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Comprehensive Review of Chest Tube Management
A Review

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IMPORTANCE Thoracostomy, or chest tube placement, is used in a variety of clinical indications and can be lifesaving in certain circumstances. There have been developments and modifications to thoracostomy tubes, or chest tubes, over time, but they continue to be a staple in the thoracic surgeon's toolbox as well as adjacent specialties in medicine. This review will provide the nonexpert clinician a comprehensive understanding of the types of chest tubes, indications for their effective use, and key management details for ideal patient outcomes.

OBSERVATIONS This review describes the types of chest tubes, indications for use, techniques for placement, common anatomical landmarks that are encountered with placement and management, and an overview of complications that may arise with tube thoracostomy. In addition, the future direction of chest tubes is explored, as well as the management of chest tubes during the COVID-19 pandemic.

CONCLUSIONS AND RELEVANCE Chest tube management is subjective, but the compilation of data can inform best practices and safe application to successfully manage the pleural space and ameliorate acquired pleural space disease.

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Thoracostomy tube, otherwise known as chest tube, insertion can be traced back to the fifth century BCE when Hippocrates described using a hollow tin tube to drain what was likely an empyema.[1] In 1889, valved tubes with air-tight seals were first reported to prevent outside atmospheric pressure from collapsing the lung on inspiration.[2] In 1922, chest tubes were first documented in the postoperative care of patients undergoing modern thoracic surgery.[3] They were used throughout World War II to restore lung function after traumatic thoracotomies, were used during the Korean War, and later became the standard of care for drainage of the pleural space for trauma during the Vietnam War.[4] Chest tubes and their management continue to evolve and are modified to fit modern needs, including clinical conditions associated with the COVID-19 pandemic.

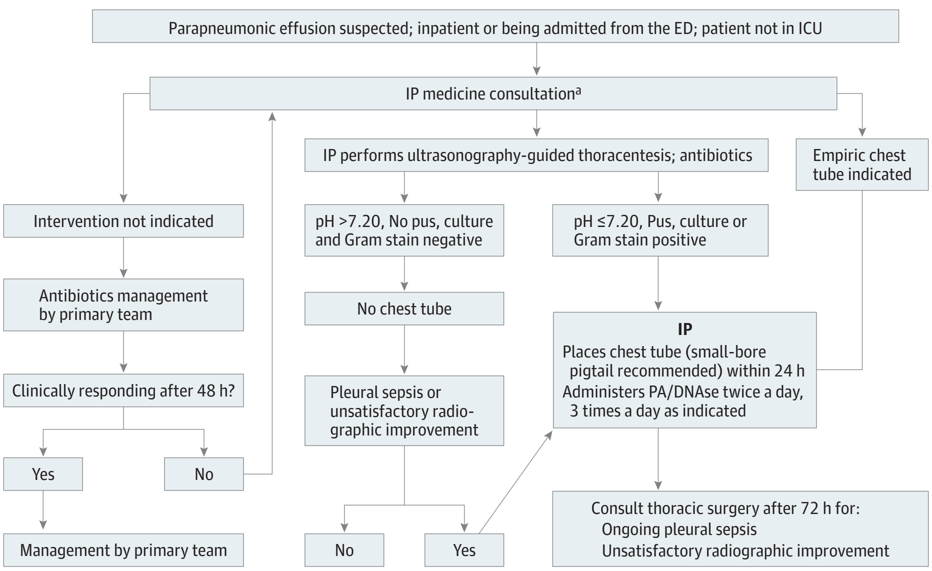
Indications

The potential space between the visceral pleura that envelops the lungs and the parietal pleura covering the chest wall, diaphragm, and mediastinum is the pleural cavity, which contains lubricating pleural fluid secreted by the parietal pleural capillaries. Air and abnormal fluid can accumulate in this space, causing mass effect and disruptions in the normal negative intrathoracic pressure.

When air fills the pleural cavity, it is called a pneumothorax, which is further categorized according to its etiology as primary spontaneous, secondary spontaneous, or traumatic.[5-7] Chest tubes are used to evacuate air in the pleural cavity and reestablish the negative intrathoracic pressure, allowing the lung to reexpand and restore physiologic ventilation and cardiac function.[6-9] A tension pneumothorax develops when air enters on inspiration and is unable to escape on expiration. This leads to effective mass effect on intrathoracic structures, such as the lung itself; mediastinal structures, such as the venae cavae; and cardiac chambers, resulting in hemodynamic compromise from restricted venous return and cardiac output. This is a medical emergency and should initially be managed with immediate needle thoracentesis to decompress trapped and expanding pleural air before the placement of a formal chest tube.

Chest tubes are also used to evacuate excessive fluid from the pleural cavity, which is known as a pleural effusion. When there is pus in the pleural cavity, then it is considered an empyema. There are several ways to evacuate fluid from the pleural cavity and chest tubes are only one of the many options. A Cochrane review from 2017[10] compared the surgical option of video-assisted thoracic surgery (VATS) with chest tube drainage of pleural empyema and found no difference in mortality or complications between the groups, but early VATS reduced the hospital length of stay. VATS has been considered the first-line treatment for retained hemothorax and empyemas with other modalities, such as intrapleural lytic therapy, reserved for poor operative candidates or as a second line treatment.[11] However, a meta-analysis by Hendriksen et al[11] found that treating retained hemothorax with lytic therapy rather than VATS allowed for an overall operative avoidance rate of 87% (95% CI, 81%-92%), with no heterogeneity in the pooled studies (Q = 10.2; df = 9; P = .33; I^2 = 15.07%). The type of intrapleural lytic treatment is also important as Hendriksen et al[11] found that using tissue plasminogen acti-

Figure 1. Parapneumonic Effusions: University of California, Davis, Pulmonary and General Thoracic Surgery Management Pathway



[a] Interventional pulmononologist (IP) recommends thoracic surgery evaluation for late presentation (>7 d from index symptoms) plus thick pleural rind or for very complex effusion. ED, emergency department; ICU, intensive care unit; PA, tissue plasminogen activator.

vator (t-PA) as the lytic agent allowed for a favorable number of patients to avoid surgical intervention compared with other lytic agents. The combination of t-PA and dornase (DNase) was associated with a 60% reduction in pleural fluid collection as seen on imaging and with a significant reduction in pleural opacity, compared with placebo in the randomized clinical trial by Rahman et al.[12] When t-PA and DNase were used on their own as opposed to in combination, this study did not find a significant reduction in the pleural fluid collection compared with placebo.[12] The evidence supports combining t-PA and DNase for intrapleural lytic therapy. Given the effectiveness of treating early-phase empyema with a chest tube and intrapleural use of t-PA and DNase, as well as the use of VATS to reduce length of hospital stay, the authors developed a multidisciplinary protocol with general thoracic surgery and interventional pulmonary medicine for the algorithmic care of patients presenting with empyema, starting with a small-bore chest tube placement followed by intrapleural use of t-PA and DNase. If this initial step is unsuccessful, the next stage of the pathway is thoracic surgical consultation for VATS decortication (**Figure 1**).

Types of Chest Tubes

Chest tubes come in a variety of sizes and materials to best suit the clinical needs of the patient. In the US, they are generally measured by the internal diameter of the tube in units of French. One increment of the French scale is equal to a one-third–millimeter diameter, (eg, 24F is equal to an 8-mm caliber). By most prevalent convention, a tube of 20F or larger is considered a large-bore chest tube and a tube less than 20F tube is considered a small-bore chest tube, although there are some studies that define a large-bore chest tube as larger than 14F.[5,13,14] A common type of small-bore chest tube is a pigtail catheter, named because the tip coils at the end like a pig's tail to prevent dislodgement.[13]

Small-bore chest tubes are used as the first-line treatment for pneumothorax, transudative pleural effusions, and simple empyemas, whereas large-bore chest tubes are often necessary for more viscous disease processes, such as a hemothorax and complex exudative effusions and empyemas.[13,15] A meta-analysis by Chang et al[5] demonstrated that small-bore chest tubes are associated with lower complications rates and shorter drainage duration and hospital stay compared with large-bore chest tubes. A randomized clinical trial by Hussain et al[16] identified similar findings of a reduction in drainage duration and hospital stay with small-bore pigtail catheters compared with large-bore chest tubes in patients with secondary spontaneous pneumothorax. The most prominent advantage of a small-bore chest tube is its size, which allows for a smaller incision and decreased pain experienced by the patient.[16,17] The randomized clinical trial by Kulvatunyou et al[17] demonstrated a lower pain score in individuals with a pigtail catheter compared with a large-bore chest tube for traumatic pneumothorax. However, the small diameter of small-bore chest tubes may come at the cost of inefficient flow, as per Poiseuille's law ($\Delta P = 8\mu LQ/\pi R^4$, where Δp is change in pressure, μ is viscosity, Q is flow and R is radius) the decreasing radius of small-bore chest tubes can lend to a lower flow rate, which is the reason large-bore chest tubes are necessary in conditions that would otherwise clog a smaller tube, such as high-viscosity (μ) fluid.[5,13,15]

Insertion

The placement of a chest tube is important and is performed by many different specialties in various settings. The ideal point of insertion is through an external landmark space known as the triangle of safety (**Figure 2**), which is bordered by the edge of the latissimus dorsi muscle, pectoralis major muscle, the base of the axilla, and transverse to the nipple line or inframammary fold, at or above the fifth

Figure 2. Triangle of Safety for Chest Tube Placement

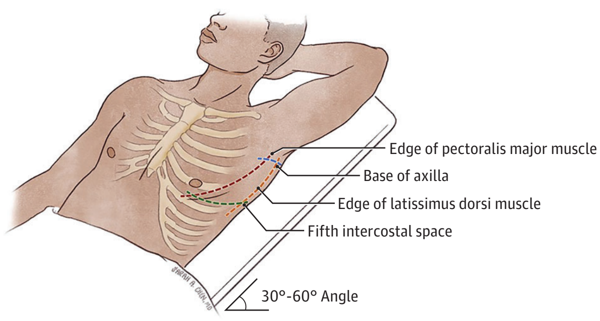
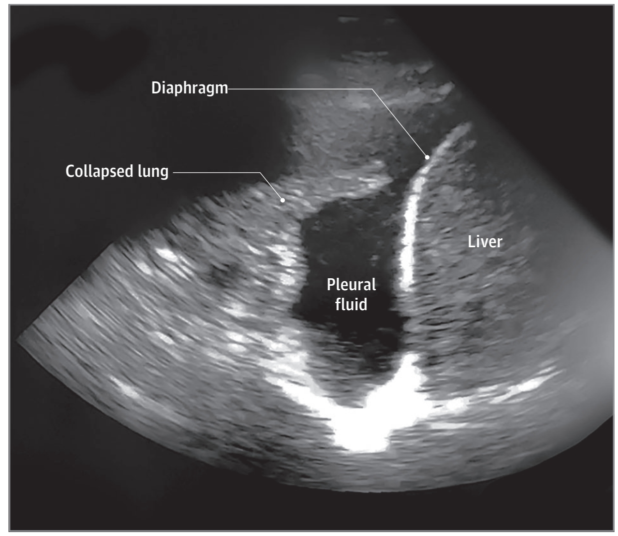


Figure 3. Representative Sonographic Image Demonstrating the Target Abnormal Collection of Pleural Fluid



intercostal space.[13,14,18-20] However, placement of chest tubes is also influenced by the indication. For an apical pneumothorax, a chest tube can be placed in the second intercostal space in the midclavicular line, although less comfortable for the patient, and adequate drainage of an unloculated pneumothorax can be performed via lateral insertion at the fifth intercostal space.[14,18] If the tube is placed in the triangle of safety, it is important to place it in a line anterior to the anterior superior iliac spine. Placing in the tube in a line behind this surface landmark may cause the patient to lie on the tube when in the supine position and mechanically occlude the tube. For a pleural effusion, a lower intercostal space may be used for insertion but special care must be taken to avoid penetrating the diaphragm, and subsequently the liver on the right and spleen and bowel on the left.[13]

The 3 ways to insert a chest tube are dissective, Seldinger (often ultrasonography guided), and the trocar technique, again often ultrasonography guided.[13,14,19,20] Ultrasonography can be an invaluable tool to safely identify internal landmarks for chest tube placement. **Figure 3** presents a representative sonographic image demonstrating the target abnormal collection of pleural fluid, in the right chest, for chest tube drainage, and adjacent structures of atelectatic lung, diaphragm and liver. **Figure 4**A highlights an important step for chest tube placement, which is using a finder needle (often a syringe with local anesthetic) just above the target rib to avoid the intercostal neurovascular bundle and aspirating the pleural space to confirm the location of the pleural pathology. For dissective insertion, a 1- to 2-cm incision is made overlying the rib of choice (the authors do not tunnel to a rib above), a Schnidt tonsil clamp is used to bluntly dissect through the subcutaneous tissue, the 3 muscular layers of the intercostal space (ie, the external intercostal muscle, the internal intercostal muscle, and innermost intercostal muscle), transthoracic fascia, and the parietal pleural until the clamp enters the pleural cavity. When attempting to enter the fifth intercostal space, it is important to dissect not perpendicular to the chest wall, but generally posterior and apical, the direction that most tubes should be placed (Figure 4B). Dissecting perpendicular to the chest wall and into the fifth intercostal space can lead to the tube heading directly into the oblique fissure, and then be entrapped by the subsequent expanded lung, rendering the tube ineffective after lung expansion. After successful spreading into the pleura space, a finger is used to confirm entry into the pleural space and the presence of adhesions. Adhesions are not bluntly broken with the finger, as pleural adhesions are often vascular and blunt dissection can lead to small vessel disruption and subsequently hemothorax.[13,14] The Seldinger technique uses guidewires and tract dilators to assist the tube into the pleural cavity, all under ultrasonography guidance.[19,21] Lastly, the trocar method may be used; however, it is associated with more complications owing to the rigid tip of the trocar causing intrathoracic injuries and has subsequently fallen out of favor for chest tube insertion.[19,20,22] Regardless of the insertion technique, the chest tube needs to be advanced on the superior edge of the rib to avoid the neurovascular bundle bordering the rib above.[13,14] It should also be positioned posteriorly and advanced until the tip is in a posteroapical location. The tube should also be fully inserted to ensure that the most proximal (sentinel) hole is within the pleural space to allow the chest tube to function properly.[14] Lastly, it is important to secure the chest tube with a suture to prevent it from falling out. Most tubes can be removed without suture skin closure, but in children and adults with very low body mass index (calculated as weight in kilograms divided by height in meters squared), placement of an untied adjunctive chest tube suture at the time of insertion allows for closure of skin defects at the time of tube removal, especially large-bore tubes, to prevent entraining atmospheric air with tube removal.

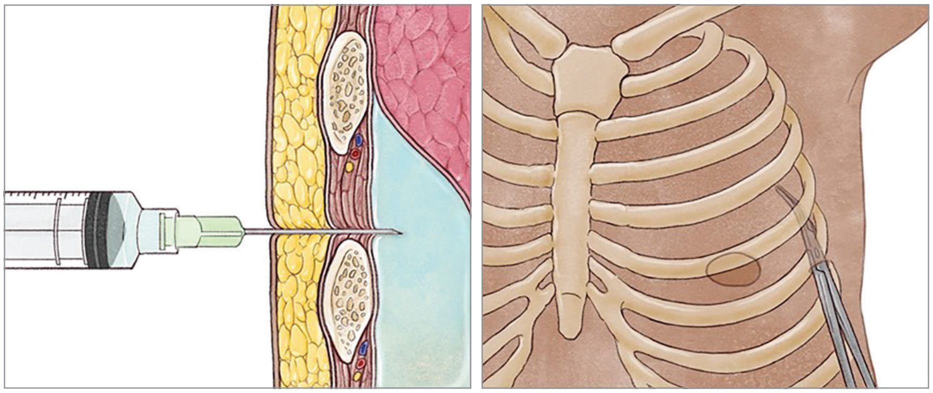
Management

Once a chest tube is placed, it is connected to a drainage device, which, like the chest tube itself, has evolved over the years. The first rendition was a 1-compartment system reported by Playfair[23] in 1875, which used a 1-way valve to allow air to egress from the pleural cavity during expiration without returning on inspiration. In 1926, Lilienthal[24] developed a 2-compartment system, which allowed the accumulation of fluid in the first collection bottle without compromising the efficiency of the system and its ability to drain, as would have been observed in the first model. Then, the 3-compartment system emerged in 1952 with Howe, which allowed collection, water sealing, and suction and manometer capabilities that are combined into a single pleural drainage unit (PDU).[19,25] This forms the

Figure 4. Insertion Technique

A Tube placement over target rib

B Posterior and apical tube placement



foundation of the modern PDU devices today, some of which are digitally operated.

Once placed, chest tubes may be attached to a PDU and set to active suction or to water seal, which is simple dependent drainage. The phrase "place a chest tube on water seal" is a misnomer, as modern PDUs have a constitutive water seal chamber that serves as a 1-way valve, preventing air from returning into the pleural space; placing a chest tube on water seal simply means taking the tube off active suction. The randomized clinical trial by Cerfolio et al[26] found that water sealing the chest tube on postoperative day 2 after thoracic surgery resulted in a significant resolution of small air leak the following day, with the authors noting that large air leaks do not benefit from water sealing. Another randomized clinical trial[27] demonstrated similar results of a shorter duration of air leak with early water sealing for postthoracic surgery chest tubes, which subsequently decreased the duration the chest tube was needed. Both of these studies, albeit randomized clinical trials, are limited by their small sample sizes. Brunelli et al[28] performed a randomized clinical trial with a larger sample size, did not find an advantage with water seal over suction for postthoracic surgery patients and the authors favor a hybrid approach of moderate suction overnight and water sealing during the day to allow for mobilization of the patient. The systematic review and meta-analysis by Coughlin et al[29] determined that there was no advantage of suction over water seal after thoracic surgery, with the exception of suction being superior to water seal in preventing a radiographic identification of pneumothoraces.

For patients with a traumatic chest injury, the systemic review and meta-analysis by Feenstra et al[9] demonstrated evidence that favors low-pressure suction over water seal. This meta-analysis is limited in the number of studies, and therefore patient sample size, included. In addition, there are few patients with chest tubes in the setting of mechanical ventilation included in this study, which is an important subset of trauma patients. Patients who have an occult pneumothorax and are receiving positive pressure mechanical ventilation are at risk of developing a tension pneumothorax, therefore it may be necessary for a chest tube to be placed on suction in this subset of patients.[30] Overall, the management of a chest tube depends on the indication for insertion with evidence favoring suction over water seal for both postthoracic surgery patients and traumatic chest injury patients, until resolution of air leak.

Removal

There are many factors that come into play when determining the correct time to remove a chest tube. The quality of the fluid should be free of chyle, or blood suggestive of active bleeding, and be nonpurulent.[31,32] However, the quantity of fluid that is acceptable before the removal of a chest tube is without consensus, with varying recommended volume thresholds ranging from 200 mL per day to 500 mL per day.[31-33] Cerfolio et al[32] performed a retrospective cohort analysis that demonstrated that chest tube removal up to 450 mL per day was acceptable in patients who underwent elective pulmonary resection. They reported that 364 of 1988 patients (18%) were able to go home sooner owing to surgeons changing to the higher threshold (450 mL per day) and only 11 patients (0.55%) were readmitted as a result of a recurrent symptomatic effusion. Grodzki et al[34] tested this conclusion a year later and removed chest tubes at the higher threshold of 450 mL per day and found that 6 of 40 patients (15%) were readmitted with pleural effusions, thus leading the authors to revert to their original practice of following a threshold of 200 mL per day for chest tube removal. The limitation in the former study is the lack of reliable follow-up, which could account for the low readmission rate, and the limitation in the latter study is the small sample size. Larger randomized clinical trials would be helpful in clarifying this gap in our understanding.

Whether to remove the chest tube at the end of expiration or inspiration is another question that has been widely debated. Novoa et al[31] recommended removing the chest tube at the end of expiration during a Valsalva maneuver, which corresponds to the time when the difference between the atmospheric pressure and pleural pressure is at its lowest.[31] Other studies, such as French et al,[35] emphasized the importance of a Valsalva maneuver during chest tube removal regardless of the respiratory phase in which it is removed. The chest tube should be removed swiftly and the defect in the chest wall should be closed with either a suture that was placed at the time of chest tube placement or with a properly occlusive dressing.

Complications

The retrospective review by Platnick et al[36] found that certain risk factors, such as chest tube placement in the emergency department, placement by emergency medicine clinicians, and placement in patients with a body mass index greater than 30 were all associated with chest tube complications. However, the exact complication rate associated with chest tubes is variable and has been quoted as high as 40%.[36-38] The variability in the reported complication rate can be attributed to a lack of a universally accepted way to categorize the many different complications. Aho et al[20] proposed a way to standardize the reporting of complications surrounding chest tubes to allow for easier recording and collection of data. The 5 complication categories proposed were insertional, positional, removal, infectious, and malfunction. Insertional complications include injury to intrathoracic or extrathoracic organs within 24 hours of insertion, which is a complication most common with chest tubes being inserted via the trocar technique.[19,20] Positional complications are defined as occurring 24 hours after insertion, including erosions into adjacent organs or any tube kinking, obstruction, or being entrapped in the fissure after lung expansion.[19,20] Removal complications encompass failure to seal the chest defect after the chest tube is removed, resulting in entraining atmospheric air, or the retention of any foreign objects after removal.[20] Infectious complications involve any infection, either external from improper sterilizing techniques or internal with the development of an empyema.[20] Malfunction complications include problems that may arise from the health care clinician managing the chest tube or equipment issues.[20] Defining complications in these distinct categories allows clinicians to create a foundation to compare data collected in future studies and protocols to reduce the risk of complication associated with chest tubes.

COVID-19

Chest tube management during the COVID-19 pandemic, or any future coronavirus or H1N1 pandemic, is challenging owing to the risk of aerosolizing dangerous virions. Proper personal protective equipment, minimizing water seal, and using filters to decrease the number of aerosolized particles escaping into the air are modifications that have been implemented in many intensive care units around the world.[37,39] A small observational cohort study[40] found that connecting 2 closed underwater drainage systems in series with an air filter attached to the second system was associated with a decrease in the dissemination of coronavirus particles, as evidenced by a lack of COVID-19 infection reported in their health care workers during the study. However, this study was limited with its small power.

Future Directions

More recent studies are leaning toward conservative management in some specific pleural disease processes. The randomized clinical trial by Hallifax et al[41] demonstrated that the use of ambulatory devices for the treatment of primary spontaneous pneumothorax compared with usual care, which included aspiration or chest tube insertion, was associated with a significantly shorter hospital length of stay. These findings suggest that this subset of patients can be treated in an outpatient setting and that ambulatory devices should be considered as an effective treatment strategy for this disease process. However, there was an increase in the number of adverse events associated with the treatment with ambulatory devices, including enlarging pneumothorax and problems associated with the device, such as kinking or dislodgement, which will require more research if this approach is going to replace the current standard of care.

In a study by Brown et al,[42] conservative treatments, such as observation of moderate- to large-sized primary spontaneous pneumothorax, were found to be noninferior to the placement of a small-bore chest tube regarding resolution of the pneumothorax within 8 weeks. The study reports that 118 of 125 patients (94%) of patients undergoing conservative management did not require an invasive procedure, thus challenging the paradigm that all patients with a hemodynamic and respiratory stable primary pneumothorax should routinely undergo decompression with a chest tube as the first treatment option.

The routine placement of a chest tube after thoracic surgery is another area with emerging research. The randomized clinical trial by Zhang et al[43] showed that the placement of a novel air-extraction double-lumen catheter was noninferior to the placement of a traditional chest tube in the incidence of a pneumothorax on postoperative day 1. The use of this air-extraction catheter was also associated with a significantly lower patient-reported pain score, which supports the argument that more conservative techniques can be used to optimize patient comfort without compromising clinical outcomes.

Conclusions

With the advancement of technology and the push toward less invasive approaches, the treatment of pleural conditions that were once managed solely by chest tubes continues to evolve. However, chest tubes are likely to continue to be a vital part of a clinician's repertoire as they are still considered the standard of care for certain pleural disease processes and life-saving devices in others. It is imperative that trainees have a solid foundation on the management of chest tubes, as their use is a dynamic process that will continue to change as time progresses. This review highlights the studies that have shaped the way chest tubes are managed today and allows the reader to develop and cultivate their understanding.

ARTICLE INFORMATION

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