhance patient experience. However, by including more specific aspects of care following lung resection (e.g., chest tube management), the clinical pathways could potentially have a greater impact on recovery and length of hospitalization.

Review of published literature indicates that recommendations for the management of chest tubes are inconsistent (10-12). Clinical decisions are often based on institutional practices, physician training, and preferences developed from experience (13). The ideal chest tube management algorithm has yet to be determined. The timing and parameters under which chest tubes can safely be removed, the best method of removal, and the need for routine chest X-rays are still the subject of debate. Optimizing the duration of chest tube drainage after lung resection is a critical component of improved quality of care as both premature and delayed chest tube removal may lead to increased hospital stay and costs (14-16).

With the implementation for any protocol, outcomes must be continuously measured to allow for an iterative design process leading to optimal protocols meeting the needs of the patients in a particular institutional setting. Successful implementation of care pathways should include mechanisms to monitor compliance. Deviations from the expected chest tube drainage period should be reviewed to understand its feasibility and safety profile, and to allow for data-driven optimization. We have demonstrated the effectiveness of this strategy in the management of postoperative adverse events, which are prospectively recorded and reviewed on a monthly basis at our institution (17,18).

In the following sections, we will discuss four main aspects of developing a chest tube management protocol: (I) appraising the role of chest X-rays in the management of lung resection patients with chest drains; (II) selecting of a fluid output threshold below which chest tubes can be removed safely; (III) deciding whether suction should be applied to chest tubes; (IV) and developing a safe approach to chest tube removal.

Role of postoperative chest X-rays in chest tube management

The use of daily chest X-rays is often part of routine clinical practice in the postoperative management of lung resection patients. In a recent meta-analysis, including 3,649 patients, the use of routine chest X-rays was compared to selective chest X-rays in showing a mean reduction of 3.15 chest X-rays per patient ($P<0.01$) without any significant increase in mortality, intensive care unit stay or hospital length of stay (19). As part of a prospective randomized trial comparing analog and digital pleural drainage devices completed at our center, 176 patients were monitored prospectively after anatomic lung resection for lung cancer (20). Data on the use of chest X-rays was documented as an ancillary outcome. All chest X-rays were recorded and classified as normal, radiologically abnormal, or clinically abnormal. A chest X-rays was deemed radiologically abnormal when at least one of the following minor abnormalities was present: small pneumothorax (<30%), minimal subcutaneous emphysema that is not palpable and can only be seen on chest X-ray, or a small pleural effusion causing minimal blunting of the costophrenic angle. If the latter findings were more severe or if there was any other significant finding (e.g., lobar atelectasis) then the chest X-ray was labeled clinically abnormal, regardless of the patient's clinical status. The total number of postoperative chest X-rays performed was 1,550 or 1.5 per patient-day of hospitalization. Of the 176 first postoperative radiographs performed in the recovery room, the vast majority were either normal (79/176; 45%) or radiologically abnormal (87/176; 49%). Of the ten patients (6.0%) who had a clinically abnormal first postoperative chest X-ray, 6 (3.4%) had more than minimal subcutaneous emphysema and 4 (2.6%) had a pneumothorax larger than 30%. All of these patients were observed with the exception of one patient

(1/176; 0.5%) for whom chest tube suction was increased in response to the X-ray findings. None of the patients with a clinically abnormal first postoperative chest X-ray developed complications that could have been prevented using the radiologic data. Of the additional 1,374 postoperative chest radiographs performed outside the recovery room, an additional 25% (348/1,374) were normal and 52% (710/1,374) were reported as radiologically abnormal. In other words, more than 77% of routine postoperative chest X-rays showed findings that would be unlikely to influence clinical decisions regarding chest tube management following lung resection. Chest X-rays may be associated with pain or discomfort as a result of patient positioning for image acquisition or, in some cases, during transfer to the radiology department for studies not performed at the bedside. At our institution, this proportion of normal or near-normal X-rays represents an additional unnecessary time and expense. Although we cannot make definitive recommendations based on these results, our institutional data questions the clinical usefulness and cost-effectiveness of routine chest X-rays in the management of patients who are recovering from pulmonary resection. This aspect of patient care should be scrutinized in future efforts to optimize health care efficiency while maintaining high standards of patient safety.

Fluid output threshold for safe chest tube removal

Another common point of contention in the management of chest tubes is the fluid output threshold below which removal is considered appropriate. A safe threshold should minimize the probability of chest tube reinsertion for symptomatic fluid re-accumulation after chest tube removal. *Table 1* summarizes the recent literature on safe drainage thresholds to remove chest drains after pulmonary resection. Most recommendations found in the literature advocate the use of a fixed threshold that is independent of the size of the patient. The majority of the trials do not report sample size calculations or rigorously follow the Consolidated Standards of Reporting Trials (CONSORT) 2010 guidelines (27). Almost 15 years ago, randomized controlled trial data demonstrated safety in removing chest tubes draining less than 200 mL in 24 hours (21). The latter threshold was the highest evaluated at that time. Subsequently, non-randomized studies suggested that a much higher fluid output limit, from 400-500 mL per 24 hours, could be considered safe for chest tube removal (22,23,25). More recently, a randomized comparison of 100 *vs.* 300 mL per 24 hours found that a higher threshold was associated with a shorter hospital stay without any increase in adverse events (24). Another recent randomized trial reported that a fluid output of 300 mL per day was optimal (26). Eight of 51 patients (15.7%) of patients with a chest drain removal threshold of 450 mL required thoracentesis compared to 1 of 99 patients (1%) with a threshold of less than 300 mL per day. In reviewing the published literature on this topic, it is apparent that the 24-hour drainage threshold that is considered safe for chest tube removal has increased consistently over the past 15 years.

In attempting to drive consensus amongst surgeons, we developed an approach based on pleural fluid physiology which takes into account patient size and lymphatic flow, similar to what other investigators have previously put forth (28). From a pleural physiology standpoint, using the same pleural fluid output guidelines for a 90-kg man and a 50-kg woman does not make intuitive sense. It has been demonstrated that a patient's capacity to reabsorb pleural fluid, and avoid pleural fluid accumulation, can be estimated as a fraction of whole-body lymphatic flow (≈1 mL/kg/hour) which is dependent on body weight (29). The maximum pleural lymphatic flow that can occur without overwhelming pleural lymphatic reabsorption is approximately 40% of whole-body lymphatic flow. After lung surgery, it is reasonable to expect a disruption in pleural fluid circulation as a result of parenchymal resection and the inflammatory response associated with surgical trauma. For the purposes of carrying out our aforementioned prospective randomized trial, we agreed on a conservative fluid output guideline of 15% of daily whole-body lymphatic flow as a safe threshold for chest tube removal. Of the 176 study participants, 135 underwent a lobectomy and 41 had a segmentectomy or a wedge resection. The proportion of patients who had VATS resection was similar between these two groups [98/135 (73%) *vs.* 26/41 (63%); P=0.33]. The average 24-hour fluid output was statistically equivalent for lobar and sublobar resections (238±132 *vs.* 197±122 mL; P=0.08). However, in keeping with the hypothesis that surgical trauma disrupts pleural fluid reabsorption, thoracoscopic resection was associated with a significantly lower average daily fluid output than the open approach for both lobar resections (208±108 *vs.* 319±154 mL; P<0.01) and sublobar resections (153±91 *vs.* 274±134 mL; P<0.01). In this prospective cohort, a fixed volume threshold of 400 mL per 24 hours would have represented a percentage of whole-body lymphatic flow

Table 1 Literature on safe drainage thresholds for removal of a chest tube

Publication	Study design and population	Results
Younes *et al.*, 2002 (21)	Prospective RCT; 139 patients randomized after a surgical procedure to removal of chest drain at one of three thresholds; 44 patients: <100 mL per 24 hours, 58 patients: <150 mL per 24 hours, 37 patients: <200 mL per 24 hours	Median drainage time was 3.5, 3 and 3 days for a threshold of <100, <150 and <200 mL per 24 hours, respectively (P=0.174); Median length of stay in hospital was 4, 3 and 3 days for a threshold of <100, <150 and <200 mL per 24 hours, respectively (P=0.098); Incidence of radiologic reaccumulation was 9.1%, 13.1% and 5.4% for a threshold of <100, <150 and <200 mL per 24 hours, respectively (P=0.837); Incidence of thoracentesis was 2.3%, 0.8% and 2.7%, for a threshold of <100, <150 and <200 mL per 24 hours, respectively (P=0.970); Favored less than 200 mL per 24 hours
Cerfolio *et al.*, 2008 (22)	Retrospective cohort study of a prospective database and prospective algorithm from one surgeon over 10 years; 2,077 patients; Conditions to remove chest drains: no air leak, nonchylous drainage and <450 mL per 24 hours present	A total of 11 patients (0.55%) were re-admitted for symptoms related to recurrent effusion; Favored less than 450 mL per 24 hours
Göttgens *et al.*, 2011 (23)	Retrospective cohort study; 116 patients undergoing lobectomies; Conditions to remove chest drains: no air leak, nonchylous drainage and <400 mL per 24 hours present	Median duration of chest tube drainage: 1.0 day; 58.8% and 82.5% of patients had chest drain removed within 24 hours and 48 hours, respectively; Median length of stay: 4 days; No complications related to pleural effusion are reported; Favored less than 400 mL per 24 hours
Zhang *et al.*, 2014 (24)	Prospective randomized single-blinded control study; 70 consecutive patients undergoing lobectomy were randomized removal of chest drain at one of two thresholds; 29 patients: <100 mL per 24 hours, 41 patients: <300 mL per 24 hours	Median duration of chest tube drainage: 37 and 44 hours in the <100 and <300 mL per 24 hours groups, respectively (P=0.004); Median length of stay in hospital: 5 and 6 days in the <100 and <300 mL per 24 hours groups, respectively (P=0.01); Four patients (9.8%) in the <300 mL group had reaccumulation of pleural fluid compared to 0 in the <100 mL group (P=0.136); Two patients (4.9%) in the <300 mL group required thoracentesis compared to 0 patient in the <100 mL group (P=0.508); Favored less than 300 mL per 24 hours
Bjerregaard *et al.*, 2014 (25)	Prospective study; 599 patients after lobectomy; Conditions to remove chest drains: no air leak, nonchylous drainage and <500 mL per 24 hours	A total of 17 patients (2.8%) required reintervention for pleural effusion; Median duration of chest tube drainage: 2 days; Median length of stay in hospital: 4 days; Seven patients (1.2%) required readmission; Favored less than 500 mL per 24 hours
Xie *et al.*, 2015 (26)	Prospective RCT, 150 consecutive patients who underwent lobectomy randomized to removal of chest drain at one of three thresholds; 49 patients <150 mL per 24 hours, 50 patients <300 mL per 24 hours, 51 patients <450 mL per 24 hours	Mean duration of chest tube drainage: 5.4, 2.5, and 2.1 days in the <100, <300 and <450 mL per 24 hours groups, respectively (P=0.000); Mean length of stay in hospital: 7.5, 4.8, and 4.8 days in the <100, <300 and <450 mL per 24 hours groups, respectively (P=0.000); Incidence of thoracentesis: 0, 1 (2.0%) and 11 (21.6%) in the <100, <300 and <450 mL per 24 hours groups, respectively (P=0.001); Favored 300 mL per 24 hours

RCT, randomized controlled trial.

ranging from 11% to 46% [median =23%; interquartile range (IQR) =4%]. For some patients, this fixed-volume guideline would have exceeded the predicted maximum pleural reabsorption rate, and likely lead to pleural fluid accumulation. We think that using a target pleural fluid reabsorption rate, as a percentage of whole-body lymphatic flow, is best suited to variations in patient size commonly encountered in clinical practice. An increase in the selected threshold from 15% to 20% of whole-body lymphatic flow would have been associated with a range of acceptable 24-hour fluid output of 172–715 mL (median =350 mL; IQR =58 mL). In the absence of any other contraindications, the proportion of patients that would have been eligible for chest tube removal based on a 20% whole-body lymphatic flow threshold would have been: 72% on postoperative day 1, 67% on postoperative day 2, 81% on postoperative day 3, 87% on postoperative day 4, and 88% on postoperative day 5. In comparison, our selected threshold to 15% of whole-body lymphatic flow effectively reduced the proportion of patients potentially eligible for chest tube removal by 16–23% on the first 3 postoperative days. On postoperative day 4 and 5, the threshold selected (i.e., 15% or 20%) has a relatively small impact on the proportion of patients who become candidates for chest tube removal (1–6%). Analysis of our institutional data and review of the available literature suggest that, in the absence of a clinically significant air leak, it would be safe to remove all chest drains providing that the 24-hour fluid output is ≤20% of whole-body lymphatic flow (i.e., approximately 5 times the patient's weight in kilograms).

Chest tube suction versus water seal

Upon review of the evidence in support of the use of intra-pleural suction in chest tube management, it becomes clear that there is no scientific consensus. Creating guidelines is therefore challenging and, unfortunately, the door remains wide open for idiosyncrasies. *Table 2* summarizes seven randomized controlled trials and three meta-analyses comparing suction to water seal in the management of chest tubes. It should be noted that the meta-analyses were performed using data from a subset of the seven randomized trials. As summarized in a meta-analysis, all trials reviewed have significant potential for bias (11). The majority of the trials do not report sample size calculations or rigorously follow the CONSORT guidelines (27). All trials do consistently report prolonged air leak as a primary outcome but do not consistently report duration of chest tube and length of stay in hospital. Two of the seven trials and one of the three meta-analyses report an advantage to using water seal (12,30,31). One of these trials found a decrease in pneumothorax with suction in patients with a significant air leak (greater than four out of seven on an analogue scale) (30). However, four trials and two meta-analyses report no difference in incidence of prolonged air leak and duration of chest drain between water seal and suction (10,11,32,34-36). One trial compared water seal alone to a regimen of alternating suction at night with water seal during the day (33). The trial found the alternating regimen yielded a lower incidence of air leak lasting longer than 7 days, a shorter duration of chest drainage and a shorter postoperative hospital stay. This study was performed using analogue drainage device. The authors hypothesize that using suction at night allows apposition of the visceral and parietal pleura while water seal during the day allows early mobilization of the patient. New digital device provide continuous portable suction allowing patients to mobilize while maintaining negative intra-pleural pressure. Only one of seven trials used a digital drainage system to provide active physiologic pleural pressure regulation or provide active negative intra-pleural pressure regulation finding no benefit to negative intra-pleural pressures (37).

There are a few possible explanations for the conflicting evidence found in the literature with regard to the use of chest tube suction: (I) there is no cause and effect relationship between the use of suction and relevant clinical outcomes; (II) variation in chest tube management protocols introduced bias in the pooled analyses to a degree that is difficult to quantify; and (III) the analogue devices used in the trials are inaccurate and prone to inter-observer variability. Similar to other physiologic systems, it is possible that the time required for a defect in the lung parenchyma to heal may not depend on the pressure in the pleural space. Significant heterogeneity in chest tube management between studies was reported in two of the three meta-analyses (11,38). Conventional, water-sealed pleural drainage systems have been associated with poor inter-observer reliability and are deficient with regard to air leak monitoring over time. Therefore, detection and objective quantification of air leaks, especially when these are small and intermittent, can pose a significant challenge. We previously reported a poor inter-observer agreement amongst members of the surgical team when recording air leak level at the bedside after pulmonary resection (39). We demonstrated that inter-observer reliability was significantly improved with the use of digital devices. Increased adoption of this technology may generate more scientific data on the role of intra-pleural suction and assist in the development of evidence-based guidelines.

Chest tube removal

Removal of a chest tube is a very common task performed during the care of thoracic surgery patients. As part of a chest tube pathway, this task should be standardized so that all team members, including nurses and residents at various stages of training, can provide high-quality care in the removal of chest drains. A prospective randomized controlled trial reported the incidence of pneumothorax after removal of chest tubes after full expiration with a Valsalva maneuver (16%) was significantly less than removal after full inspiration with a Valsalva maneuver (32%, P=0.007) (40). Another randomized trial had previously showed no difference in the incidence of residual pneumothorax after removing chest drains with a Valsalva maneuver either at full inspiration or at full expiration (41). The phase of inhalation or exhalation is not likely as important as a Valsalva maneuver to ensure positive intrathoracic combined with rapid removal of the drain to prevent pneumothorax.

There is ongoing debate on whether a trial of water seal is required prior to removal of a chest tube. A prospective randomized study of 80 trauma patients examined the difference in outcomes between removal of pleural drains while on suction versus water seal (42). The results show that weaning from suction prior to removal prolonged chest tube drainage by an average 20 hours, and lead to an increased number of chest X-rays to monitor care.

Table 2 Literature on the use of suction and water seal after pulmonary resection

Publication	Study design and population	Results
Cerfolio *et al.*, 2001 (30)	Prospective RCT, 33 patients undergoing pulmonary resection found to have air leak on POD2 were randomized to water seal or suction at –10 cm of water; 18 patients to water seal; 15 patients to suction	A total of 12 (67%) patients in the water seal group and one (7%) patient in the suction group had resolution of air leak on POD4 on water seal; all patient in water seal group not resolving their air leak had an air leak >4 out of 7 on an analogue scale; Favored water seal
Marshall *et al.*, 2002 (31)	Prospective RCT; 68 patients undergoing pulmonary resection were prospectively randomized before surgery to water seal or suction at –20 cm of water; 34 patients to water seal; 34 patients to suction	Mean duration of air leak was 1.5 days in the water seal group and 3.27 days in the suction group (P=0.05); Mean duration of chest tube drainage was 3.33 days in the water seal group and 5.47 days in the suction group (P=0.06); Favored water seal
Brunelli *et al.*, 2004 (32)	Prospective RCT; 145 patients undergoing lobectomy with an air leak on POD1 were randomized to water seal or suction at –20 cm of water after a brief period of suction; 72 patients to water seal; 73 patients to suction	Mean duration of air leak was 6.5 days in the water seal group and 6.3 days in the suction group (P=0.9); Incidence of prolonged air leak was 27.8% in the water seal group and 30.1% in the suction group (P=0.8); Favored no difference
Brunelli *et al.*, 2005 (33)	Prospective RCT; 94 patients were randomized POD1 to water seal (24 hours a day) or water seal during the day and suction (–10 cmH_2O) at night; 47 patients to water seal; 47 patients to alternating suction	Mean duration of air leak was 4.2 days in the water seal group and 3.1 days in the alternating suction group (P=0.3); Mean duration of chest tube drainage was 8.6 days in the water seal group and 6.2 days in the suction group (P=0.002); Incidence of prolonged air leak (longer than 7 days) was 19% in the water seal group and 4% in the suction group (P=0.02); Mean length of stay was 10.4 days in the water seal group and 8 days in the suction group (P=0.004); Favored alternate suction
Alphonso *et al.*, 2005 (34)	Prospective RCT; 254 patients undergoing pulmonary resection were randomized to water seal or suction at 2 kPa; 123 patients to water seal; 116 patients to suction	Incidence of prolonged air leak (defined as longer than 7 days) was 10.1% in the water seal group and 7.8% in the suction group; Favored no difference
Prokakis *et al.*, 2008 (35)	Prospective RCT; 91 patients undergoing lobectomy were randomized to water seal or suction at –15 to –20 cm of water; 44 patients to water seal; 47 patients to suction	Five (5.5%) patients in the water seal group and seven (7.7%) patients in the suction group had a prolonged air leak (defined as longer than 7 days) (P>0.05); Ten (11.0%) patients in the water seal group and six (6.6%) patients in the suction group had a persistent pneumothorax (defined as longer than 3 days) (P>0.05); Mean length of hospital stay was 10.3 days in the water seal group and 11.2 days in the suction group (P>0.05); Favored no difference
Deng *et al.*, 2010 (10)	Meta-analysis; Six RCTs comparing water seal to suction	Odds ratio for water seal compared to suction for relative risk of prolonged air leak: 1.48 (range, 0.82–2.70); WMD of duration of air leak: 1.16 (range, 0.63–2.94); Time for removal of chest tubes: 0.96 (range, 0.12–2.05); Length of stay in hospital: 2.19 (range, 0.61–4.98); Odds ratio for postoperative pneumothorax: 0.11 (range, 0.03–0.49); favoring suction; Favored no difference
Coughlin *et al.*, 2012 (11)	Systematic review and meta-analysis; Seven RCTs comparing water seal to suction	WMD duration of air leak: 1.15 days (95% CI : –0.64 to 2.94); WMD time to discharge: 2.19 days (95% CI: –0.63 to 5.01); WMD duration of chest tubes: 0.96 days (95% CI: –0.12 to 2.05); Absolute risk reduction of prolonged air leaks: 0.04 (95% CI: –0.01 to 0.09); Absolute risk reduction of postoperative pneumothorax: –0.14 (95% CI: –0.21 to –0.07) favoring suction; Suction reduces incidence of postoperative pneumothorax; Favored no difference
Brunelli *et al.*, 2013 (36)	Prospective RCT; 100 consecutive pulmonary lobectomies with digital chest drains were randomized to regulated water seal (–2 cm water) or to regulated suction (–11 to –20 cm water); 50 patients to regulated water seal; 50 patients to regulated suction	Mean duration of air leak was 22.2 hours in the water seal group and 28 hours in the suction group (P=0.6); Incidence of prolonged air leak (defined as longer than 7 days) was 8% in the water seal group and 10% in the suction group (P=0.7); Favored no difference
Lang *et al.*, 2015 (12)	Systematic review and meta-analysis; Eight RCTs comparing water seal to suction	WMD length of stay: 1.74 days (95% CI: 1.17–2.30); WMD chest tube duration: 1.77 (95% CI: 1.47–2.07); WMD air leak duration: 1.47 days; (95% CI: 1.45–2.03) all favoring water seal; Favored water seal

RCT, randomized controlled trial; POD, postoperative day; WMD, weighted mean difference; CI, confidence interval.

This study concluded that chest tube removal on suction was safe, and that protocols requiring water seal before removal led to a longer hospital stay and more frequent chest X-rays. Another prospective randomized trial of 205 patients with a similar study design concluded that removal of chest tubes on water seal decreased the incidence of recurrent pneumothorax (13.9% *vs.* 8.0%, P<0.05) (43). Despite the increased incidence of recurrent pneumothorax, in the group of patients that had their chest tube removed on water seal the probability of requiring chest tube re-insertion was lower (6.2% *vs.* 10.7%, P<0.05). On initial analysis, there was no significant difference in chest tube duration or hospital length of stay. However, if chest tube replacement was required the hospital length of stay doubled. The authors rationalize that a period of water seal may allow occult air leaks to become clinically apparent as a pneumothorax and thus avoid the need for chest drain re-insertion. These limitations of analog pleural drainage systems have been address by new digital drainage devices which are very sensitive and provide air leak trend monitoring preceding chest tube removal eliminating the need for a trial of water seal. Lastly, the studies are likely underpowered to detect adverse events from chest tube removal. At our institution we have found a probability of chest tube re-insertion after removal of a chest drain is approximately 6%. A much larger sample size (i.e., several hundred patients in each arm) would be needed to power a study to detect a 50% reduction in this particular adverse event.

Conclusions

While there may be a lack of consensus on several aspects of chest tube management, there is ample evidence supporting the use of postoperative clinical pathways to improve patient care and allow for earlier discharge from hospital after lung resection. Our strategy is to create a chest tube management pathway that can gain wide acceptance has been primarily focused on a few key aspects of chest tube care. Based on our our review of recent literature and on institutional data, we conclude that: (I) chest X-rays should be used selectively in the care of lung resection patients with chest drains; (II) there is no strong evidence to recommend the use of intra-pleural suction over water seal; (III) it is safe to remove pleural drains at a 24-hour fluid output threshold much higher than what was previously recommended; (IV) that, with the integration of digital pleural drainage technology into clinical practice, chest drains can be safely removed without a trial period of water seal.

Given the current state of the evidence, we acknowledge that the optimal chest tube management strategy has yet to be established. However, thoracic surgeons should develop a pathway that can be consistently used for all patients at their institution. Digital pleural drainage technology will provide an opportunity to generate new evidence-based guidelines and allow an improved understanding of postoperative intra-pleural mechanics. With proper implementation and close monitoring of outcomes, clinical care pathways can assist our endeavors to maintain and improve surgical quality, and allow judicious use of costly and often limited healthcare resources.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Spanjersberg WR, Reurings J, Keus F, et al. Fast track surgery versus conventional recovery strategies for colorectal surgery. Cochrane Database Syst Rev 2011;(2):CD007635.
2. Yeung JK, Dautremont JF, Harrop AR, et al. Reduction of pulmonary complications and hospital length of stay with a clinical care pathway after head and neck reconstruction. Plast Reconstr Surg 2014;133:1477-84.
3. Dumans-Nizard V, Guezennec J, Parquin F, et al. Feasibility and results of a fast-track protocol in thoracic surgery. Minerva Anestesiol 2016;82:15-21.
4. Maruyama R, Miyake T, Kojo M, et al. Establishment of a clinical pathway as an effective tool to reduce hospitalization and charges after video-assisted thoracoscopic pulmonary resection. Jpn J Thorac Cardiovasc Surg 2006;54:387-90.
5. Ueda K, Kaneda Y, Sakano H, et al. Obstacles for shortening hospitalization after video-assisted pulmonary resection for lung cancer. Ann Thorac Surg 2003;76:1816-20.
6. Zehr KJ, Dawson PB, Yang SC, et al. Standardized clinical care pathways for major thoracic cases reduce hospital costs. Ann Thorac Surg 1998;66:914-9.
7. Shoji F, Yano T, Haro A, et al. Assessing a clinical pathway to improve the quality of care in pulmonary resections.

Surg Today 2011;41:787-90.
8. Lamarche Y, Sirounis D, Arora RC, et al. A survey of standardized management protocols after coronary artery bypass grafting surgery in Canadian intensive care units. Can J Cardiol 2011;27:705-10.
9. Harada H, Yamashita Y, Handa Y, et al. Assessment of Feasibility of Early Ambulation and Food-intake on the Operative Day after Lung Resection. Kyobu Geka 2015;68:801-8.
10. Deng B, Tan QY, Zhao YP, et al. Suction or non-suction to the underwater seal drains following pulmonary operation: meta-analysis of randomised controlled trials. Eur J Cardiothorac Surg 2010;38:210-5.
11. Coughlin SM, Emmerton-Coughlin HM, Malthaner R. Management of chest tubes after pulmonary resection: a systematic review and meta-analysis. Can J Surg 2012;55:264-70.
12. Lang P, Manickavasagar M, Burdett C, et al. Suction on chest drains following lung resection: evidence and practice are not aligned†. Eur J Cardiothorac Surg 2016;49:611-6.
13. Zardo P, Busk H, Kutschka I. Chest tube management: state of the art. Curr Opin Anaesthesiol 2015;28:45-9.
14. Varela G, Jiménez MF, Novoa N, et al. Estimating hospital costs attributable to prolonged air leak in pulmonary lobectomy. Eur J Cardiothorac Surg 2005;27:329-33.
15. Varela G, Jiménez MF, Novoa NM, et al. Postoperative chest tube management: measuring air leak using an electronic device decreases variability in the clinical practice. Eur J Cardiothorac Surg 2009;35:28-31.
16. Cerfolio RJ, Bryant AS. The benefits of continuous and digital air leak assessment after elective pulmonary resection: a prospective study. Ann Thorac Surg 2008;86:396-401.
17. Seely AJ, Ivanovic J, Threader J, et al. Systematic classification of morbidity and mortality after thoracic surgery. Ann Thorac Surg 2010;90:936-42; discussion 942.
18. Ivanovic J, Seely AJ, Anstee C, et al. Measuring Surgical Quality: Comparison of Postoperative Adverse Events with the American College of Surgeons NSQIP and the Thoracic Morbidity and Mortality Classification System. J Am Coll Surg 2014;218:1024-31.
19. Reeb J, Falcoz PE, Olland A, et al. Are daily routine chest radiographs necessary after pulmonary surgery in adult patients? Interact Cardiovasc Thorac Surg 2013;17:995-8.
20. Gilbert S, McGuire AL, Maghera S, et al. Randomized trial of digital versus analog pleural drainage in patients with or without a pulmonary air leak after lung resection. J Thorac Cardiovasc Surg 2015;150;1243-51.
21. Younes RN, Gross JL, Aguiar S, et al. When to remove a chest tube? A randomized study with subsequent prospective consecutive validation. J Am Coll Surg 2002;195:658-62.
22. Cerfolio RJ, Bryant AS. Results of a prospective algorithm to remove chest tubes after pulmonary resection with high output. J Thorac Cardiovasc Surg 2008;135:269-73.
23. Göttgens KW, Siebenga J, Belgers EH, et al. Early removal of the chest tube after complete video-assisted thoracoscopic lobectomies. Eur J Cardiothorac Surg 2011;39:575-8.
24. Zhang Y, Li H, Hu B, et al. A prospective randomized single-blind control study of volume threshold for chest tube removal following lobectomy. World J Surg 2014;38:60-7.
25. Bjerregaard LS, Jensen K, Petersen RH, et al. Early chest tube removal after video-assisted thoracic surgery lobectomy with serous fluid production up to 500 ml/day. Eur J Cardiothorac Surg 2014;45:241-6.
26. Xie HY, Xu K, Tang JX, et al. A prospective randomized, controlled trial deems a drainage of 300 ml/day safe before removal of the last chest drain after video-assisted thoracoscopic surgery lobectomy. Interact Cardiovasc Thorac Surg 2015;21:200-5.
27. Schulz KF, Altman DG, Moher D, et al. CONSORT 2010 statement: updated guidelines for reporting parallel group randomized trials. Ann Intern Med 2010;152:726-32.
28. Utter GH. The rate of pleural fluid drainage as a criterion for the timing of chest tube removal: theoretical and practical considerations. Ann Thorac Surg 2013;96:2262-7.
29. Miserocchi G. Physiology and pathophysiology of pleural fluid turnover. Eur Respir J 1997;10:219-25.
30. Cerfolio RJ, Bass C, Katholi CR. Prospective randomized trial compares suction versus water seal for air leaks. Ann Thorac Surg 2001;71:1613-7.
31. Marshall MB, Deeb ME, Bleier JI, et al. Suction vs water seal after pulmonary resection: a randomized prospective study. Chest 2002;121:831-5.
32. Brunelli A, Monteverde M, Borri A, et al. Comparison of water seal and suction after pulmonary lobectomy: a prospective, randomized trial. Ann Thorac Surg 2004;77:1932-7; discussion 1937.
33. Brunelli A, Sabbatini A, Xiume' F, et al. Alternate suction reduces prolonged air leak after pulmonary lobectomy: a randomized comparison versus water seal. Ann Thorac Surg 2005;80:1052-5.
34. Alphonso N, Tan C, Utley M, et al. A prospective randomized controlled trial of suction versus non-suction

to the under-water seal drains following lung resection. Eur J Cardiothorac Surg 2005;27:391-4.
35. Prokakis C, Koletsis EN, Apostolakis E, et al. Routine suction of intercostal drains is not necessary after lobectomy: a prospective randomized trial. World J Surg 2008;32:2336-42.
36. Brunelli A, Salati M, Pompili C, et al. Regulated tailored suction vs regulated seal: a prospective randomized trial on air leak duration. Eur J Cardiothorac Surg 2013;43:899-904.
37. Brunelli A, Cassivi SD, Salati M, et al. Digital measurements of air leak flow and intrapleural pressures in the immediate postoperative period predict risk of prolonged air leak after pulmonary lobectomy. Eur J Cardiothorac Surg 2011;39:584-8.
38. Afoke J, Tan C, Hunt I, et al. Might digital drains speed up the time to thoracic drain removal? Interact Cardiovasc Thorac Surg 2014;19:135-8.
39. McGuire AL, Petrcich W, Maziak DE, et al. Digital versus analogue pleural drainage phase 1: prospective evaluation of interobserver reliability in the assessment of pulmonary air leaks†. Interact Cardiovasc Thorac Surg 2015;21:403-7.
40. Cerfolio RJ, Bryant AS, Skylizard L, et al. Optimal technique for the removal of chest tubes after pulmonary resection. J Thorac Cardiovasc Surg 2013;145:1535-9.
41. Bell RL, Ovadia P, Abdullah F, et al. Chest tube removal: end-inspiration or end-expiration? J Trauma 2001;50:674-7.
42. Davis JW, Mackersie RC, Hoyt DB, et al. Randomized study of algorithms for discontinuing tube thoracostomy drainage. J Am Coll Surg 1994;179:553-7.
43. Martino K, Merrit S, Boyakye K, et al. Prospective randomized trial of thoracostomy removal algorithms. J Trauma 1999;46:369-71; discussion 372-3.

Cite this article as: French DG, Dilena M, LaPlante S, Shamji F, Sundaresan S, Villeneuve J, Seely A, Maziak D, Gilbert S. Optimizing postoperative care protocols in thoracic surgery: best evidence and new technology. J Thorac Dis 2016;8(Suppl 1):S3-S11. doi: 10.3978/j.issn.2072-1439.2015.10.67

