The Management of Chest Tubes After Pulmonary Resection

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KEYWORDS

• Chest tube • Air leak • Pulmonary resection • Water seal

HISTORY OF CHEST TUBES

Drainage of the space between the ribs and the lung, the pleural space, has been practiced since the time of Hippocrates.[1,2] He describes the use of an incision, cautery, and metal rods to remove "evil humors" from patients with a variety of poorly understood illnesses. Hunter, in 1800, used needle drainage to remove fluid from the pleural space, and in 1872, Playfair first placed a chest tube to underwater seal, similar to what is used today.[3,4] Gotthard Bülau, however, is credited as the originator of the first closed water seal drainage system. The improved outcome of using a closed system over the more popular open drainage system (ie, rib resection with open drainage or Eloesser flap) is derived from data accumulated by the US Army, which reported extensive experience from the battlefield and elsewhere. The mortality rate for empyema treated with rib resection and leaving the chest open compared with closed pleural drainage was 28% compared with 4%, respectively. Thus, closed pleural space drainage became the standard of care in the early twentieth century. The concept of underwater seal was born. In 1917, Evert Graham[5] described closed drainage for influenza empyema after a significant number of patients died after open drainage technique. Lilienthal,[6] in 1922, first used and later reintroduced closed pleural drainage in the postoperative care of patients after routine thoracic surgery.

Chest tubes have been given a variety of names over the years, including Bülau drains, intercostal catheters, and thoracostomy tubes. Whatever they are called, their function has been the same for more than 3000 years, to drain fluid or air from the pleural space. Modifications of the material used to make chest tubes themselves as well as to the pleural drainage systems have continued. Not only has the chest tube itself undergone improvements but also the drainage systems used have seen many modifications and improvements, including an air leak meter, smaller and more compact size to allow home discharge, and recently some feature digital measurements of air leaks as well as the digital record of the amount of effluent each hour.

DEFINITION OF IMPORTANT TERMS

Before reviewing the data on chest tube management, several terms must be defined. There remains significant confusing about much of the vocabulary that is used for chests tubes and the pleural space. Although thoracic surgeons are the best-trained physicians to manage chest tubes and pleural space problems, they often do not speak the same language or recommend similar treatment algorithms even to each other. This

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leads to confusion. Moreover, confidence in recommendations is eroded if they change with each surgeon who is on call.

The pleural space has a negative intrathoracic pressure and anything that disturbs this can lead to physiologic compromise. For this reason the first drainage systems featured a 3-bottle system (**Fig. 1**). A 1-bottle system was used initially; however, as the fluid or blood that drained from patients rose in the only bottle, it increased the resistance to further drainage. Moreover, the mixture of air in the bottle and blood from patients caused a foamy effluent to build up in the bottle, again impeding drainage. Therefore, a 2-bottle system quickly became adopted. The second bottle allowed fluid to drain into the first bottle only and the air escaped into the second. This prevented the foam from forming and the 2-bottle system had to be drained less frequently. The problem with the 2-bottle system was that the added length of the tubing increased the dead space and again added significant resistance. Some patients actually had reversal of flow and often their chest tube effluent would start to go back up into the tube and back into the pleural space of these patients. For that reason the famed 3-bottle system arrived (see **Fig. 1**). The third bottle allows for active suction to be exerted on the system. This active suction prevents the chest tube effluent from going back toward the patient. Essentially, all commercial systems use this technology now and some have a 1-way tip over valve.

ACTIVE SUCTION COMPARED WITH PASSIVE SUCTION

An important distinction should be made between active suction and passive suction. Underwater seal or passive suction occurs when a chest tube is attached to a drainage system but there is no further suction added (most commonly from external tubes connected to the wall). This is often called a water seal because the tube is connected to a system that essentially has the distal end of the chest tube submerged under approximately 2 cm of water. During expiration or coughing, air from the pleural space is expelled through the tubing and overcomes the hydrostatic pressure. It also produces a siphon effect, which enhances drainage. This is why air leaks can be visualized in the water chamber in many commercial systems. Some feature an air leak meter to quantify the size of the air leak, ranging from 1 to 7.

When external suction is applied to the drainage system, this added suction is called active suction because it is added to the passive suction that already exists in the drainage system's underwater seal. Some refer to this as wall suction but new digital units are able to exert active suction on their own and do not require any wall suction attachments.

Once it was observed that a 3-bottle system clinically was best, companies began to come up with ways to add all 3 bottles into one compact, user-friendly, commercial system. Initially the suction that was added was termed, *wet suction*. The term, *wet*, was used because the suction had to be under water. These systems are safe, because it is difficult to exert greater than a -15 or -20 cm H_2O pressure and they allowed inadequate airflow in patients who had a large air leak. In these systems, a certain level of water was needed and the amount of suction was determined by the height of water.

These wet systems have been replaced for the most part by dry suction for several reasons. In

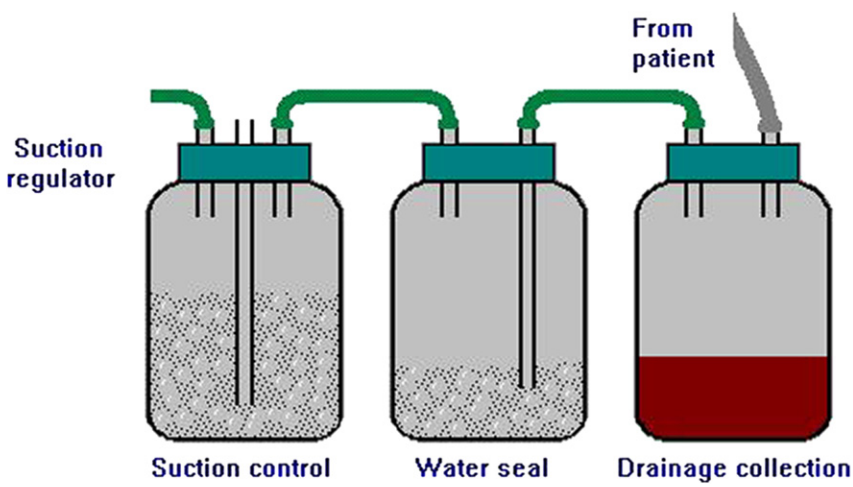

Fig. 1. 3-Bottle chest tube drainage system.

the wet systems, a continuous bubbling of suction under water was needed, which was was loud and annoying to patients and nurses. In addition, because the water was constantly evaporating, it had to be replaced, leading to an inconsistent amount of suction. Dry suction systems are easier to set up, provide higher levels of suction if needed, and are quieter. Probably most importantly, because they regulate the amount of suction not by a height or column of water but rather via a self-compensating regulator, they provide a more consistent amount of suction.[7] A final term needs to be addressed: a *fixed pleural space deficit* is defined as a nonresolving pneumothorax when the lung is fully expanded.[8]

INITIAL EVALUATION OF AN AIR LEAK—IS IT REAL?

If confronted with an alveolar-pleural fistula (air leak), the clinician at the bedside must ensure that the leak is really from the patient and is not a system leak. All connections between the chest tube and the drainage system should be checked. When the leak is confirmed as coming from inside the patient's chest and not the system, it should be classified. Careful observation at the bedside reveals that the natural history of air leaks is based on two main features, the type of air leak (the qualitative aspect of the system, determined by when the air leak occurs during the respiratory cycle) and the size of the air leak (the quantitative aspect of the classification system). The authors have developed[9] and refined a classification[10] system for alveolar-pleural fistulas (air leaks), the Robert David Cerfolio Classification System for Air Leaks (RDC System), named after the first author's father. It is described at length elsewhere.[11] The authors believe that in the future, digital systems, already on the market, will replace this analog system. The full implementation of these systems, however, will be based on cost, and many hospitals outside of North America and Eastern Europe will probably continue to use the analog systems for several years.

EVIDENCE-BASED MEDICINE FOR THE MANAGEMENT OF CHEST TUBES AFTER PULMONARY RESECTION

Over the past several years there has been an interest in bring the scientific method to chest tube management. A PubMed literature search shows that before 1996, there were fewer than 10 articles that described studies on how to manage air leaks and chest tubes. From 1997 to 2009, however, there were 11 publications by the authors (University of Alabama at Birmingham [UAB], Birmingham, AL, USA) and 9 from Brunelli (Umberto, Regional Hospital Ancona, Italy) on the management of chest tubes and air leaks. Therefore, many of the recommendation come from these two centers.

The study of the management of chest tubes is based on two factors that slow or prevent removal: air leaks and a high volume of pleural drainage. These two factors need to be considered separately and a more aggressive management style is needed to help speed the safe removal of chest tubes to decrease pain and to prevent empyema. Postoperative pain reduction improves respiratory mechanics and limits splinting and shallow breathing, thus reducing the chance for postoperative pneumonia and other complications.

AIR LEAK MANAGEMENT

Air leaks are the most common complication after pulmonary resection. Historically, chest tubes were placed to suction after chest surgery to promote the drainage of fluids out of the chest. Because of this initial practice, wall suction or active suction (discussed previously) has been the historical and preferred setting for chest tubes. In 1996, the authors made the simple observation at the bedside that suction made air leaks bigger, thus theorizing that if the pleural-pleural apposition were maintained when chest tubes were placed to water seal (ie, there was no new pneumothorax) that a water seal helped air leaks stop sooner.

The authors and Brunelli and colleagues have studied the problem of alveolar-pleural fistulas (air leaks) using prospective randomized trials or predetermined algorithms in an attempt to bring some science to what had been a subjective art form. **Table 1** provides an overview of some of the larger prospective studies addressing the issue of chest tube management—placing chest tubes to water seal (passive suction) or to suction (active suction). Although overall review of this data leads to the conclusion that the optimal chest tube setting is not yet proved for all patients, certain definitive statements can be made from these reports.

The first prospective study, which was from the authors' group, found that most air leaks occurred during expiration.[9] Also reported in that first study was that pulmonary function testing consistent with emphysema increased the risk of having an air leak after pulmonary resection. This study showed that placing chest tubes on water seal not only was safe for air leaks but also seemed superior to suction at stopping leaks in patients who maintained parietal-pleural to visceral pleural

Table 1
Recent studies evaluating the management of chest tubes in post-thoracotomy patients

Author, Year of Publication	Study Type	Comparison	Findings
Cerfolio et al,[10] 2001	Prospective randomized trial (postpulmonary resection)	Suction POD 1, then randomized to S versus W on POD 2	Water seal superior after POD 0 of suction
Marshall et al,[12] 2002	Prospective randomized study (postpulmonary resection)	Initially S, then randomized to S or W	Water seal shorted the duration of AL and CT duration
Ayed,[13] 2003	Prospective randomized (patients with spontaneous ptx)	S versus W	Water seal after brief period of suction decreased CT duration
Brunelli et al,[14] 2005	Prospective randomized trial (postlobectomy with air leak on POD 1)	S versus W	No difference
Brunelli et al,[15] 2004	Prospective randomized (postlobectomy)	Alternating S versus W	Alternating suction superior to water seal (reduced incidence of AL, decreased CT duration, LOS)
Cerfolio et al,[16] 2005	Retrospective review (patients with ptx and air leak)	S versus W	Water seal superior unless ptx is large/ symptomatic or patient develops subcutaneous emphysema
Okamoto et al,[17] 2006	Retrospective	S versus W	No difference

Abbreviations: AL, air leak; CT, chest tube; LOS, length of stay; POD, postoperative day; ptx, pneumothorax; S, suction; W, water seal.

apposition. It provided safety data to perform a prospective randomized study.

The second study on air leaks was also from the authors' institution at UAB. It was a prospective randomized trial of 140 patients, 33 of whom had air leaks.[10] This study showed that patients who had their tubes placed on water seal (passive suction) instead of wall suction (active suction) were more likely to have their leak stop. A water seal also made air leaks smaller. A water seal did not stop large expiratory leaks, however, because patients when placed to passive suction often developed a pneumothorax. The RDC system for air leaks was further refined and validated between blinded observers. The classification system has become a critical component for the management of tubes. It helps guide treatment. For example, if patients have an expiratory 5 leak, their tubes are best left on suction and not placed to water seal because an enlarging pneumothorax is probable. The passive suction (water seal) not stopping these leaks corroborates one of Brunelli's theories. This may be because these leaks, when placed on water seal or passive suction, led to a pneumothorax. They are too large for passive suction and air is not fully evacuated from the pleural space. This prevented pleural-pleural apposition, thus the leak did not seal. This concept is supported by Brunelli and colleagues,[14] who favor active suction at night and passive suction during the day. This conclusion is from their 2005 study. They performed a randomized controlled trial comparing water seal (passive suction) to alternating wall suction (active suction) with water seal (passive suction) in postpulmonary resection patients. They used suction at night and waters seal during the day for ease of ambulation. They found that alternating suction with water seal was superior to water seal alone. Patients on the alternating treatments had a significantly shorter hospital length of stay and chest tube duration.[14] The authors believe this regimen may be best for

a bigger air leak (>an expiratory 3) in many patients.

Marshall and colleagues[12] from The University of Pennsylvania reported another prospective randomized study and found that placing chest tubes on water seal (passive suction) after pulmonary resection shortens the duration of air leaks and decreases the time chest tubes remain in place. Brunelli and colleagues,[15] however, recently published a report on series of selected patients, many of whom had undergone pleural tenting. The investigators reported that those patients on water seal had more complications compared with those who were treated with suction. This finding needs to be further explored.

Other reports have found that if patients have large (E6 or E7) air leaks on postoperative day 1, they continue to have an air leak by postoperative day 4 irrespective of the chest tube management. These patients are discharged home (if otherwise ready for discharge) on a Heimlich valve.[18] Because of the accuracy and reliability of the classification system, these patients can be informed about the need for discharge with an indwelling tube early in their hospital course. This allows patients, families, nurses, and physicians to prepare mentally and physically for discharge home on a Heimlich valve. Moreover, this information has helped the authors care for patients with spontaneous pneumothoraces. If patients suffer their first spontaneous pneumothorax, the authors usually place a chest tube only and observe the patients. But if the air leak is large, an E4 or greater, the natural history of that leak is prolonged. The authors' most recent article on leaks reports that water seal is safe for patients with an air leak and a pneumothorax.[16] If the leak is large (>an E4) or the pneumothorax is large (>8 cm on a measurement scale defined in that article), however, the seal is not safe.

Another important aspect of air leak management is the use of intraoperative techniques to stop leaks. There are many studies that have evaluated the efficacy of using pulmonary sealants to prevent leaks.[19–21] There is only one Food and Drug Administration–approved pulmonary sealant and it is just coming to the market in 2010. Studies are under way to assess its efficacy and cost savings.

TREATMENT OF PERSISTENT AIR LEAKS

The Society of Thoracic Surgeons' database defines persistent air leak as one that lasts more than 5 days. In the authors' practice, however, a persistent air leak is defined as one that prolongs hospitalization. If, on the third postoperative day, the leak is larger than an forced expiratory 3 (FE3), it will not seal overnight. For that reason the patient's chest tubes are connected to a Heimlich valve or to an outpatient device (the authors have used Express [Atrium, Hudson, NH, USA], MINI Sahara [Teleflex, Research Triangle Park, NC, USA], and, most recently, Thopaz [Medela, Baar, Switzerland]). If a Heimlich valve is used, the other end is connected to a urinary leg bag or a compact portable drainage system. A chest x-ray (CXR) is obtained after 24 hours on the Heimlich valve, and if no new subcutaneous emphysema or no new or enlarging pneumothorax is seen, patients are discharged home on postoperative day 4 or 5. Neither a pneumothorax nor subcutaneous emphysema usually occurs unless the air leak is large, greater than an E4 in the RDC system. If a CXR identifies a problem, such as subcutaneous air or a new or enlarging pneumothorax, patients must be returned to water seal or -10 cm H_2O of suction, whichever is needed to alleviate the pneumothorax. This process is repeated in 2 days. If a second pneumothorax occurs, the options are to perform a bedside chemical pleurodesis or to wait 48 hours. If a bedside pleurodesis is performed using doxycycline, the tubing cannot be clamped. Tubing should be hung well over a patient's bed so that after the sclerotic agent is shot into the tube, it is hung over the patient and then attached to the drainage system, which is placed on passive suction (water seal). Often, an extra length of rubber tubing is needed to accomplish this height. This technique allows the sclerotic agent to stay in the chest but air can escape.

OUTPATIENT MANAGEMENT OF CHEST TUBES

Once patients are discharged home on an outpatient device, no specific instructions are needed. The authors use a daily subtherapeutic dose of cephalexin hydrochloride (Keflex, MiddleBrook Pharmaceuticals, West Lake, TX, USA) (500 mg once a day) as a prophylaxis measure to help prevent empyema and have shown this is safe and effective and that the chest tube can be removed in 2 weeks almost without exception even if patients still have a leak.[22] This is an important concept because many continue to have reservation about tube removal in patients with an air leak. Provocative chest tube clamping can be performed (described previously) if the leak is worrisome. More recently, the authors have switched from the Heimlich valve system to a compact, self-contained devise and have had success with this system because it allows better

capturing of the effluent and is more compact, clean, and user friendly than the Heimlich valve hooked to a Foley catheter drainage bag.

HIGH-VOLUME DRAINAGE

Although air leaks are the most common complication after pulmonary resection, it is the drainage of over 250 mL/day that is the most common cause of delayed discharged and chest tube removal in the United States. Many surgeons use this unproved strict criteria for the amount of drainage a tube can have before removing it. Patients often have chest tubes left in because the drainage was "greater than 150 mL/day," "greater than 50 mL/shift," or greater than "250 mL/day." Because this number seemed arbitrary and completely unsubstantiated by data, the authors performed a study in 2008[23] assessing the safety of the removal of tubes with higher outputs. In this study, the authors removed chest tubes when the drainage was 450 mL/day or less, if there was no air leak, and if cerebrospinal fluid (CSF), chylothorax, or hemothorax was ruled out. It seemed not only was the amount of drainage important but also the character of the drainage should be factor. If the effluent was clear and not CSF, blood, or chlye, then removal of the tube even with high drainage should be safe. This study included 2077 patients and only 11 (<1%) were readmitted for recurrent effusions. The authors concluded that chest tubes can be safely removed with up to 450 mL/day of nonchylous drainage after pulmonary resection, and higher numbers need to be tested because 450 mL is also arbitrary.

THE ROLE OF DAILY CXRS

A final word about the use of daily CXRs is needed. Although the vast majority of surgeons ordered a daily CXR on patients with a chest tube in place, there are few data that show this is needed. CXRs are expensive and if done early in the morning, so as to be available for morning rounds, are disruptive and uncomfortable for patients. In the majority of patients, if postoperative recovery room film shows pleural-pleural apposition and patients do not develop an air leak or other clinical problems, daily CXRs rarely influence chest tube management or patient care decisions. If patients develop any type of clinical scenario that includes shortness of breath, decreasing saturation, or subcutaneous emphysema, then a film is needed and should be ordered.

In conclusion, air leaks are a common clinical problem after pulmonary resection. The management of tubes, drains, and air leak can be studied with randomized trials and objective data. A validated, objective classification system is now available and helps guide treatment, and new digital systems show great promise. Randomized studies have shown that placing chest tubes to water seal (passive suction) is superior to suction and better at stopping air leaks when a pneumothorax does not occur when patients are placed to water seal. Large leaks (ie, >E4), however, will probably fail water seal and patients may develop a pneumothorax or enlarging subcutaneous emphysema. In these patients or in others who lose pleural-pleural apposition on water seal (passive suction), some suction is best, and the Brunelli concept of alternating active suction at night with passive suction during the day is probably best. Prolonged air leaks are more common in patients with emphysematous lungs and with pulmonary resections that remove large amounts of lung. A pneumothorax itself is not an indication for suction because many patients have a fixed pleural space deficit. Finally, patients can safely go home with an air leak and with chest tubes in place. The tubes can be managed on an outpatient basis and then removed by postoperative day 21, even if patients still have an air leak as long as there is no subcutaneous emphysema or a symptomatic pneumothorax. Further randomized studies are needed.

REFERENCES

1. Chadwich J, Mann WH. The medical works of Hippocrates. Springfield: Charles C Thomas; 1950.
2. Miller KS, Sahn SA. Chest tubes. Indications, technique management and complications. Chest 1987;91:258–64.
3. Hochberg LA. Thoracic surgery before the 20th century. New York: Vantage Press; 1960. p. 244.
4. Bowditch HI. On pleuritic effusions and the necessity of paracentesis for their removal. Am J Med Sci 1852;22:320.
5. Graham EA. Some fundamental considerations in the treatment of empyema thoracis. St Louis: Mosby; 1925. p. 7–110.
6. Lilienthal H. Pulmonary resection for bronchiectasis. Ann Surg 1922;75:257.
7. Cerfolio RJ. Closed drainage and suction systems. Pearson's Thoracic and Esophagael Surgery. 3rd editon. Philadelphia: Churchill, Livingstone; 2008. p. 1147–63.
8. Cerfolio RJ. Recent advances in the treatment of air leaks. Curr Opin Pulm Med 2005;11:319–24.
9. Cerfolio RJ, Tummala RP, Holman WL, et al. A prospective algorithm for the management of air

leaks after pulmonary resection. Ann Thorac Surg 1998;66:1726–31.

10. Cerfolio RJ, Bass CS, Katholi CR, et al. Prospective randomized trial compares suction versus water seal for air leaks. Ann Thorac Surg 2001;71:1613–7.
11. Cerfolio RJ. Advances in thoracostomy tube management. Surg Clin North Am 2002;82:833–48.
12. Marshall MB, Deeb ME, Bleier JI, et al. Suction vs water seal after pulmonary resection: a randomized prospective study. Chest 2002;121:831–5.
13. Ayed AK. Suction versus water seal after thoracoscopy for primary spontaneous pneumothorax: prospective randomized study. Ann Thorac Surg 2003;75:1593–6.
14. 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.
15. 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.
16. Cerfolio RJ, Bryant AS, Singh S, et al. The management of chest tubes in patients with a pneumothoerax and an air leak after pulmonary resection. Chest 2005;128:816.
17. Okamoto OJ, Fukuyama Y, Ushijima C, et al. The use of waters seal to manage air leaks after a pulmonary lobectomy: a retrospective study. Ann Thorac Cardiovasc Surg 2006;12:242–4.
18. Heimlich HJ. Valve drainage of the pleural cavity. Dis Chest 1986;53:282–7.
19. Lang G, Csekeo A, Stamatis G, et al. Efficacy and safety of topical application of human fibrinogen/thrombin-coated collagen patch for treatment of air leakage after standard lobectomy. Eur J Cardiothorac Surg 2004;25:160–6.
20. Porte HL, Jany T, Akkad R, et al. Randomized controlled trial of a synthetic sealant for preventing air leaks after lobectomy. Ann Thorac Surg 2001; 71:1618–22.
21. Wain JC, Kaiser LR, Johnsotne DW, et al. Trial of a novel synthetic sealant in preventing air leaks after lung resection. Ann Thorac Surg 2001;71: 1623–9.
22. Cerfolio RJ, Minnich DJ, Bryant AS. The removal of chest tubes despite an air leak or a pneumothorax. Ann Thorac Surg 2009;87:1690–4.
23. 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.