Over the past ten years, the spectrum of diagnostic techniques available to the pulmonary physician has expanded greatly. Fiberoptic bronchoscopy with transbronchial biopsy, transbronchial needle aspiration, and newly developed laser applications exemplify one aspect of the explosion. Percutaneous needle biopsy and thoracoscopy are examples of the wider scope of invasive techniques now employed by the pulmonologist. Present-day care of critically ill patients often requires invasion of the chest vessels for monitoring and administration of nutrients. However, the price of this invasion is a definite incidence of complications, particularly a potentially life-threatening complication, pneumothorax (hemopneumothorax). Traditionally, tube thoracostomy for pneumothorax or hemothorax has been handled by the thoracic surgeon. Today, because of the increased use of invasive procedures by the pulmonologist, those individuals performing such procedures should be competent in tube thoracostomy and principles of management. In addition to emergency placement, elective indications for tube thoracostomy for the pulmonologist include thoracoscopy and pleurodesis of a symptomatic malignant pleural effusion. The purpose of this paper was to (1) review the historic development of tube thoracostomy; (2) discuss technique of insertion, drainage systems, and management of chest tubes; (3) examine individual components and their optimal characteristics; and (4) note the spectrum and incidence of complications associated with the procedure.

HISTORIC PERSPECTIVE

Hippocrates was the first to consider drainage of the pleural space when he described incision, cautery, and metal tubes to drain empyemas. This concept re-emerged in the midnineteenth century. Hunter, in the 1860s, developed a hypodermic needle capable of being inserted into the pleural space for drainage purposes. Playfair placed a drainage tube with an underwater seal in 1872, and Hewitt described closed tube drainage of an empyema in 1876. Due to technical problems, the procedure was not employed widely until 1917 when it was successfully used to drain postinfluenzal epidemic empyemas. The use of chest tubes in postoperative thoracic care was reported by Lilienthal in 1922. Although used regularly post-thoracotomy in World War II, emergency tube thoracostomy for acute trauma did not become commonplace until the Korean War.

CHARACTERISTICS OF CHEST TUBES

Modern chest tubes are distinctly different from their earlier counterparts. They are made of clear plastic of varying internal diameter, with distance markers, multiple drainage holes, and a radiopaque stripe, which outlines the proximal drainage hole. This addition permits better determination of appropriate tube position on a postplacement chest roentgenogram. They are pliable but not supple enough to kink or obstruct drainage. Tube diameter can vary from 20 to 40 French (5 to 11 mm internal diameter) for adults, 6 to 26 French (2 to 6 mm) for children. The proximal end is slightly bevelled and flared to allow ease of connection to accessory tubing.

INDICATIONS FOR CHEST TUBES

Indications for insertion of a chest tube are listed below, but those of most import to the pulmonologist include spontaneous pneumothorax, iatrogenic pneumothorax, and drainage of malignant effusions with pleurodesis.

Indications for tube thoracostomy include the following:

1. Spontaneous pneumothorax (large, symptomatic or presence of underlying lung disease)
2. Tension pneumothorax (or suspected)
3. Iatrogenic pneumothorax (progressive)
4. Penetrating chest injuries
5. Hemopneumothorax in acute trauma
(6) Patient in extremis with evidence of thoracic trauma
(7) Complicated parapneumonic effusions (empyema)
(8) Pleurodesis for intractable symptomatic effusions, usually malignant
(9) Chylothorax
(10) Postthoracic surgery
(11) Bronchopleural fistula

Absolute contraindications do not exist per se, although coagulopathies and platelet defects might weigh on the clinician's judgment.

SELECTED PULMONARY INDICATIONS FOR CHEST TUBE INSERTION

When pneumothorax is encountered, size, symptoms, and presence of underlying lung disease guide therapeutic intervention. Those patients with minimal, transient symptoms, and a pneumothorax less than 20 to 25 percent without evidence of an increase in the pneumothorax over several hours can be observed. Those with moderate to severe pain, respiratory distress, or evidence of continued air leak should have tube thoracostomy performed. Obviously, any acute pneumothorax under tension should be treated with decompression and tube thoracostomy. Smaller tubes (16 to 20 Fr) placed to underwater seal and directed toward the lung apex should be sufficient to evacuate air from the pleural space and allow lung expansion. When physical examination demonstrates good breath sounds, a visceral pleural line can not be seen on chest roentgenogram, and the water seal reveals no air leak, the tube may be clamped for 12 to 24 hours and removed if the pneumothorax does not recur. If the air leak persists, application of suction (−20 cm H₂O) may aid in evacuating air from the pleural space, allowing the lung to expand, sealing the defect against the parietal pleura and promoting pleural symphysis.

Large symptomatic malignant pleural effusions may be managed by repeated thoracentesis in patients with a limited expected survival. In patients with an expected survival of several months, tube thoracostomy for drainage and instillation of tetracycline usually is recommended. A small tube (16 to 20 Fr) should be inserted and directed posterobasally for optimum fluid removal. Large effusions should be drained slowly, not more than 1,000 ml during the first 30 minutes, to avoid postthoracentesis pulmonary edema. Suction may be applied to remove that fluid which does not drain spontaneously over the next 12 to 24 hours. When drainage is minimal and the chest roentgenogram shows complete lung expansion, tetracycline (20 mg/kg) should be instilled through the chest tube into the pleural space. Following instillation, the chest tube should be clamped for one to two hours. Preliminary data suggest that complete pleural space dispersion occurs without patient movement. Following unclamping, suction is applied to the pleural space to promote fluid removal and apposition of the pleural surfaces. The chest tube is removed when drainage is minimal (50 to 100 ml/24 hours), and the chest roentgenogram shows complete lung expansion and a paucity of fluid.

When a patient who has undergone tube thoracostomy for a large pneumothorax of effusion and develops dyspnea in the postoperative period, the diagnosis of reexpansion pulmonary edema should be considered. The likelihood of this complication appears to be increased when there is chronic collapse, endobronchial obstruction, trapped lung, rapid removal of air or fluid, and increased intrapleural negative pressure due to suction. Roentgenograms reveal diffuse alveolar filling in the ipsilateral lung. The alveolar edema fluid is rich in protein suggesting more than a simple hydrostatic leak in an acutely hyperperfused lung. Treatment involves intravascular volume assessment, supplemental oxygen, diuresis, and if necessary, intubation and ventilation. Although a potentially fatal problem, early recognition and treatment leads to a favorable outcome.

When empyema is diagnosed, tube thoracostomy is indicated immediately. Some patients with pneumonia have pleural effusions that require drainage despite not satisfying criteria for empyema. These complicated parapneumonic effusions are defined by their biochemical parameters (pH < 7.20, glucose < 40 mg/dl, and LDH < 1,000 U/L). Although the fluid at the time of thoracostentesis may not be purulent, complicated parapneumonic effusions behave clinically like empyemas and should be treated in similar fashion. Early drainage of these free-flowing effusions removes potentially fibrogenic material from the pleural space rapidly and prevents loculation, extensive pleural fibrosis, trapped lung and a restrictive ventilatory defect. Large tubes (28 to 36 Fr) should be inserted to drain these effusions. Tubes should be directed posteriorly and inferiorly into the area of loculation and connected to suction to promote optimal drainage. Once the patient becomes afebrile, pleural space drainage is serous, totaling less than 50 ml/24 hours, and minimal fluid remains on chest roentgenogram, the tube should be removed in the absence of an empyema cavity.

TECHNIQUE OF CHEST TUBE PLACEMENT

Traditional teaching suggests that the site of insertion depends upon the site of obstruction being removed from the pleural space. The relatively wide, avascular second intercostal space in the midclavicular line generally is the recommended insertion site for treatment of a pneumothorax, as air rises to the apical
region of the pleural space. If cosmetic results are of prime concern, the third to fifth intercostal space in the midaxillary line, just below the pectoralis major muscle in the axilla, can be used to avoid an obvious surgical scar. Others suggest posterior apical tube placement. Once inserted, the tube is directed anteropically.

Free-flowing pleural effusions may be drained by a chest tube inserted in the sixth intercostal space in the midaxillary line and directed inferiorly and posteriorly. Loculated fluid should be drained by insertion of the tube into the specific area indicated on plain roentgenogram or as directed by ultrasound or computed tomographic guidance. Although air and fluid usually can be drained from a single, appropriately placed tube, multiple loculated collections of both air and fluid may require more than one chest tube. The substance being drained dictates tube size, as pneumothorax or serous effusions may be drained by smaller 16 to 20 Fr tubes, while blood, pus, or thick fluid require a larger bore 28 to 36 Fr tube to allow adequate drainage. Occasionally, as in bronchopleural fistula, a large bore tube may adequately drain the pleural space when a smaller tube might not allow a satisfactory flow rate to keep the lung expanded. Some bronchopleural fistulas may require two drainage tubes to evacuate air adequately from the pleural space and promote pleural symphysis. The pleural drainage unit needs to be evaluated carefully when a persistent bronchopleural fistula exists as the leak may exceed the capabilities of the apparatus.

When inserting a chest tube, the site selected should be cleaned with povidone iodine and liberally infiltrated with 1 percent xylocaine (10 to 20 ml). Infiltration of the peristeum of the adjacent rib and the parietal pleura prevents unnecessary pain for the patient. Employing sterile technique, a 2 cm incision should be made over and parallel to the midportion of the rib. Prior to tube insertion, a simple mattress suture should be placed through the incision for two reasons. First, when the tube is inserted, the ends of the suture can be wrapped around the tube and tied as an anchoring device and second, on removal of the tube, tension applied to the untied suture ends helps close the incision and prevents entry of air.

The two techniques for insertion commonly employed are as follows: (1) trocar method; and (2) blunt dissection. Chest tubes can be purchased with or without a trocar, a sharp-tipped metal rod which extends through the distal end of the plastic tube. This rigid trocar is sufficiently sharp that it can be inserted into the incision site and forced into the pleural space with direct pressure and a twisting motion. This method of insertion, without a safety mechanism to prevent over-penetration, has an increased risk of lacerating the lung or other intrathoracic structures.

Blunt dissection into the pleural space by a Kelly clamp has replaced the use of a trocar in many institutions (Fig 1). Once entry has occurred by pressure on the Kelly clamp, the instrument is withdrawn and a finger inserted to lyse any adhesions and assure that the pleural space has been entered. The tube is clamped at the proximal end with forceps and inserted into the pleural space. With either method, it is important that a diagonal subcutaneous tunnel be created on insertion, to lessen the likelihood of infection, to decrease the chance of air entry into the pleural space on tube removal, and to aid in primary union of the wound when the tube is removed. After insertion, the tube should be directed anteropical for a pneumothorax and posterobasal for fluid drainage. A postplacement posteroanterior and lateral chest roentgenogram confirms appropriate tube position.

After appropriate positioning, several methods of securing the tube can be utilized to prevent accidental removal. Initially, the loose ends of the mattress suture can be wrapped around the end of the tube and tied off, anchoring the tube to the chest wall. Although some physicians prefer covering the incision with petroleum-laden gauze to prevent air leaks, the application may macerate the skin and predispose to infection, and thus, is not recommended. Bacteriostatic ointment may be applied to the site and covered with dry gauze. Surgical tape then is applied, to cover the wound and anchor the tube. Several inches proximally, an omental tag of tape can hold the tube close to the chest wall and still allow some motion without disturbing the site of
entry. Once connected to drainage, pinning the accessory tubing to the bed sheet provides additional security.

**DRAINAGE SYSTEMS**

Once secured, tubing and connectors should be selected to attach the chest tube to a drainage device. In a survey of 328 thoracic surgeons, Munnell and Thomas found that clear, plastic, serrated connectors of at least ¼ inch internal diameter were preferred and that glass or opaque connectors were avoided. Glass connectors are subject to breakage and opaque connectors hide possible obstruction. The larger the connector, the less likely that blood, fluid, or tissue will obstruct this smallest component of the system. Taping the ends of the connectors to the tubing aids in preventing accidental separation at this site.

When selecting tubing, it should be remembered that gas moving through tubing displays laminar flow and obeys Poiseuille's Law ($v = \frac{\pi r^4 P}{8\eta L}$). Both radius and length are important in determining resistance to flow. A plot of flow vs tube radius suggests an exponential relationship, with tubes of ½ inch internal diameter being capable of handling flows of 50 to 60 L/min; this is the tubing size preferred by most thoracic surgeons. Moist air in a hydropneumothorax displays turbulent flow, and the Fanning equation ($v = \frac{\pi r^4 P}{6\eta L}$) indicates the greater importance of the radius of the tube. In both situations, tubing length is important, and most operators prefer a standard length of six feet. Tubing should be clear, flexible, and sufficiently strong to resist tearing.

When inserting a chest tube, a preselected drainage system should be prepared for immediate connection. All drainage systems, simple or complex, require a water seal. This seal allows fluid or air to drain without allowing air to be "sucked into" the pleural space. In the case of a primary spontaneous pneumothorax (no clinical lung disease), water-seal drainage may be all that is necessary (Fig 2). If a persistent air leak exists, suction may be necessary to achieve complete expansion of the lung and apposition of the pleural surfaces. A two-bottle system is optimal for drainage of effusions, with the first being a trap and the second acting as the water seal (Fig 3). Addition of the trap bottle obviates recurrent manipulation of the water seal tube, which needs to be kept only 2 to 3 cm below the water line, and would necessitate repeated withdrawal as fluid accumulated in the water seal bottle.

When an unregulated vacuum source exists and a constant negative pressure is desired, a third water manometer bottle can be added to the system (Fig 4). This bottle has an input and output tube, and a central moveable vent tube, which can be raised or lowered to adjust its underwater depth. Its depth below the water level determines the negative pressure the system will generate. When high (50 to 60 cm) negative pressure is desired and an unregulated wall suction source exists, an inordinately large column of water may be necessary to appropriately adjust the water manometer vent tube. This problem may be obviated by using liquids of differing density in the manometer bottle. A 1-cm column of mercury is equivalent to 13.76 cm of water; and the addition of small, measured amounts of mercury will allow generation of greater negative pressures.
without the presence of awkward, large manometer chambers. The presence of mercury in the third of a three-bottle system is safe and is not a hazard to the patient.

This three-bottle system has been compartmentalized into a plastic unit which is unbreakable, easily transportable, readily pressure adjustable, and permits easy access to obtain specimens. These compact units have their own intrinsic resistance, as does each segment of a chest tube system. Capps et al. showed that although flow through these units is primarily limited by the maximum flow rate at the suction source, the unit itself contributes significantly to the resistance of the system. They examined capabilities of five commonly used chest drainage units under the following two conditions: (1) wall suction set at 40 L/minute; and (2) suction pressure at -20 cm H2O. As noted in Table 1, they found that flow through the unit when suction was set at 40 L/min decreased as the internal resistance of the unit increased. Likewise, flow at a set suction pressure fell as resistance increased. Control valves between chambers and the water manometer chamber itself were considered the points of highest internal resistance. When high flow rates are necessary, one should consider the flow characteristics of these systems and employ one with a low intrinsic resistance. Although convenient, these units are relatively expensive and may be considered an extravagance. Despite their cost, they enjoy widespread use and familiarity with their workings is desirable.

Like any closed system with air and tubing, chest tube drainage systems have intrinsic compliance. The larger the collection bottle and the longer the tubing, the more backflow can be generated on inspiration. In some situations, as much as 60 ml of air may re-enter the pleural space on inspiration. Although not often a problem, it could be a contributing factor to continued respiratory failure in patients with severe underlying lung disease.

When suction is indicated, flow and pressure requirements must be considered. Low pressure systems capable of generating between 15 and 20 cm H2O negative pressure and between 5 to 10 L/min of flow include the Stedman, Gomco, and Thermovac. Emerson and Sorenson systems are high pressure systems capable of pressures of -60 cm H2O with flows of >20 L/min. When selecting a suction system, care should be exercised to provide a negative pressure greater than the possible positive pleural pressure seen on expiration, for if these conditions are not met, a tension situation could be created despite continuous suction. Overall, in Munneill and Thomas's survey, 82 percent of surgeons favored a high pressure, high flow system, with one-half selecting an Emerson or similar device.

Table I—Resistance Characteristics of Chest Drainage Units*

<table>
<thead>
<tr>
<th></th>
<th>Wall Suction at 40 L/Min Measured Flow (L/Min)</th>
<th>Suction Pressure Set at -20cm H2O Measured Flow (L/Min)</th>
<th>Calculated Resistance at 40 L/Min Resonance (cmH2O/L/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emerson WS</td>
<td>35.5</td>
<td>35.5</td>
<td>15.0</td>
</tr>
<tr>
<td>Pleur-evac A4000</td>
<td>34.0</td>
<td>34.0</td>
<td>22.8</td>
</tr>
<tr>
<td>Pleur-evac A4005</td>
<td>33.5</td>
<td>32.7</td>
<td>38.0</td>
</tr>
<tr>
<td>Thoraklex</td>
<td>22.5</td>
<td>19.7</td>
<td>62.7</td>
</tr>
<tr>
<td>Sentinel Seal</td>
<td>5.8</td>
<td>2.3</td>
<td>&gt;450</td>
</tr>
</tbody>
</table>

*Modified from Capps et al. 

262 Chest Tubes (Miller, Sahn)
CHEST TUBE TROUBLE SHOOTING

When the functional status of a tube is questioned, several simple maneuvers can be employed to assess its integrity. Observation of synchronous water seal and respiratory motion suggest the tube is still functioning in the pleural space and all connections are tight. If the tube is not functioning and occlusion of the drainage holes is suspected, the tube can be disconnected and flushed with saline solution, in an effort to dislodge obstructing debris. In the past, instillation of streptokinase and streptodornase was employed successfully to open occluded tubes.24,25 Today, saline irrigation generally is the initial approach to tube obstruction with the fibrinolytic agents an alternative, especially in parapneumonic effusions.

If an air leak is suspected at a particular point in the system, be it bottle, tube, or connector, sequential clamping with distal suction before and after the spot in question should be performed. Demonstration of bubbling air through the water seal when the drainage system is clamped just proximal to the point in question which disappears when clamped just distal to that point identifies the site of leakage; the identified component then can be changed.

CHEST TUBE REMOVAL

When the indication for tube thoracostomy is no longer present or the tube is nonfunctional, it should be removed. Authors differ on the methods to remove chest tubes.26,27 Opinion is divided as to the necessity of clamping prior to tube removal, with 75 percent of thoracic surgeons surveyed favoring clamping for 12 to 24 hours prior to removal.28 Clamping allows for identification of persistent air leak or re-accumulation of fluid. We suggest that in preparation for removal, the bandage should be removed, the site cleaned, and the previously-tied mattress suture clipped, allowing its ends to be freed. At the time of removal, the patient should exhale and perform a Valsalva maneuver. With tension applied to the mattress suture, to hold the incision edges together, the tube is removed quickly and smoothly at end-expiration. The mattress suture then can be tied to oppose the wound margins. Routine wound care and suture removal at three to five days allows for optimum healing. A chest roentgenogram, 12 to 24 hours following chest tube removal, for observation of residual air or fluid is recommended.

COMPLICATIONS

Few studies of thoracostomy tube complications exist; most reports are anecdotal. Milliken et al29 retrospectively analyzed complications in patients receiving tube thoracostomy in the setting of acute trauma over an 11-year-period. Technical complications were analyzed in a subgroup of 447 patients whose tubes were placed by blunt dissection after trocar insertion was no longer performed. Four of 447 (1 percent) patients suffered a technical complication including diaphragm laceration (two), lung laceration (one), avulsion injury to the lesser curve of the stomach (one), and a laceration to the left lobe of the liver (one). Of a total of 1,249 patients, there were 30 cases of empyema (2.4 percent), 19 associated with trocar insertion and 11 with blunt dissection. There were no deaths in the series directly attributable to tube insertion.

The literature reports a variety of complications. Laceration of the lung, reported frequently, is more likely to occur in patients with lungs that have decreased compliance or when pleural symphysis or adhesions exist.29,30 This situation also may exist following an unsuccessful attempt at pleural symphysis with sclerosing agents. Splenic, liver, and stomach lacerations have been reported by inadvertent passage of the tube through the diaphragm.29 This occurs more often than expected, since the diaphragm may rise as high as the fourth intercostal space on full expiration. Intercostal artery bleeding can be avoided by placing the tube just superior to the rib and avoiding the inferior margin of the rib above with its underlying neurovascular bundle. Moreover, the operator should be aware that the intercostal vessels tend to become more tortuous with age.31 Unilateral pulmonary edema is a well-described complication which follows rapid removal of a large pleural effusion or pneumothorax.32 Subcutaneous33 or direct abdominal placement34 of tubes has been reported. A rare complication is infarction of a peripheral segment of lung aspirated into the drainage port of the chest tube.35 Subcutaneous emphysema can occur at the site of tube insertion and spread over the chest wall but is generally only a cosmetic problem.

Prophylactic antibiotic administration with chest tube placement is controversial. In a study of patients requiring tube thoracostomy for penetrating chest wounds, Grover and associates36 found that 2.6 percent of clindamycin-treated patients developed pleural space infection vs 16 percent of control subjects. In contrast, Neugebauer et al,37 in a study of 143 patients with spontaneous pneumothorax, found that those receiving prophylactic antibiotics had a higher complication rate (13.8 vs 3 percent). In the absence of trauma and with good aseptic technique, there is no need for prophylactic antibiotics with chest tube insertion.

REFERENCES

3 Playfair GE. Case of empyema treated by aspiration and subsequently by drainage: recovery. Br Med J 1875; 1:45
6 Lillenthal H. Resection of the lung for supportive infections with a report based on 31 consecutive operative cases in which resection was done or intended. Ann Surg 1922; 75:257-320
8 Wallach HW. Intrapleural tetracycline for malignant pleural effusions. Chest 1975; 68:510-12
10 Waquardin M, Berstein A. Re-expansion pulmonary edema. Thorax 1975; 30:54-60
11 Bernstein A. Re-expansion pulmonary edema. Chest 1980; 77:708
22 Capps JS, Tyler ML, Busch VW, Pierson DJ. Potential of chest drainage units to evaluate bronchopleural air leaks. Chest 1985; 88:57
24 Miller JM, Ginsberg M, Lipin RJ, Long PH. Clinical experience with streptokinase and streptodornase. JAMA 1951; 145:620-24
31 Carney M, Ravin CE. Intercostal artery laceration during thoracentesis: increased risk in elderly patients. Chest 1979; 75:520-22