CHAPTER 144  ■ PLEURAL DISEASE IN THE INTENSIVE CARE UNIT

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Pleural disease itself is an unusual cause for admission to the intensive care unit (ICU). Conditions potentially requiring ICU admission include a large pleural effusion causing acute respiratory failure, hemothorax producing respiratory or hemodynamic compromise, secondary spontaneous pneumothorax with respiratory failure, empyema with sepsis, and re-expansion pulmonary edema. Pleural complications of disease processes and procedures performed in the ICU are common, however, and the changes in respiratory physiology are additive to that of the underlying lung disease. The development of a pneumothorax in a critically ill patient, particularly in mechanically ventilated patients, may be a life-threatening event. Pleural effusions may be overshadowed by the illness requiring ICU admission in the critically ill patient. Pleural effusions and pneumothoraces may not be detected on chest radiographs because the radiologic appearance may differ in the supine patient.

PLEURAL EFFUSIONS IN THE INTENSIVE CARE UNIT

Radiologic Evaluation

In the normal pleural space, air and fluid tend to distribute following gravitational influences, with air initially accumulating between the superior portion of the lung and the apex of the thorax, while fluid accumulates between the inferior margin of the lung and the diaphragm. Pleural air and fluid collections shift location when radiographs are obtained in positions other than the erect position. Because radiographs in critically ill patients are taken in the supine or semierect position, the radiographic appearance of air and fluid in the pleural space may thus change.

In normal humans in the supine position, the radiolucency of the lung base is equal to or greater than that of the lung apex due to the anteroposterior diameter of the lung being greatest at the lung base. In addition, in the supine patient, breast and pectoral tissues will tend to move laterally away from the lung base. A pleural effusion should be suspected when increased homogeneous density is present over the lower lung fields as compared with the upper lung fields. Patient rotation, an off-center x-ray beam, prior lobectomy, or a pleural or chest wall mass may produce a unilateral homogeneous density that simulates the appearance of a pleural effusion (1). Cardiomegaly, a prominent epicardial fat pad, and lobar collapse or consolidation may obscure the detection of a pleural effusion on a supine radiograph.

Approximately 175 to 325 mL of pleural fluid will produce blunting of the costophrenic angle on an erect chest radiograph (2). This quantity of pleural fluid can usually be detected on a supine radiograph as an increased density over the lower lung zone. Blunting of the costophrenic angle (meniscus sign), subluxation of the hemidiaphragm, and apical capping may be seen with larger effusions (3). An apparent elevation of the hemidiaphragm may be secondary to a subpulmonic collection of pleural fluid. A diffuse increase in the radiodensity of the hemithorax, or “veiling,” may be seen with very large effusions in the supine radiograph. Thus, the major radiographic finding of a pleural effusion in the supine patient is an increased homogeneous density over the lower lung field that does not obliterate normal bronchovascular markings, does not demonstrate air bronchograms, and does not produce hilar or mediastinal displacement until the effusion is massive. If a pleural effusion is suspected in the supine patient, obtaining an erect or lateral decubitus radiograph may be helpful.

Because the critically ill patient often has underlying parenchymal lung disease, the diagnosis of pleural effusion can be problematic. Ultrasonography (US) or computed tomography (CT) scanning may be required to confirm or exclude the presence of a pleural effusion. US provides good characterization of pleural disease and has an advantage of being able to be performed at the bedside in critically ill patients who are not stable for transport to the radiology department for CT. Disadvantages include impedance of the ultrasound wave by air in the lung or pleural space, a restricted field of view, inferior evaluation of the lung parenchyma compared to CT, and operator dependence (1). In one study of 74 ICU patients evaluated by both chest radiograph and US, the latter detected a pleural effusion that was not appreciated on chest radiograph in 10 additional patients (28% of patients determined to have a pleural effusion) (4). In another study, US was helpful in making a diagnosis in 27 of 41 (66%) patients and influenced treatment planning in 17 of 41 critically ill patients (41%) (5). US-guided thoracentesis at the bedside was successful in 24 of 25 patients in that same study. Other studies have noted the usefulness of US to safely guide bedside thoracentesis in mechanically ventilated patients (6–8). The presence of complex septated, complex nonseptated, and homogeneously echogenic patterns within pleural fluid collections are typically indicative of an exudative pleural effusion (9). Homogeneously echogenic effusions suggest hemorrhagic effusions or empyemas whereas US evidence of fibrin septae suggests a parapneumonic effusion, empyema, hemothorax, or malignant effusion (9).

CT may also be helpful in assessing pleural processes in the critically ill patient, and has the advantages of better lung parenchymal imaging, evaluation of the mediastinum, and
ability to distinguish pleural from parenchymal abnormalities (1). On CT, free-flowing pleural fluid produces a saddle-shaped opacity in the most dependent part of the thorax (10). Loculated pleural fluid collections are seen as lenticular or rounded opacities in a fixed position with a relatively homogeneous water density (10). CT may be particularly helpful in the diagnosis and management of loculated pleural effusions (11). The most reliable sign of empyema, the split pleura sign, is usually identified during the organizing phase. Following administration of intravenous contrast, the parietal and visceral pleura will be thickened and enhanced and will be noted to be separated, and the extrapleural fat between the empyema and the chest wall may be increased in size (12,13). In one study, this sign was present in only 68% of patients, however (12). CT may be helpful in assessing inadequately drained fluid collections in patients with persistent fevers or sepsis due to malpositioned chest tubes (14).

**Diagnostic Thoracentesis**

Pleural effusions are common in the ICU. In one prospective study of 100 consecutive patients admitted to a medical ICU, pleural effusions were found on chest radiographs and/or by US in 62% of patients (4). Patients with a pleural effusion provide the opportunity to diagnose, at least presumptively, the underlying process responsible for the accumulation of pleural fluid. Although disease of any organ system can cause a pleural effusion in critically ill patients, the diagnoses listed in Table 144.1 represent most causes in the ICU.

When a pleural effusion is suspected on physical exam and confirmed radiographically, a diagnostic thoracentesis should be considered to establish the cause of the effusion. Observation alone may be reasonable in situations in which the clinical diagnosis is reasonably secure and a small amount of pleural fluid is present, such as in atelectasis or uncomplicated heart failure (15). Thoracentesis should be performed, however, if the patient’s clinical condition changes. When the distance from the pleural fluid line to the inside of the chest wall is less than 1 cm on lateral decubitus radiograph, the risk of thoracentesis probably outweighs the value of pleural fluid analysis. If the underlying disease causing the pleural effusion becomes clinically problematic, the effusion will often increase in size and allow for safe thoracentesis. When sampling of a small-volume pleural effusion is indicated, thoracentesis should be performed with US guidance.

The indications for diagnostic thoracentesis are not different in the ICU patient, and receiving mechanical ventilation is not a contraindication. Establishing the diagnosis quickly in critically ill patients may be more important than in the noncritically ill. The reported incidence of pneumothorax in nonventilated patients ranges from 4% to 30% (16–20). Various risk factors for developing a pneumothorax after thoracentesis have been reported, although operator inexperience, baseline lung disease, and use of positive pressure mechanical ventilation appear to be the most established risk factors. Several earlier studies have demonstrated that the incidence of pneumothorax after blind thoracentesis in mechanically ventilated patients (21–23). If the patient on mechanical ventilation does develop a pneumothorax, however, a significant sign of progression to a life-threatening tension pneumothorax exists. As such, some authors have advocated the routine use of ultrasound guidance for all thoracentesis procedures in mechanically ventilated patients given the observed pneumothorax rates of 0% to 3% with ultrasound guidance in nonventilated patients (20,24), as well as in patients receiving mechanical ventilation (6–8). Strong consideration should be given to using US guidance in patients with small or moderate effusions, although large effusions may be sampled relatively safely unless the operator is inexperienced. US or CT guidance should be used to sample loculated pleural fluid collections. There are no absolute contraindications to diagnostic thoracentesis. The major relative contraindications are a bleeding diathesis or anticoagulation. In one study of 207 patients with mild to moderate coagulopathy, defined as a prothrombin time (PT) or partial thromboplastin time (PTT) up to twice normal or a platelet count from 50,000 to 100,000 cells/μL, no increase in bleeding complications was noted (25). Thoracentesis should not be performed through an area of active skin infection.

### **Therapeutic Thoracentesis and Physiologic Effects**

The primary indication for therapeutic thoracentesis or chest tube drainage of a pleural effusion is relief of dyspnea, although pulmonary mechanics and oxygenation may be improved in some patients (26). Contraindications to therapeutic thoracentesis are similar to those of diagnostic thoracentesis. Complications from therapeutic thoracentesis are similar to that of diagnostic thoracentesis, with the additional complications of hypoxemia, re-expansion pulmonary edema, and hypovolemia. An increased risk of pneumothorax compared to diagnostic thoracentesis has been noted with therapeutic thoracentesis in some studies (18,20,27) although not others (19,28).

### **TABLE 144.1**

<table>
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<tr>
<th>Causes of Pleural Effusions in ICU Patients</th>
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<tr>
<td>Abdominal surgery</td>
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<td>Acute respiratory distress syndrome (ARDS)</td>
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<td>Atelectasis</td>
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<td>Chylous effusion</td>
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<td>Congestive heart failure</td>
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<td>Coronary artery bypass surgery</td>
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<td>Empyema</td>
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<td>Hemorrhage</td>
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<td>Hepatic hydrothorax</td>
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<td>Iatrogenic</td>
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<tr>
<td>Central venous catheter placement</td>
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<tr>
<td>Nasogastric tube placement</td>
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<tr>
<td>Vascular erosion by central venous catheter</td>
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<tr>
<td>Intra-abdominal abscess</td>
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<tr>
<td>Malignancy</td>
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<tr>
<td>Pancreatic/Pancreatic pseudocyst</td>
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<td>Pneumonia</td>
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<td>Postcardiac injury syndrome</td>
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<td>Pulmonary embolism</td>
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<td>Uremia</td>
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We would recommend the use of a catheter-over-needle system in performing therapeutic thoracentesis to reduce the risk of developing a pneumothorax. In patients with pleural effusion and ipsilateral shift suggesting endobronchial obstruction or a trapped lung, the risk of re-expansion pulmonary edema may be increased, and the patient may be less likely to experience a beneficial effect. In addition, patients with initial negative pleural pressures and those with more precipitous falls in pleural pressures with fluid removal also likely have trapped lung or endobronchial obstruction and are less likely to benefit from therapeutic thoracentesis (29).

Pleural effusions compress the lung, causing atelectasis, ventilation/perfusion mismatch, and shunt physiology with resultant hypoxemia (30). Pleural fluid tends to enlarge the volume of the hemithorax more than it compresses lung volume. Studies in humans have shown that total lung capacity following thoracentesis increases by only approximately one third of the thoracentesis fluid volume, and forced vital capacity increases by approximately one half of the increase in total lung capacity (31). Studies evaluating gas exchange in non-ventilated patients have been mixed. One study found a decrease in PaO$_2$ (32), one study found no change in PaO$_2$ (33), and one study showed a mild increase in PaO$_2$ (34). More recent studies have also shown variable results, with one study reporting a small increase in PaO$_2$ and decrease in alveolar-arterial O$_2$ gradient (35), although another noted no change in PaO$_2$, alveolar-arterial O$_2$ gradient or shunt, while the amount of blood flow to low ventilation/perfusion units increased slightly (30).

Despite these mixed results, some patients requiring mechanical ventilation may benefit from pleural fluid drainage. Talmor et al. (26) reported that 19 patients with acute respiratory failure and pleural effusions who had a poor response to positive end-expiratory pressure (PEEP)—defined as the inability to wean FiO$_2$ to 0.5 with PEEP up to 20 cm H$_2$O—benefited from chest tube drainage of the pleural effusions. Studies evaluating gas exchange in non-ventilated patients have been mixed. One study found a decrease in PaO$_2$ (32), one study found no change in PaO$_2$ (33), and one study showed a mild increase in PaO$_2$ (34). More recent studies have also shown variable results, with one study reporting a small increase in PaO$_2$ and decrease in alveolar-arterial O$_2$ gradient (35), although another noted no change in PaO$_2$, alveolar-arterial O$_2$ gradient or shunt, while the amount of blood flow to low ventilation/perfusion units increased slightly (30).

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**Abdominal Surgery**

Approximately one half of patients undergoing abdominal surgery will develop small unilateral or bilateral pleural effusions 24 to 48 hours following surgery (37,38). The incidence of pleural effusions is higher in procedures involving the upper abdomen, in patients having ascitic fluid at time of surgery, and in patients who have postoperative atelectasis (29). Larger left-sided effusions are common following splenectomy. The effusion after abdominal surgery is usually exudative with a normal glucose level, pH > 7.40, and less than 10,000 nucleated cells/μL (37). Small effusions generally do not require diagnostic thoracentesis and resolve spontaneously without becoming clinical significant. Thoracentesis is indicated to exclude empyema if the effusion is relatively large or localized or if the possibility of a subdiaphragmatic abscess related to the surgery exists.

**Acute Respiratory Distress Syndrome**

The presence of pleural effusions in acute respiratory distress syndrome (ARDS) has not been well appreciated or studied. In a retrospective study of 23 patients with ARDS, 36% were found to have pleural effusions (39). All patients had exudative alveolar infiltrates in addition to pleural effusions. Pleural effusions have been observed in animal models of ARDS using α-naphthylthiourea, oleic acid, and ethchlorvynol (40,41). In the oleic acid model, 35% of the excess lung water collected in the pleural spaces (40). Effusions are likely under-diagnosed in ARDS because the patient has bilateral alveolar infiltrates and the radiograph is taken in the supine position. In experimental models of ARDS, the effusions are serous to serosanguineous with a predominance of polymorphonuclear leukocytes (PMNs) (41). These effusions resolve as the ARDS resolves and require no specific therapy.

**Atelectasis**

Atelectasis is a common cause of small pleural effusions in the ICU due to patients being immobile (4). Atelectasis and small effusions are commonly observed following cardiothoracic or abdominal surgery. Other potential causes include endobronchial obstruction from tumor, foreign body, or mucus plugging as well as extrinsic airway compression from malignancy. With lung collapse, local areas of increased negative pressure are created by the separation of the lung and chest wall. The decrease in pleural pressure favors the movement of fluid into the pleural space, presumably from the surface of the parietal pleura (15).

Pleural effusions in atelectasis are serous transudates with a few mononuclear cells, but a glucose concentration equal to serum, and a pH of 7.45 to 7.55. The pleural effusions dissipate over several days when the atelectasis resolves.

**Chylothorax**

A chylothorax is defined as the accumulation of chyle in the pleural space. The predominant mechanisms of chylothorax formation include disruption of the thoracic duct or extravasation from pleural lymphatics, and transdiaphragmatic efflux from chylous ascites (42). The most common cause of chylothorax is lymphoma, accounting for 37% of chylothoraces in

**Footnotes**

- Effusions are termed exudative—or not—by lactate dehydrogenase (LDH) and protein criteria. Only LDH and protein values are used in the Light criteria although albumin level is used by some. pH, glucose, and cell counts are not part of the classification of transudates versus exudate.

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a series of 191 patients (43). The second most frequent cause is surgical trauma, which represented 25.5% of cases in the same series of 191 patients (43). The incidence of chylothorax following thoracic surgery has been reported to be 0.36% to 0.42% (44,45) and 1.9% following lower neck surgery (46). A higher proportion of chylothoraces are noted following esophagectomy (44,45). Virtually all intrathoracic surgical procedures, including lobectomy, pneumonectomy, and coronary artery bypass grafting, have been reported to cause chylothorax (43). Non-surgical trauma, including blunt and penetrating injuries to the neck, thorax, and upper abdomen as well as obstruction of the superior vena cava or thrombosis of the left subclavian vein from indwelling central venous catheters, may produce chylothoraces in ICU patients (47).

The patient may be asymptomatic if the effusion is small and unilateral, or may be dyspneic with a large unilateral effusion or bilateral effusions. The pleural fluid is usually milky but can be serous, xerostereosanguineous, or bloody. The fluid may not have a milky appearance if the patient is malnourished or not eating (48). The pleural fluid typically has less than 7,000 nucleated cells/μL, which are greater than 80% lymphocytes. The pH is alkaline (7.40–7.80), and the triglyceride levels exceed plasma levels (15). A pleural fluid triglyceride concentration greater than 110 mg/dL makes the diagnosis of chylothorax highly likely, whereas a concentration less than 50 mg/dL makes the diagnosis highly unlikely. With triglyceride concentrations of 30 to 110 mg/dL, lipoprotein electrophoresis is indicated to demonstrate the presence of chylomicrons, which confirms the diagnosis of chylothorax (48).

Up to 2 to 3 L of chyle may drain daily, causing loss of fluid, electrolytes, protein, fat, fat-soluble vitamins, and lymphocytes. Severe nutritional depletions and immunodeficiency may result if these losses are not addressed. In addition to chest tube drainage, initial conservative management consists of intravenous hydration and a nonfast, high-protein, high-calorie diet with medium-chain triglycerides, which are absorbed directly into the portal system, or discontinuing all oral feeding and initiating total parenteral nutrition. If the chylothorax fails to resolve with conservative measures after 7 to 14 days, then surgery with thoracic duct ligation may be considered (44,45), although pleuropertitoneal shunting has also been used.

### Congestive Heart Failure

Congestive heart failure (CHF) is the most common cause of all transudative pleural effusions and in one study was the most common cause of pleural effusions in a medical ICU (4). Pleural effusions due to CHF are associated with increases in pulmonary venous pressure. In a study of 37 patients admitted for CHF, the mean pulmonary capillary wedge pressure (PCWP) was higher in patients with pleural effusions than in those without—24.1 versus 17.2 mm Hg, respectively (49). Isolated increases in right heart pressures were not associated for CHF, the mean pulmonary capillary wedge pressure (PCWP) was higher in patients with pleural effusions than in those without—24.1 versus 17.2 mm Hg, respectively (49). Isolated increases in right heart pressures were not associated with pleural effusions. Patients with chronic obstructive pulmonary disease (COPD) and cor pulmonale, in the absence of left ventricular dysfunction, thus rarely have pleural effusions, and other causes for pleural effusions should be sought in these patients.

Most patients with pleural effusion secondary to CHF have the usual signs and symptoms. The chest radiograph classically demonstrates cardiomegaly and bilateral small to moderate pleural effusions of similar size, with right-sided effusions often being slightly greater than the left. Radiographic evidence of pulmonary edema is usually present, with the severity of pulmonary edema correlating with the presence of effusions. In patients who have been hospitalized, records will usually show intake greater than output for several days, weight gain, an increasing alveolar-arterial O2 gradient, and decreasing compli-

### Esophageal Rupture

Spontaneous esophageal rupture—Boerhaave syndrome—is a potentially life-threatening event and requires immediate diagnosis and therapy. Esophageal rupture or perforation may rarely occur with blunt thoracic trauma or as a complication of endoscopy and nasogastric/orogastric tube placement. The history in spontaneous esophageal rupture is usually severe...
Pleural effusions are found in approximately 50% of patients 48 to 72 hours following esophageal sclerotherapy (56). Effusions may be unilateral or bilateral, with no prediction for side. The effusions tend to be small, serous exudates with variable nucleated (38,000-80,000 cells/µL) and red cell counts (126,000 to 140,000 cells/µL) and glucose concentrations similar to serum. The mechanism for development of these effusions is likely extravasation of the sclerosant beyond the esophageal mucosa, resulting in mediastinal and mediastinal pleural inflammation. An effusion that is not associated with fever, chest pain, or signs of perforation is not important clinically, and will usually resolve over several days to weeks without specific therapy. A diagnostic thoracentesis should be performed and an esophagram considered in patients with symptomatic effusions for 24 to 48 hours to exclude empyema and esophageal perforation.

Hemotherax

Hemotherax needs to be differentiated from a hemorrhagic pleural effusion, as the latter can be the result of only a few drops of blood in serous pleural fluid. The arbitrary definition of a hemotherax is a pleural fluid to blood hematocrit ratio greater than 50%. Most hemotheraxes result from blunt or penetrating thoracic trauma (57). Hemotherax also results from invasive procedures, pulmonary infarction, malignancy, and ruptured aortic aneurysms. Anticoagulation therapy or coagulopathy may rarely cause a spontaneous hemotherax. Hemothorax should be suspected in any patient with an iatrogenic or penetrating chest trauma with a pleural effusion on chest radiograph. Chest tube thoracotomy with a 28 to 32 French chest tube should be performed in these patients and pleural fluid hematomatocrit measured. In the patient with suspected iatrogenic or spontaneous hemotherax, thoracentesis should be performed, and if positive, a chest tube should be inserted. Chest tube drainage allows the monitoring of the rate of bleeding, may potentially tamponade the bleeding, and will evacuate the pleural space, thus decreasing the risk of developing empyema or a subsequent fibrothorax (57,58). Indications for surgical exploration vary between clinicians, but general guidelines are hemodynamic instability despite adequate resuscitation, initial drainage greater than 1,500 mL, continued bleeding of greater than 200 mL/hour for 3 consecutive hours, continued bleeding of greater than 1,500 mL/day, and radiographic evidence of significant retained clot (greater than one third of the pleural space).

Hepatic Hydrothorax

Pleural effusions are present in approximately 6% of patients with cirrhosis and clinically apparent ascites (59,60). The effusions result from movement of ascitic fluid through congenital or acquired diaphragmatic defects. Rarely, a hepatic hydrothorax may be found in a patient without clinical ascites but with asces demonstrated only by US, implying the presence of a large diaphragmatic defect. With a small pleural effusion, the patient may be asymptomatic, whereas with large to massive effusions, the patient may have varying degrees of dyspnea. The chest radiograph usually demonstrates a normal cardiac silhouette and a right-sided pleural effusion in 70% of patients, which can vary from small to massive. Effusions are less commonly isolated to the left pleural space (17%) or are bilateral (15%). The pleural fluid is a serous transudate with a low nucleated cell count and a predominance of mononuclear cells, pH greater than 7.40, a glucose level similar to serum, and an amylase less than serum amylase (53). The diagnosis is substantiated by demonstrating that the pleural fluid and ascitic fluid have similar chemistries. If the diagnosis is still in question, injection of a radionuclide into the ascitic fluid with subsequent detection on chest imaging supports the diagnosis (61).

Treatment of hepatic hydrothorax is directed at resolution of the ascites with sodium restriction, diuretics, and paracen- tesis. It is not uncommon for the effusion to persist until all of the ascitic fluid is mobilized. If the patient is acutely dyspneic or hypoxic, therapeutic thoracentesis may be done as a temporizing measure. Chest tube drainage should be avoided, as it can cause infection of the fluid, and the prolonged drainage can lead to volume depletion, protein and lymphocyte depletion, and may precipitate renal failure. Chemical pleurodesis is usually unsuccessful due to rapid movement of ascitic fluid into the pleural space. Transjugular intrahepatic portal systemic shunt (TIPS) has been used to treat symptomatic hepatic hydrothorax refractory to medical management (59,60), as has video-assisted thoracoscopic surgery to patch the diaphragmatic de- fect followed by pleural abrasion or talc poudrage (62).

Hepatic hydrothorax may occasionally be complicated by spontaneous bacterial empyema (SBE) (63). The formation of SBE is a result of either bacterial translocation from infected
ascitic fluid or bacteremia and seeding of a hepatic hydrothorax. The criteria for diagnosing SBE are similar to that for diagnosing spontaneous bacterial peritonitis and include a positive Gram stain, positive pleural fluid culture, or total neutrophil count greater than 500 cells/μL. Treatment of SBE is conservative with antibiotic therapy alone, unless frank pus is present, in which case chest tube thoracostomy should be considered.

### Hypoalbuminemia

Many patients admitted to the medical ICU have chronic illnesses and associated hypoalbuminemia. Pleural effusions may be observed when the serum albumin is less than 1.8 g/dL. In one study evaluating the association of pleural effusions with hypoalbuminemia, 3 of 21 (14%) patients with serum albumin less than 2.0 g/dL had pleural effusions (64). Since the normal pleural space has an effective lymphatic drainage system, pleural fluid tends to be the last site of collection of extravascular fluid in patients with low oncotic pressure. It is, therefore, unusual to find a pleural effusion solely due to hypoalbuminemia in the absence of anasarca. The chest radiograph usually shows small to moderate bilateral effusions with a normal heart size. The pleural fluid is a serous transudate with less than 1,000 nucleated cells/μL, predominantly mesothelial cells and lymphocytes. The pH ranges from 7.45 to 7.55, and the glucose level is similar to serum. Diagnosis is presumptive if other causes of transudative effusions are sufficiently excluded. The effusions resolve when the hypoalbuminemia is corrected.

### Iatrogenic

Insertion of a central venous catheter or extravascular migration of a central venous catheter can cause a pneumothorax, hemothorax, chylothorax, or transudative pleural effusion (65,66). Extravascular migration of a catheter, occurring in approximately 0.4% to 1.0% of insertions, is more common with insertion into the left subclavian and internal jugular veins due to the horizontal orientation of the left brachiocephalic vein in relation to the superior vena cava (58). The postprocedure chest radiograph should always be assessed for proper catheter placement, with catheter positioning parallel to the long axis of the superior vena cava and tip positioning at the right tracheobronchial angle indicating proper placement (67).

In the conscious patient, acute infusion of intravenous fluid into the mediastinum usually results in heart and diaphragmatic descent. Depending on the volume and rate of infusion of fluid into the mediastinum, tachycardia, respiratory distress, or cardiac tamponade may occur. The chest radiograph demonstrates the catheter tip in an abnormal position, widened mediastinum, and unilateral or bilateral effusions. The effusion can have characteristics similar to the infusate (milky if lipid is being given), and may be hemorrhagic and neutrophil predominant due to trauma and inflammation. If a glucose-containing solution is administered, a chest tube should be placed. Observation is sufficient if the effusion is small. If the effusion is large or causes respiratory distress, thoracocentesis or tube thoracostomy should be performed. If a hemothorax is discovered, a chest tube should be placed.

### Pancreatitis

Pleural effusions are commonly associated with pancreatitis due to the close proximity of the pancreas to the diaphragm. Pleural effusions have been noted in 3% to 20% of patients with pancreatitis (68). The chest radiograph usually demonstrates a small to moderate left-sided effusion (60%), although effusions may be isolated to the right side (30%) or occur bilaterally (10%–169). The patient usually presents with abdominal symptoms of pancreatitis. The diagnosis is confirmed by an elevated pleural fluid amylase concentration that is greater than serum, although a normal pleural fluid amylase may be found early in the course of acute pancreatitis. The pleural fluid is an exudate with 10,000 to 50,000 nucleated cells/μL, predominantly PMNs. The pleural fluid pH is usually 7.30 to 7.35, and the glucose level is similar to serum (15).

No specific treatment is necessary for pleural effusions associated with acute pancreatitis. The effusion resolves as the pancreatic inflammation subsides. If the pleural effusion does not resolve in 2 to 3 weeks, pancreatic abscess or pseudocyst should be suspected. Recent studies suggest that the presence of pleural effusions in acute pancreatitis is correlated with increased morbidity and mortality (68,70).

### Parapneumonic Effusions and Empyema

Patients with severe community-acquired pneumonia admitted to the ICU and patients who develop nosocomial pneumonia often develop parapneumonic effusions, with progression to empyema being less common. An empyema is defined as the presence of pus in the pleural space, although many clinicians extend the definition to include pleural fluid that has a positive Gram stain for bacteria or a positive bacterial culture. Complicated parapneumonic effusions are defined as pleural effusions that will not respond to antibiotic therapy alone and require drainage for resolution, whereas uncomplicated parapneumonic effusions do not require drainage and respond to antibiotic therapy alone for the underlying pneumonia (71–74).

The usual presentation is similar to the non-ICU patient with fever, dyspnea, chest pain, purulent sputum, leukocytosis, and a new alveolar infiltrate on chest radiograph. In the elderly, debilitated, or immunosuppressed patient, however, many of these findings may be absent. Although pleural space infections most commonly occur in association with pneumonia, it should also be recognized that pleural space infections may result from thoracic surgery, chest tube placement, penetrating chest trauma, esophageal perforation, mediastinitis, subdiaphragmatic abscesses, spontaneous bacterial peritonitis, and bacteremic seeding of a pre-existing effusion (71).

The pleural fluid protein concentration, nucleated cell count, or percentage of PMNs is not helpful in differentiating a complicated from an uncomplicated effusion. When the effusion is free-flowing, as demonstrated by lateral decubitus views or US, and thoracentesis shows a nonpurulent PMN-predominant exudate with a glucose level greater than 40 mg/dL, lactate dehydrogenase (LDH) less than 1,000 IU/L, and pH greater than 7.20, the patient has a high likelihood of pleural fluid resolution with antibiotics alone over 7 to 14 days (uncomplicated effusion). If pus is aspirated on
Pleuritic chest pain is reported by virtually all patients, whereas one half of patients will be noted to have dyspnea, fever, pericardial rub, and rales. Half of the patients have a leukocytosis, and almost all have an elevated erythrocyte sedimentation rate. The chest radiograph is abnormal in most patients, although the number of red blood cells exceeds 100,000 cells/μL in less than 20% (15). The nucleated cells range from 500 to 39,000 cells/μL, with a predominance of PMNs early in the course (15). The finding of pericardial fluid on echocardiogram suggests PCIS. The diagnosis is made clinically after pulmonary embolism and parapneumonic effusion have been excluded. An antimonyocardial antibody titer in pleural fluid greater than in serum further supports the diagnosis (85). PCIS is usually self-limited and may not require treatment if symptoms are minor. PCIS usually responds to aspirin or non-steroidal anti-inflammatory agents, although some patients may require corticosteroids for resolution. Following treatment, the pleural effusion resolves within 1 to 3 weeks. It is important to not misdiagnose PCIS as a pulmonary embolism, as anticoagulation therapy may lead to pericardial hemorrhage and tamponade.

**Pulmonary Embolism**

Pulmonary embolism occurs in up to 50% of patients with pulmonary embolism (86). The pathogenesis of pleural effusions in pulmonary embolism includes ischemia and inflammatory mediator-induced increased pleural capillary permeability, imbalance in microvascular and pleural space hydrostatic pressures, pleuroperitoneal hemorrhage, and atelectasis. Pulmonary infarction, necrosis and hemorrhage into the lung and pleural space may result. More than 90% of patients with pulmonary infarction will have bloody pleural effusions, while up to 40% of patients without radiographic evidence of infarction will also have hemorrhagic fluid (86). Spontaneous pleural effusion occurs in most patients with pleural effusions complicating pulmonary embolism. A coexistent pulmonary infariture is noted on chest radiograph in approximately half of patients with pulmonary embolism and pleural effusion.

Pleural fluid analysis is variable and may demonstrate either an exudate or a transudate (15,87). A bloody pleural effusion in the presence of chest trauma, recent cardiac injury, asbestos exposure, or malignancy should increase the suspicion of pulmonary embolism (88). The pleural fluid is hemorrhagic in two thirds of patients, although the number of red blood cells exceeds 100,000 cells/μL in less than 20% (15). The nucleated cell count ranges from less than 100 (presumably atelectatic transudates) to 50,000 cells/μL (pulmonary infarction). When thoracentesis is performed near the time of acute symptoms, PMNs are predominant; with later thoracentesis, lymphocytes represent the majority of cells, and eosinophils may be present as well. The effusion from pulmonary embolism is usually apparent (92%) on the initial chest radiograph and reaches a maximum volume during the first 72 hours. In patients who demonstrate progression of effusions after 72 hours of therapy, recurrent embolism, hemotherax secondary to anticoagulation, an infected infarction, or an alternative diagnosis should be considered. The effusions usually resolve in 1 week in the absence of an infarct on chest radiograph. When an infarct is present, presumably representing a pulmonary infarction, the resolution time is longer, typically 2 to 3 weeks (86).

The association of a pleural effusion with pulmonary embolism does not alter therapy. The presence of a bloody effusion is not a contraindication to full-dose anticoagulation, since hemotherax is a rare complication of heparin therapy for pulmonary embolism (89,90). An enlarging pleural effusion on therapy necessitates thoracentesis to exclude hemotherax, empyema, or another cause. The development of a hemotherax during therapy requires discontinuation of anticoagulation, chest tube thoracostomy, and placement of a vena cava filter.

**Uremia**

Uremic pleural effusions have been reported in 1% to 5% of patients undergoing chronic dialysis (91). In one study evaluating the cause of pleural effusions in 100 patients requiring long-term hemodialysis, uremic pleural effusion was present in 8% (92). Patients may manifest fever, cough, chest pain, and pleural friction rubs. The chest radiograph usually shows a moderate unilateral effusion, although massive and bilateral pleural effusions may be present.
Pneumothorax, defined as accumulation of air in the pleural space, represents one form of extra-alveolar air. Other forms of extra-alveolar air include pulmonary interstitial emphysema, pneumomediastinum, pneumopericardium, pneumomediastinum, pneumothorax, and systemic air embolism. Three pathologic processes may give rise to extra-alveolar air: (1) generation by gas-forming micro-organisms during an infectious process; (2) direct introduction following trauma to cutaneous or mucosal barriers; and (3) alveolar rupture due to pressure gradients between alveoli and the surrounding interstitial space (barotrauma) (98).

The mechanisms of spontaneous generation of extra-alveolar air were first delineated by Macklin and Macklin (99). In situations in which intra-alveolar pressure is increased, a gradient is produced between the alveoli and the adjacent vascular sheath, causing the alveoli to rupture at their bases. Following rupture, air is introduced in the perivascular adventitia, resulting in interstitial emphysema. The air then dissects proximally to the lung hilum and mediastinum due to a lower mean pressure in the mediastinum compared to that of the lung parenchyma. Once in the mediastinum, the accumulated air may decompress along paths of least resistance into the subcutaneous tissues or, less commonly, into the pericardium, pleura, or the peritoneum. If mediastinal pressure increases abruptly or if decompression via these routes is not sufficient, the mediastinal parietal may rupture, resulting in pneumothorax. Alternatively, air from ruptured alveoli may dissect to the periphery of the lung and rupture via subpleural blebs through the visceral pleura into the pleural space (100).

Pneumothoraces are classified as spontaneous, which occur without preceding trauma or other obvious causes, and traumatic, which occur as a result of direct or indirect trauma to the chest. Spontaneous pneumothoraces can be subdivided into primary spontaneous, which occur in otherwise healthy patients without clinical lung disease, and secondary spontaneous, which occur in patients with underlying lung disease. Traumatic pneumothoraces can be subdivided into the categories of iatrogenic and related to blunt or penetrating chest trauma. In addition, pneumothoraces can be classified as simple or complicated, with complicated pneumothoraces consisting of tension pneumothorax, hemo- and pneumomediastinum, pneumothorax, and open pneumothorax in which the integrity of the chest wall is disrupted. The potential causes of pneumothoraces in critically ill patients are listed in Table 144.2. We will focus mainly on iatrogenic pneumothoraces and pneumothoraces resulting from barotrauma, as these are the most common causes of pneumothoraces in ICU patients.

### TABLE 144.2

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<tr>
<th>CAUSES OF PNEUMOTHORAXES IN ICU PATIENTS</th>
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<td><strong>SECONDARY SPONTANEOUS</strong></td>
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<td>- COPD</td>
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<td>- Idiopathic pulmonary fibrosis</td>
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<td>- Tuberculosis</td>
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**BAROTRAUMA/VOLUTRAUMA**
- Mechanical ventilation
- Acute respiratory disease syndrome (ARDS)
- Status asthmaticus
- COPD
- Inhalational drug usage
- Decompression injury

**JATROGENIC**
- Endotracheal intubation
- Central venous catheter placement
- Thoracentesis
- Nasogastric tube placement
- Bronchoscopy with bronchoalveolar lavage (BAL) or biopsies
- Postoperative
- Nasal mask ventilation
- Cardiopulmonary resuscitation

### Radiologic Evaluation

The radiographic signs of pneumothorax in the supine patient frequently differ from the classic visceral pleural line seen on erect views. In a review of 88 critically ill patients with 112 pneumothoraces, only 22% of pneumothoraces were in the classic apical location (101). In this same study, 30% of pneumothoraces were not detected initially, and of these, half progressed to a tension pneumothorax. The anterolateral position is the most common location for pneumothoraces in the supine patient since this area is the least dependent pleural recess (102). With anteromedial collections of air above the level of the pulmonary hilum, the lucency sharply outlines adjacent vascular structures such as the ascending aorta, superior vena cava, and azygous vein. Below the hilum, the lateral cardiac borders are sharply outlined and paralleled by zones of radiolucency. Increased lucency in the region of the anterior
cardiophrenic sulcus may also result from air below the hilar level (102).

In addition to the anteromedial and apicolateral locations, pneumothoraces in supine patients can also occur in the subpulmonic and posteromedial locations (101). A subpulmonic pneumothorax may be recognized as a basilar hyperlucency, most commonly in the left hemithorax (103,104). A pleural line defining the base of the lung may be apparent in some cases, allowing for diagnosis of pneumothorax. Other features that may help in the recognition of a subpulmonic pneumothorax include lucency extending deep into the costophrenic sulcus (deep-sulcus sign), depression of the hemidiaphragm, and visualization of an unusually distinct cardiac apex (105,106).

An erect or decubitus radiograph should be obtained if possible to confirm or refute the presence of a pneumothorax. In problematic cases, CT or US can be diagnostic. Several studies have demonstrated the presence of pneumothoraces on CT that were not apparent or not appreciated on conventional radiographs (14,107). Occasionally, a pneumothorax may be confused with a large bulla in patients with COPD and other pulmonary diseases that generate cystic changes. In these instances, a CT may be helpful in making the correct diagnosis (100). If the patient is too unstable to obtain a CT, bedside US can be used to evaluate for the presence of a pneumothorax by determining the presence or absence of “lung sliding.” In patients without pneumothorax, the lung–chest wall interface, which represents a to-and-fro movement synchronized with respiration, can be identified. In one study, the disappearance of lung sliding was 95% sensitive for detecting pneumothorax, although false positives did occur (108).

**Primary and Secondary Spontaneous Pneumothorax**

Patients with pneumothorax have a decrease in vital capacity and an increase in the alveolar–arterial oxygen gradient, with hypoxemia being present in some patients. The hypoxemia is thought to be secondary to development of both anatomic shunts and areas of low ventilation/perfusion in the atelectatic lung. Patients with primary spontaneous pneumothorax rarely require admission to the ICU, as the contralateral lung can maintain the necessary alveolar ventilation and hypoxemia can be managed with supplemental oxygen. Patients with secondary spontaneous pneumothorax may need ICU admission because the gas exchange abnormality caused by the pneumothorax is superimposed on pre-existing gas exchange abnormalities and, thus, severe hypoxemia can occur. Patients with secondary spontaneous pneumothoraces are more likely to develop hypercapnic respiratory failure than are patients with primary spontaneous pneumothorax (109,110).

**Iatrogenic Pneumothorax**

Insertion of central venous catheters (CVC) is the most common cause of iatrogenic pneumothoraces in the ICU. In two studies of mechanical complications of central venous catheters, 1.1% of 534 patients and 1.0% of 713 patients suffered a pneumothorax (111,112). Cannulation of the subclavian vein is associated with a higher risk of pneumothorax than cannulation of the internal jugular vein (113,114). Most pneumothoraces occur at the time of the procedure from direct lung puncture, but delayed pneumothoraces have been noted. Bilateral pneumothoraces have been reported to occur from unilateral cannulation attempts (115). A postprocedure chest radiograph should be obtained following placement of a central venous catheter, regardless of the site cannulated, to assess for pneumothorax and proper catheter tip position.

Cardiopulmonary resuscitation has been reported as a cause of iatrogenic pneumothorax. Pneumothorax in this setting may arise either from barotrauma as a consequence of bag-ventilation or from rib fractures sustained during the resuscitation. Hillman and Albus (116) described three patients who developed subcutaneous emphysema and pneumothoraces, one of whom had bilateral pneumothoraces following cardiopulmonary resuscitation with bag-ventilation. Shulman et al. (117) reported two patients in whom barotrauma was observed following resuscitation. One of the patients was ventilated with an Ambu-bag whereas the other was ventilated with a positive pressure demand valve. Other cases of pneumothorax related to cardiopulmonary resuscitation or malfunctioning valves in self-inflating bags have been reported (118,119).

Based on these observations, a chest radiograph should be obtained on all patients after a successful resuscitation to evaluate for pneumothorax. During cardiopulmonary resuscitation, if the patient is difficult to ventilate, subcutaneous emphysema is noted, or pulseless electrical activity (electromechanical dissociation) is present, the diagnosis of pneumothorax, particularly tension pneumothorax, should be suspected. In a study analyzing postmortem chest radiographs, only 40 of 77 patients had been clinically diagnosed as having a pneumothorax. In this study, procedures most frequently associated with pneumothorax were mechanical ventilation and cardiopulmonary resuscitation. Rib fractures were noted in 23 of the 77 cases (120).

Pneumothoraces may rarely occur following endotracheal intubation, usually due to rupture of the posterior membranous portion of the trachea (121). In a prospective study of translaryngeal intubation in 297 critically ill patients in a teaching hospital, pneumothorax occurred in 1% of patients (122). Pneumothoraces may also result from tracheostomy, either from open procedures or bedside percutaneous dilatational tracheostomy (123). The incidence of pneumothorax after tracheostomy in adults has been reported to be between 0% and 4% (124).

Bronchoscopy in critically ill patients may also cause pneumothoraces. The risk is higher when transbronchial biopsies are obtained, although the degree of increased risk compared to nonventilated patients and the influence of high airway pressures and positive end-expiratory pressure (PEEP) is unknown. It should be recognized that performing bronchoaveolar lavage (BAL) alone may produce a pneumothorax (125–127).

**Pneumothorax Associated with Mechanical Ventilation**

Pneumothorax is a frequent, potentially lethal complication of mechanical ventilation. The pathogenesis of pneumothorax associated with mechanical ventilation—barotrauma—is related to the decompression of extra-alveolar air contained...
in the mediastinum through the mediastinal pleura or rupture of subpleural blebs through the visceral pleura, as previously described. Conditions associated with an increased risk of pneumothorax while patients undergo mechanical ventilation include ARDS, COPD, asthma, fibrotic lung diseases, aspiration pneumonia, necrotizing pneumonia, and right mainstem bronchus intubation (100).

More recently conducted studies in mechanically ventilated patients with acute lung injury or ARDS have reported pneumothorax occurrence rates between 7% and 42% (128–133). The relationship of barotrauma and pneumothorax to ventilatory pressures in patients with ARDS continues to be debated given earlier studies that suggested a causal relationship.

Gammon et al. (128) observed that of 139 patients requiring mechanical ventilation for various diagnoses, the group with pneumothorax had higher peak inspiratory pressure (PIP) (55 vs. 44 cm H2O) and levels of PEEP (7.7 vs. 3.3 cm H2O). When patients with ARDS and those with other diagnoses were analyzed separately, however, no differences in airway pressures were found between patients with and without pneumothoraces. In a subsequent study by Gammon et al. (129) of 168 patients, trends toward higher airway pressures were observed, however, multivariate analysis revealed that only the presence of ARDS was independently correlated with the development of pneumothorax. Weg et al. (131), in their study of 725 patients with ARDS and those with other diagnoses who had a pneumothorax and/or air leak and those pressures may increase with a coexisting decrease in lung compliance, worsening oxygenation is often seen. Peak inspiratory pressures may increase with a coexisting decrease in lung compli-

A tension pneumothorax occurs when intrapleural pressure exceeds atmospheric pressure throughout expiration, and often inspiration as well. This develops when a break in the visceral or parietal pleura produces a one-way valve that is open during inspiration, allowing air to enter the pleural space, but is closed during expiration, preventing the egress of air collecting in the pleural space (92). Tension pneumothoraces most commonly develop as a complication of mechanical ventilation—barotrauma or volutrauma—or as a result of blunt and penetrating thoracic trauma, although tension pneumothoraces can occur in 1% to 4% of patients with spontaneous pneumothoraces (134,135). Attempts at CVC placement in patients receiving positive pressure ventilation may also cause tension pneumothoraces, with delayed presentations having been reported (136). It is important to consider the presence of a tension pneumothorax in the differential diagnosis of a patient with pulseless electrical activity (electrocardiographic dissociation) undergoing cardiopulmonary resuscitation (CPR).

Tension pneumothorax usually presents as an acute cardiopulmonary emergency beginning with respiratory distress and, if unrecognized and untreated, progresses to cardiovascular collapse and death. Conscious patients with tension pneumothorax appear acutely ill with dyspnea, tachycardia, tachypnea, diaphoresis, and cyanosis. Patients with tension pneumothorax often exhibit decreased ipsilateral breath sounds, hyperresonance to percussion, distended neck veins, tracheal deviation to the contralateral side, and hypotension. Caveats to the aforementioned findings are that severe parenchymal disease or airway obstruction, coupled with the noise generated by ventilator cycling, may cause difficulty in appreciating differences between the hemithoraces, and distension of the neck veins may not be present in patients who are volume depleted. The absence of physical exam findings does not completely exclude the diagnosis of a tension pneumothorax. In the unconscious or critically ill patient, worsening oxygenation may be one of the earliest signs. Increases in airway peak and plateau pressures and decreases in compliance are often observed in mechanically ventilated patients. During hand bagging of the patient, increased pressure requirements to deliver breaths and difficulty in delivering adequate tidal volume may be noted. Increases in pulmonary artery diastolic pressures may be seen in patients who have a Swan-Ganz catheter in place (137).

On the chest radiograph in a patient with tension pneumothorax, in addition to the pneumothorax, there is often shift of the trachea and mediastinum to the contralateral side, ipsilateral diaphragmatic depression, and increased distance between contiguous ribs compared to the unaffected side. It should be emphasized, however, that tension pneumothorax is a clinical diagnosis, and these radiographic findings may be observed in patients without physiologic evidence of a tension pneumothorax. It should also be noted that patients may have cardiopulmonary compromise due to a tension pneumothorax without observing tracheal or mediastinal shift on chest radiograph (118,139).

In one study of 16 ARDS patients with tension pneumothorax, only 5 patients had subtle mediastinal shift (138). Of these 16 patients, 11 had flattening of the diaphragm and 8 had depression of the diaphragm. Diaphragmatic abnormalities may therefore be a more sensitive indicator of tension pneumothorax in patients with ARDS. In 15 of the 16 patients, the location of a loculated tension pneumothorax was subpulmonic or paracardiac. Potential explanations for these observations include the presence of adhesions between the parietal and visceral pleura, as documented in patients with ARDS, which prevent lung collapse and spread of air throughout the pleural space. In addition, the noncompliance of lungs in patients with ARDS may prevent collapse of the ipsilateral lung and compression of the contralateral lung, allowing a small volume of air to significantly increase intrapleural pressure (138,139).

It is important to note that patients with ARDS can develop tension pneumothoraces despite the presence of a chest tube on
the ipsilateral side being placed for a previous pneumothorax (138–141). In the 16 patients reported by Gohren et al. (138) and the 3 patients reported by Ross et al. (139), all patients had a functional ipsilateral chest tube and had localized pneumothoraces. In a study by Heffner et al. (140), 14 patients had recurrent pneumothoraces despite ipsilateral chest tubes, with 9 of the 14 having tension pneumothoraces. In the latter study, 12 of the 14 chest tubes had horizontal as opposed to vertical placement on chest radiograph. The chest tubes in all 9 patients with tension pneumothoraces had horizontal placement. Seven of the 14 patients had subsequent CT scans, with the finding that all 7 chest tubes were placed within interlobar fissures. Thus, chest tubes placed into interlobar or posterior locations may not drain anterior gas localizations, the most common location of pneumothoraces in ARDS patients (101,142), allowing for development of localized tension pneumothoraces. In the patient reported by McConaghy and Kennedy (141), the chest tube was intraparenchymal.

Management of Pneumothoraces and Tension Pneumothoraces

Most critically ill patients in the ICU will have poor cardiopulmonary reserves and may be unable to tolerate a pneumothorax, even in the absence of tension physiology. In nonventilated patients who are hemodynamically stable and have adequate oxygenation and ventilation, simple pneumothoraces that occur as a result of a procedure and are small may reasonably be managed without chest tube placement with serial radiographs. Patients with secondary pneumothoraces who require ICU care will usually require chest tube placement because of their poor pulmonary reserve. Patients who are not receiving positive pressure ventilation, but are hemodynamically unstable, should be treated with chest tube thoracostomy, since the additive effects of development of hypoxia or early tension physiology could quickly precipitate cardiopulmonary arrest.

In general, chest tube thoracostomy should be performed in mechanically ventilated patients with a pneumothorax of any size given the significant risk of progression to a tension pneumothorax. Attempts to decrease plateau airway pressures, tidal volumes, and PEEP should be considered if possible after development of a pneumothorax in patients receiving mechanical ventilation. Controlled hypoventilation with the use of neuromuscular blockers or deep sedation may be required in some patients to achieve these goals. For patients with ARDS and recurrent pneumothoraces, the chest tube attempts should be made to place anteriorly where the localization is most likely to occur. In those patients with recurrent pneumothoraces who are stable for transport to the radiology department, we advocate the use of CT-guided percutaneous drainage, as blind placement of chest tubes into loculi may be difficult (143,144). When extra-alveolar gas is observed in the absence of a pneumothorax, similar attempts to decrease plateau pressure, tidal volume, and PEEP should be considered. No evidence exists that placement of “prophylactic” chest tubes will prevent these patients from suffering a subsequent pneumothorax. These patients should be closely monitored for development of a tension pneumothorax, and equipment to perform an emergent bedside tube thoracostomy should be available.

The development of a tension pneumothorax represents a medical emergency, and the deteriorating patient should be treated based on clinical presentation without waiting for radiographic confirmation. In one series of 74 patients with tension pneumothorax, a diagnosis was made clinically in 45 patients (61%), and these patients had an attributable mortality of 7%. In the remaining 29 patients, diagnosis was delayed between 30 minutes and 8 hours; 31% of these patients died of pneumothorax (145). If a chest tube is not immediately available, a large-bore needle or intravenous catheter should be inserted into the pleural space through the second intercostal space at the midclavicular line. Escape of air from the needle confirms the diagnosis. After decompression, the needle or catheter should be left in place and in communication with the atmosphere until definitive chest tube thoracostomy is performed. As previously mentioned, a high index of suspicion for tension pneumothorax should be maintained for patients who are in cardiac arrest and exhibit pulsless electrical activity.

A bronchopleural fistula (BPF) represents a communication between the bronchial tree and the pleural space. Bronchopleural fistulae (BPFs) most commonly result from surgical procedures including pneumonectomy, segmentectomy, and wedge resections of the lung, with an incidence of 1.6% to 6.8% (146). The mortality in patients with BPFs following surgical resection is reported to be between 25% and 71%, usually due to infectious complications (146–148). BPFs may also result from blunt or penetrating chest trauma, pulmonary infarction, and as a complication of pulmonary and pleural infections such as tuberculosis, necrotizing pneumonia, lung abscess, or empyema (149,150). Last, BPFs may result as a complication of mechanical ventilation for acute respiratory failure, particularly in patients with ARDS, and, as such, represent a form of barotrauma/volutrauma (149,151). For this discussion, we will focus primarily on BPFs in the setting of patients requiring mechanical ventilation.

BPF in the ventilated patient is defined as an air leak that persists for more than 24 hours following placement of a chest tube. BPFs in patients receiving mechanical ventilation may present acutely with the development of a pneumothorax, with or without tension, or with sudden expectoration of potentially infected material from the pleural space, with flooding of the ipsilateral and contralateral airways leading to respiratory compromise. Several potential adverse effects of a BPF in the mechanically ventilated patient have been noted. Depending on the size of the fistula, flow resistance through the fistula versus the airways and lung parenchyma, and pressure gradient between the airways and pleural space, air may be redirected from normal intrapulmonary routes to the BPF (152). This can cause loss of effective tidal volume, which may lead to difficulty in oxygenating and ventilating the patient and subsequent development of life-threatening hypoxemia and respiratory acidosis (151). If incomplete lung expansion due to the BPF is present, ventilation/perfusion mismatching and shunt may occur. There may be difficulty in maintaining PEEP with further decrements in oxygenation (153,154). If a high level of chest tube suction is
used, the negative pressure may be transmitted to the proximal airways, causing inappropriate ventilator cycling (153,155). Last, BPFs may cause pleural space infection or contamination of the airways.

The amount of air flow through a BPF is typically estimated by subtracting the expired tidal volume from the inspired tidal volume as measured by the ventilator. This method, however, becomes increasingly inaccurate as the size of the leak decreases, particularly when the size of the leak is less than 200 mL/breath (156). More accurate, albeit cumbersome, methods have been developed to quantify the amount of flow through a BPF (157–160). Air flows through BPFs have been reported up to 22 L/min (157). It has been recognized that the air escaping from a BPF does not flow passively from the airways into the pleural space, but instead participates to some degree in physiologic gas exchange. In two studies evaluating CO₂ excretion by BPF in 15 patients, the percent of minute ventilation lost through the BPF ranged from 4% to 53%, with 3% to 44% of CO₂ excretion occurring via the BPF (161,162).

The development of a BPF has been regarded as a serious and life-threatening complication of mechanical ventilation. In one of the largest series reported—a 1,700 consecutive patients receiving mechanical ventilation—Person et al. (163) observed that 39 (2.3%) patients developed a BPF. In that study, overall mortality in patients with BPF was 87%. Mortality was higher in patients who developed a BPF late in their illness (94%) than when it occurred within 24 hours of admission (45%). Patients with air leaks greater than 500 mL/breath had a mortality of 100% compared with a mortality of 57% in patients with air leaks less than 500 mL/breath. Mortality was also higher in patients with ARDS than in patients without—81% versus 50%—and in patients with pleural space infections compared to those with said infection—87% versus 54%. A more recent ARDS study by Weg et al. (138), however, suggested that mortality was not different between patients with or without air leaks, 46% versus 39%, respectively. In that study, however, the duration of mechanical ventilation was 4.3 ± 1.3 days, which may not be typical for many patients with BPF, and the subset of patients with BPF was not analyzed separately. It may be that the presence of a BPF is a marker for severity of lung injury and by itself does not directly contribute to mortality.

### Management of Bronchopleural Fistulae

Numerous interventions, listed in Table 144.3, have been proposed in the management of BPFs. Many of these are based on the concept of decreasing the pressure gradient between the airways and the pleural space, with decreased air flow through the fistula allowing for earlier closure. Although the various manipulations theoretically make sense, they have not been evaluated in controlled trials. The suggested changes in ventilator settings may actually worsen oxygenation and ventilation in some patients with ARDS. We will discuss those interventions for which some data are available in the following sections. In the absence of difficulty oxygenating or ventilating the patient, it is unknown if active measures to close the BPF affects outcome. Definitive therapy for BPFs includes surgical procedures such as bronchial stump closure with thoracoplasty, myoplasty, or omentoplasty, or completion pneumonectomy (146,148). Unfortunately, most critically ill patients will not be sufficiently stable to undergo these procedures and must be managed medically. Adequate pleural space drainage, antibiotic therapy for pleural space infections, and support of nutritional status is vital in these patients. Adequate chest tube drainage and full expansion of the lung should be assessed in patients with BPF. An appropriately sized chest tube should be placed, recognizing that air flow through a chest tube is inversely proportional to the length and radius to the fifth power of the tube. It has been suggested that a tube with an internal diameter of 6 mm (18 Fr) is the smallest acceptable size because it will allow a maximum possible flow rate of 15 L/minute at –10 cm H₂O (164). Our preference is to use at least a 28 Fr chest tube in these patients. Placement of additional chest tubes or CT-guided percutaneous catheters—if the pleural space is complicated—should be considered if the lung is not fully expanded. As with the chest tube, resistance to flow of air through a chest tube drainage system may need to be considered. In an animal model of BPF, when the size of air leak reached 4 to 5 L/minute, the Thora-Klex and Sentinel Seal systems become clinically impractical. The Pleur-Evac system can handle flow rates up to 34 L/minute, although its use with

### Table 144.3

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<th>Potential Options for Management of Bronchopleural Fistulae in Mechanically Ventilated Patients</th>
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<td><strong>ALTERNATIVE MODES OF MECHANICAL VENTILATION</strong></td>
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<td><strong>CHEST TUBE MANIPULATION</strong></td>
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<td><strong>DIRECT CLOSURE/OCCCLUSION OF BRONCHOPLEURAL FISTULA (BPF)</strong></td>
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rates greater than 28 L/min is impractical due to intense bubbling in the control chamber. The Emerson pump, which can be set to deliver chest tube suction greater than −20 cm H.O, is capable of handling air flows up to 35 L/min and is the system of choice for BPFs with extremely high flow rates (164).

Manipulation of the level of chest tube suction may affect BPF air flow, and some authors have suggested using the least amount of suction that maintains lung inflation (151,152). BPF air flow, and some authors have suggested using the least amount of suction that maintains lung inflation (151,152). An animal model demonstrated that increasing negative intrapleural pressures increased air flow in large BPFs but had no effect on small BPFs (165). Roth et al. (160) reported that increasing chest tube suction from 0 to 22.5 cm H.O increased BPF flow in a patient from 24.6 to 26.7 L/minute. In a study of six patients by Powner et al. (158), increasing chest tube suction from 0 to 25 cm H.O increased BPF flow in two patients, had no effect in two patients, and decreased flow in two patients. To decrease air loss through the BPF and applied PEEP, some investigators have applied PEEP to the chest tube (154,166,167), while others have devised systems to synchronously occlude the chest tube during inspiration (168,169). A lack of success using these methods has been noted by other investigators, however (163). These techniques may pose a risk of increasing the size of the pneumothorax or causing a tension pneumothorax; thus, the patient should be closely monitored.

The goals of mechanical ventilation in patients with a BPF are to maintain adequate oxygenation and ventilation while reducing fistula flow. In general, strategies for conventional mechanical ventilation that limit airway pressure and tidal volumes may reduce the amount of air flow escaping through the BPF and allow the fistulous site to heal. As such, it has been recommended to use the lowest possible tidal volume, fewest mechanical breaths per minute, lowest level of PEEP, and shortest inspiratory time.

Alternative methods of mechanical ventilation have been used in a few patients. High-frequency jet ventilation (HFJV) and high-frequency oscillatory ventilation (HFOV) have been used based on the principle that lower airway pressures may be generated in these modes of ventilation and should, therefore, decrease BPF air flow. In one animal model of BPF, an increase in fistula flow was seen with increasing mean airway pressures, and effects on flow were similar whether mean airway pressure was changed by manipulating peak inspiratory pressure, PEEP, or inspiratory-expiratory (I:E) ratios (165). In another animal model, a nonsignificant trend toward increasing BPF flow with increasing peak inspiratory pressures, and a significant increase in BPF flow with increasing PEEP was observed (170).

Several studies comparing HFJV and HFOV with conventional ventilation using animal models have shown less BPF air flow during HFJV and HFOV (171–174), although one study using HFJV demonstrated no difference (175). In studies reporting blood gases, improved oxygenation was seen during HFJV and HFOV compared with conventional ventilation (172–174). Increasing levels of PEEP were also noted to increase BPF flow in two studies (171,175). It is problematic to extrapolate these studies to patients in the ICU because the animal models were cannulated in more proximal bronchi and the lung parenchyma was relatively normal.

HFJV has been used successfully in BPF patients failing conventional therapy (176–180). The two case series comparing the use of HFJV with conventional ventilation have reported disappointing results. In one study, HFJV was of clinical value in only two of the seven patients (159). In that study, no change in the air leak was observed in three patients; one had an unacceptable decline in oxygenation, and one patient disliked the sensation of HFJV and refused further therapy. In the other series of seven patients, no significant decrease in BPF flow was seen, while three patients had an increase in the air leak despite a decrease in peak airway pressures (181). Oxygenation deteriorated in six of the seven patients when switched to HFJV.

Other modes of mechanical ventilation have also been used in patients with BPF. Case reports have reported independent lung ventilation to be of benefit (182–184). Case reports of combining independent lung ventilation with high-frequency, low tidal volume ventilation of the affected lung (185) and HFJV of the affected lung have been published (186,187). Different lung ventilation using a single ventilator and a variable resistance valve attached to one lumen of a bifurcated endotracheal tube has also been described (188,189). Discussion of the techniques of independent lung ventilation and its attendant difficulties is beyond the scope of this chapter, and the reader is referred to other reviews (190,191).

Because many critically ill patients are unable to tolerate a major thoracic procedure, bronchoscopic techniques may provide viable alternatives for closure of BPFs. Endobronchial occlusion of BPFs has been reported with cyanoacrylate-based tissue adhesives (Histoacyrl, Bucrylate), fibrin sealants (Tis-seal, Hemaseal, thrombin plus fibrinogen or cryoprecipitate), absorbable gelatin sponge (Gelfoam), vascular occlusion coils, doxycycline and blood, Nd:YAG laser, silver nitrate, and lead shot (192–194). The agent initially seals the leak by acting as a plug and subsequently induces an inflammatory process with fibrosis and mucosal proliferation, permanently sealing the area. Of these techniques, the uses of cyanoacrylate tissue adhesives and fibrin sealants have been most widely reported. Airway stents may be used to cover and seal the fistula in selected patients depending on the location of the fistula. BPFs due to breakdown of a stump after lobectomy or pneumonectomy, or bronchial dehiscence after lung transplantation or bronchoplastical procedures are the most amenable to successful closure with airway stenting. More recently, the successful closure of BPFs using bronchoscopic placement of endobronchial valves designed for emphysema has been described (195–197). Pleurodesis with various agents has also been tried to effect closure of BPFs. Autologous "blood patch" pleurodesis has been described to be effective in some patients (198–200). Pleurodesis with fibrin glue has also been reported (201,202).

However, none of these patients was undergoing mechanical ventilation at the time of pleurodesis.

**Complications of Thoracentesis and Chest Tube Thoracostomy**

**Thoracentesis**

The most common complication of diagnostic or therapeutic thoracentesis is pneumothorax. The rate of pneumothorax with blind thoracentesis in nonventilated patients has been reported to be between 4% and 30% in prospective studies.
Re-expansion Pulmonary Edema

Re-expansion pulmonary edema (RPE) represents one of the most potentially life-threatening complications of therapeutic thoracentesis and chest tube thoracostomy for pleural effusion and pneumothorax. RPE has also been reported following re-expansion of atelectasis from endobronchial obstruction and right mainstem bronchus intubation (218–220). Patients developing significant hypoxemia from RPE will often require admission to the ICU. The precise incidence of RPE is unknown. In two series of 400 and 375 cases of spontaneous pneumothorax, no cases of RPE were noted (221,222). Matsuura et al. (223), however, reported that 14 of 146 patients treated for spontaneous pneumothorax developed RPE. In a series of 320 patients with spontaneous pneumothorax, Rozeman et al. (224) observed a 0.9% incidence of RPE, which is likely to best represent the clinical occurrence of RPE. To our knowledge, no studies have been done evaluating the incidence or clinical course of RPE in ICU patients undergoing thoracocentesis or chest tube placement. In the study by Matsuura et al. (223), 8 of the 21 patients with RPE were reported as having tension pneumothoraces.

Clinical signs and symptoms include cough, chest tightness or pain, dyspnea, tachypnea, tachycardia, and ipsilateral crackles. Patients may produce pink frothy sputum or have frank hemoptysis. The onset of symptoms is immediate or within 1 hour of thoracocentesis or chest tube placement in two thirds of patients but may be delayed up to 24 hours (225). In a review of reported cases by Mahfood et al. (225), however, 8 of 47 (17%) patients and 9 of the 21 (43%) patients in the series of Matsuura et al. (223) had pneumothoraces for less than 24 hours.

Although hypoxic respiratory failure is a well-recognized complication of RPE, it may not be appreciated that RPE may cause hypotension and cardiovascular collapse. Several case reports have noted severe hypotension with RPE despite adequate oxygenation in some patients (227–230). In patients in whom a Swan-Ganz catheter was placed, a low cardiac output, low or normal PCWP, and normal systemic vascular resistance were uniformly observed (227–230). Hemoconcentration was noted in some patients, suggesting that third-spacing of fluids into the lung accounted for part of the hypotension (230). Many of these patients remained hypotensive despite administration of large amounts of intravenous fluids and vasopressor agents, however, and mortality was 40% (four of ten patients).

Treatment of RPE is mainly supportive, with mechanical ventilation and PEEP being the mainstay of therapy. Diuretics and corticosteroids have been used by some clinicians, although evidence that they are of benefit is lacking. In patients with hypotension, administration of intravenous fluids and vasopressor agents may be necessary. The development of RPE carries a substantial mortality. In a review of 53 reported cases of RPE, Mahfood et al. (225) noted an observed mortality of 20%.
References


Section XIII: Respiratory Disorders


Pleural Disease in the Intensive Care Unit


Chapter 145

Massive Hemoptysis

Michael A. Jantz • Veena B. Antony

Hemoptysis is defined as the expectoration of blood that originates from the lower respiratory tract. Pseudohemoptysis is the expectoration of blood from a source other than the lower respiratory tract such as the nares, oropharynx, larynx, or the gastrointestinal tract. Massive hemoptysis is defined as expectoration of blood exceeding 200 to 1,000 mL over a 24-hour period, with expectoration of greater than 600 mL in 24 hours being the most commonly used definition (1). In practice, the rapidity of bleeding and ability to maintain a patent airway are critical factors; life-threatening hemoptysis can alternatively be defined as the amount of bleeding that compromises ventilation (2). Only 3% to 5% of patients with hemoptysis have a massive bleed, with the mortality rate ranging from 20% to as high as 80% in some case series (3–6). Most patients who die from massive hemoptysis do so from asphyxiation (3,7,8).

In practice, the rapidity of bleeding and ability to maintain a patent airway are critical factors; life-threatening hemoptysis can alternatively be defined as the amount of bleeding that compromises ventilation (2). Only 3% to 5% of patients with hemoptysis have a massive bleed, with the mortality rate ranging from 20% to as high as 80% in some case series (3–6). Most patients who die from massive hemoptysis do so from asphyxiation (3,7,8).

The causes of massive hemoptysis are listed in Table 145.1. Virtually all causes of hemoptysis may result in massive hemoptysis. The bronchial arteries are the main source of blood to the airways, large airways, such as the trachea and mainstem bronchi, drain into the bronchial circulation, alveolar hemorrhage due to conditions such as Wegener granulomatosis and Goodpasture syndrome may occasionally cause massive hemoptysis (Table 145.2).

Anatomic Sources of Hemoptysis

The sources of lower respiratory tract bleeding include the pulmonary and bronchial circulations. The pulmonary circulation is a low-pressure circuit when normal pulmonary artery pressures are present. The pulmonary arteries supply blood to the pulmonary parenchyma. The bronchial circulation consists of the bronchial arteries, which originate from the aorta and have systemic arterial pressures, and the bronchial veins, which drain into the systemic veins to the right side of the heart. The bronchial and pulmonary circulations are normally interconnected by a bronchopulmonary anastomosis near the junction of the terminal and respiratory bronchioles. The bronchial arteries are the main source of blood to the Airways, large branches of the pulmonary vessels, and supporting structures of the lung. The bronchial arteries feeding the proximal Airways, such as the trachea and mainstem bronchi, drain into bronchial veins, which empty into the right side of the heart. Bronchial arteries serving the intrapulmonary Airways and lung parenchyma drain through the bronchopulmonary anastomosis into the pulmonary veins, which empty into the left side of the heart. Angiographic studies of patients with active hemoptysis have demonstrated that the bronchial artery circulation is...
Chapter 145: Massive Hemoptysis

TABLE 145.1
POSSIBLE CAUSES OF MASSIVE HEMOPTYSIS

<table>
<thead>
<tr>
<th>NEOPLASM</th>
<th>INFECTIOUS</th>
<th>PULMONARY</th>
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<tr>
<td>Bronchogenic cancer</td>
<td>Lung abscess</td>
<td>Bronchectasis</td>
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<tr>
<td>Metastasis (parenchymal or endobronchial)</td>
<td>Tuberculosis</td>
<td>Cystic fibrosis</td>
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<tr>
<td>Carcinoid</td>
<td>Necrotizing pneumonia</td>
<td>Barcooideos (fibrovascular)</td>
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<tr>
<td>Leukemia</td>
<td>Fungal pneumonia</td>
<td>Diffuse alveolar hemorrhage</td>
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<td>Septic pulmonary emboli</td>
<td>Airway foreign body</td>
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<tr>
<th>CARDIAC/VASCULAR</th>
<th>CONGESTIVE HEART FAILURE</th>
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<tr>
<td>Mitral stenosis</td>
<td>Pulmonary arteriovenous fistula</td>
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<tr>
<td>Pulmonary embolism/infarction</td>
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<tr>
<td>Arteriovenous malformation</td>
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<tr>
<td>Bronchocutaneous fistula</td>
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<td>Ruptured aortic aneurysm</td>
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<tr>
<th>IATROGENIC/TRAUMATIC</th>
<th>HEMATOLOGIC</th>
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<tbody>
<tr>
<td>Blunt or penetrating chest trauma</td>
<td>Coagulopathy</td>
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<tr>
<td>Tracheal/bronchial tear or rupture</td>
<td>Disseminated intravascular coagulation</td>
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<tr>
<td>Tracheobronchomunitate artery fistula</td>
<td>Thrombocytopenia</td>
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<tr>
<td>Bronchoscopy</td>
<td>DRUGS/TOXINS</td>
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<tr>
<td>Pulmonary artery rupture from pulmonary artery catheter</td>
<td>Anticoagulants</td>
</tr>
<tr>
<td>Endotracheal tube suctioning trauma</td>
<td>Antithrombotic agents</td>
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<td></td>
<td>Crack cocaine</td>
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is responsible for bleeding in approximately 90% of cases (9). Bronchial arteries arise directly or indirectly from the thoracic aorta at the level of the third through the eighth thoracic vertebrae, originating most commonly at the level of the fifth and sixth vertebrae. The bronchopulmonary anastomosis may increase in size due to chronic inflammatory conditions such as bronchiectasis, cystic fibrosis, and tuberculosis (10). New collateral vessels from bronchial arteries or other intrathoracic systemic arteries may also develop in chronic inflammatory conditions.

TABLE 145.2
CAUSES OF ALVEOLAR HEMORRHAGE

<table>
<thead>
<tr>
<th>Goodpasture syndrome</th>
<th>Vasculitis/collagen vascular disease</th>
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<tr>
<td>Wegner granulomatosis</td>
<td>Microscopic polyangiitis</td>
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<td>System lupus erythematosus</td>
<td>Mixed connective tissue disorder</td>
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<td>Systemic sclerosis (scleroderma)</td>
<td>Rheumatoid arthritis</td>
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<td>Henoch-Schonlein purpura</td>
<td>Mixed cryoglobulinemia</td>
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<td>Behcet syndrome</td>
<td>Diffuse alveolar damage</td>
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<tr>
<td>Antiphospholipid syndrome</td>
<td>Idiopathic pulmonary hemosiderosis</td>
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<td>Hematopoietic stem cell/bone marrow transplantation</td>
<td>Coagulopathy</td>
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<tr>
<td>Mitral stenosis</td>
<td>Mitral stenosis</td>
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<tr>
<td>Lymphangioleiomyomatosis</td>
<td>Drugs/Toxins</td>
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<td>Anticoagulants</td>
<td>Isocyanates</td>
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<td>D-penicillamine</td>
<td>Trimellic anhydride</td>
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<tr>
<td>Nitrofurantoin</td>
<td>D-penicillamine</td>
</tr>
<tr>
<td>All-trans retinoic acid</td>
<td>Crack cocaine</td>
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INITIAL EVALUATION

A detailed history and physical examination should be performed. Patients with a history of tuberculosis may have bleeding from rupture of a pulmonary artery aneurysm in the cavity lumen, known as a Rasmussen aneurysm, or by breakdown of bronchopulmonary anastomoses within the wall of old cavities (11). Bronchogenic carcinoma should be suspected in smokers older than 40 years of age. Repeated episodes of hemoptysis over months to years suggest bronchiectasis or a carcinoid tumor. Chronic sputum production predating the hemoptysis implies a diagnosis of chronic bronchitis, bronchiectasis, or cystic fibrosis. Pulmonary embolism should be suspected in patients with a history of deep venous thrombosis or risk factors for pulmonary thromboembolism. A febrile illness with sputum production, night sweats, and weight loss suggests a lung abscess or tuberculosis. Excessive anticoagulation, thrombolytic therapy, and coagulopathy may also cause hemoptysis (12,13). In children with hemoptysis, the most likely diagnoses are carcinoid tumors, vascular anomalies, and aspiration of foreign bodies (14,15). Alveolar hemorrhage should be suspected in patients with dyspnea, hypoxemia, and diffuse pulmonary infiltrates. The triad of upper airway disease, lower airway disease, and renal disease suggests Wegener granulomatosis (16). Goodpasture syndrome should be suspected in young men with alveolar hemorrhage and microscopic or macroscopic hematuria (17). Patients with a history of systemic lupus erythematosus may develop alveolar hemorrhage at any time during the course of their disease, and alveolar hemorrhage may be
the initial manifestation (18). Alveolar hemorrhage should be considered in patients with diffuse pulmonary infiltrates who have recently undergone hematopoietic stem cell or bone marrow transplantation (19). Although an uncommon cause of hemoptysis, a tracheoinnominate artery fistula is an important consideration in patients with tracheostomy (20,21). The peak incidence is between the first and second week, although hemorrhage can occur as early as 48 hours and as late as 18 months after the procedure. A sentinel self-limited bleed is observed in 35% to 50% of patients. Trauma from suctioning, particularly in the setting of abnormal coagulation, may also cause hemoptysis in patients with a tracheostomy tube or in those who are intubated with an endotracheal tube. The possibility of traumatic rupture of a pulmonary artery should be considered in patients with a pulmonary artery catheter in place (22,23).

**Physical Examination**

The physical examination may provide clues to the diagnosis of massive hemoptysis. A saddle nose deformity and/or septal perforation suggest Wegener granulomatosis. Stridor or unilateral wheezing indicates a possible laryngeal tumor, tracheobronchial tumor, or airway foreign body. Pulmonary embolism should be considered in patients with tachypnea, a pleural friction rub, and lower extremity phlebitis. Diffuse rales on examination raise the possibility of diffuse alveolar hemorrhage, diffuse parenchymal lung disease, or cardiac disease as the cause of the hemoptysis. The presence of telangiectasias of the skin or mucous membranes suggests hereditary hemorrhagic telangiectasia or a connective tissue disease as the cause. Ecchymoses or petechiae suggest a hematologic abnormality or coagulopathy. Clubbing of the fingers may be a sign of a lung carcinoma, bronchiectasis, and cystic fibrosis. The finding of pulsation of the tracheostomy tube is of concern for the development of a tracheoinnominate fistula.

**Laboratory Studies**

Laboratory studies, including a complete blood count (CBC), coagulation studies, urinalysis, and chest radiograph, should be obtained in all patients. The CBC may suggest an infectious process or hematologic disorder as the cause of hemoptysis and indicates the need for blood transfusion. Coagulation studies may provide evidence for a hematologic disorder as the cause for the hemoptysis, or may identify a coagulopathy that is causing or contributing to the bleeding from another disease. Hematuria may be noted on urinalysis, which suggests the diagnosis of Goodpasture syndrome, Wegener granulomatosis, or another systemic vasculitis.

**Chest Radiograph**

The chest radiograph is an important study to identify the cause and side of bleeding. The chest radiograph may demonstrate abnormalities such as lung masses, cavitary lesions, atelectasis, focal infiltrates, and diffuse infiltrate. Single or multiple pulmonary cavities suggest neoplasms, tuberculosis, fungal disease, lung abscess, septic pulmonary emboli, parasitic infection, or Wegener granulomatosis as the cause for hemoptysis. The presence of a mass within a cavitary lesion indicates a possible mycetoma (aspergilloma). The appearance of a new air-fluid level in a cavity or infiltrate around a cavity is suggestive of the site of bleeding. A solitary pulmonary nodule may be an arteriovenous malformation. Diffuse pulmonary infiltrates suggest diffuse alveolar hemorrhage (Table 145.2), bleeding from coagulopathy, lung contusions from blunt chest trauma, hemorrhage with multiple areas of aspiration, or pulmonary edema with a cardiac cause for hemoptysis. Chest radiographs may be normal or nonlocalizing in 20% to 45% of patients (24,25).

**Computed Tomography**

The role of computed tomography (CT) in the management of massive hemoptysis is somewhat controversial. CT may demonstrate abnormalities that are not visible on the chest radiograph. It is helpful in the diagnosis of bronchiectasis (26), although abnormalities from bronchiectasis can usually be appreciated on the chest radiograph. CT with contrast may detect pulmonary emboli, thoracic aneurysms, or arteriovenous malformations. CT scans may also demonstrate cavitation with a surrounding infiltrate, the halo sign, which suggests a necrotizing infection such as aspergillosis or mucormycosis (27,28). Some studies have noted that CT scanning before bronchoscopy may increase the yield of bronchoscopy (29). In one retrospective study of 80 patients with large or massive hemoptysis, chest CT was superior to chest radiograph or bronchoscopy in determining the cause of bleeding and was similar to bronchoscopy in successfully localizing the site of bleeding (30). Some authors have argued that transport of the potentially unstable patient with massive hemoptysis may not be judicious, however. The patient should be adequately stabilized prior to obtaining a chest CT.

**Angiography**

Angiography can determine the site of bleeding in 90% to 95% of cases. However, in one case series, the routine use of diagnostic angiography provided a diagnosis not identified on bronchoscopy in only 4% of patients (31). Angiography can be helpful in detecting a pseudoaneurysm that has formed after healing of a pulmonary artery tear from pulmonary artery catheterization (32). As previously noted, the bronchial arteries and other collateral systemic arteries account for the source of bleeding in most cases of massive hemoptysis. Pulmonary angiography is usually performed only when there is suspicion for pulmonary aneurysms, arteriovenous malformations, and pulmonary embolism. Technetium-labeled red blood cell or collodion studies rarely provided any information that is not obtained by bronchoscopy and chest CT. The use and timing of bronchoscopy will be discussed in a subsequent section.

**Other Studies**

Depending on the suspected causes of massive hemoptysis, additional studies may be indicated. For potential infections, sputum and bronchoscopic specimens should be sent for bacterial
cultures, fungal stains and cultures, viral cultures, acid-fast bacilli stains, and mycobacterial cultures. Bronchoalveolar lavage (BAL) specimens may also be sent for cytology, with special stains to evaluate for fungi, Pneumocystis, viruses, protozoa, and parasites. Bronchoscopic specimens should be obtained if a neoplasm if suspected. Echocardiography may be performed if a cardiac cause is possible. If diffuse alveolar hemorrhage syndromes are suspected, laboratory testing, including antiglomerular basement membrane antibody, antineutrophil cytoplasmic antibody, autoimmune antibody, rheumatoid factor, complement levels, cryoglobulins, rheumatoid factor, and antiphospholipid antibodies, should be performed depending on the causes that are being considered. Transbronchial lung biopsy, open lung biopsy, or kidney biopsy may be indicated in some cases of alveolar hemorrhage to establish a diagnosis.

**MANAGEMENT OF MASSIVE HEMOPTYSIS**

### Airway Protection and Stabilization

Once the diagnosis of massive hemoptysis is established, the initial priorities are to protect the airway and stabilize the patient. In general, the patient with massive hemoptysis should be monitored in the ICU setting, even if intubation and mechanical ventilation are not required. Large-bore IV access should be established and supplemental oxygen provided. Blood should be drawn for a CBC, arterial blood gas analysis, coagulation studies, electrolytes, serum electrolyte tests, and liver function tests. The patient should be type and cross-matched for blood, and 4 to 6 units of packed red blood cells should always be available. Correction of thrombocytopenia and coagulopathy, if present, with appropriate blood products should be considered. Attempts to lateralize the site of bleeding should be made in anticipation of steps to prevent aspiration into the nonbleeding lung. The patient may be positioned in a lateral decubitus position with the bleeding lung down.

Airway patency must be ensured in patients with massive hemoptysis, as deaths from this process are predominantly due to asphyxiation. Most patients with ongoing massive hemoptysis will require intubation and mechanical ventilation, although select patients who are not hypoxicemic and are able to keep the airway clear on their own may not require intubation. Although intubation generally preserves oxygenation and facilitates blood removal from the lower respiratory tract, the endotracheal tube (ET) can become obstructed by blood clots, leading to the inability to oxygenate and ventilate the patient. The largest possible ET should be inserted to allow the use of bronchoscopes with a 2.8 to 3.0 mm working channel for more effective suctioning and to allow for better ventilation with the bronchoscope in the airway for prolonged periods of time. In severe cases, the mainstem bronchus of the nonbleeding lung can be selectively intubated under bronchoscopic guidance to preserve oxygenation and ventilation from the normal lung.

Some authors have recommended the use of a double-lumen ET to isolate the normal lung and permit selective intubation. Although double-lumen endotracheal tubes have been used successfully in the airway management of massive hemoptysis, there are several potential pitfalls. First, placement of a double-lumen ET is difficult for less-experienced operators, particularly with a large amount of blood in the larynx and oropharynx. Second, the individual lumens of the ET are significantly smaller than a standard ET and are at significant risk of being occluded by blood and blood clots. Last, positioning of the double-lumen ET and subsequent bronchoscopic suctioning of the distal airways requires a small pediatric bronchoscope with working channels of 1.2 to 1.4 mm. Adequate suctioning of large amounts of blood and blood clots through such bronchoscopes is extremely problematic. In one series of 62 patients with massive hemoptysis, death occurred in 4 of 7 patients managed with a double-lumen ET due to loss of tube positioning and aspiration (35). In general, we do not recommend the use of double-lumen ETs for airway management in massive hemoptysis. As an alternative to selective mainstem bronchial intubation or intubation with a double-lumen ET, an ET that incorporates a bronchial blocker, such as the Univent tube, may be used.

### Localization of Source and Cause of Hemoptysis

Once the patient is stabilized and airway patency is achieved, the source of bleeding should be localized as precisely as possible, and the cause of bleeding should be determined. Identification of the cause and location of the bleeding potentially allows for more specific therapy. Methods of localization include patient history, physical examination, chest radiograph, chest CT, bronchoscopy, and angiography. In one study of 105 patients with hemoptysis, patients themselves were able to localize the side of bleeding in 10% of cases but with an accuracy of 70% when able to do so (34). Localization by a physical examination performed by a physician was possible in 43% of patients. Chest radiographs were able to localize bleeding in 60% of cases. Bronchscopy was accurate in localizing the source of bleeding in 86% of patients. In another study, 9 of 24 patients were able to accurately localize the side of their bleeding (35). Chest radiographs should be routinely obtained to help localize the source of bleeding and determine the cause. As discussed earlier, chest CT may provide additional information beyond the chest radiograph, and may be more accurate in localizing the bleeding and determining the cause, although concerns about transporting a potentially unstable patient out of the ICU exist (36,37). Bronchoscopy and angiography remain the modalities for localizing the source of hemoptysis and offer potential therapeutic intervention.

Early—rather than delayed—bronchoscopy should be performed to increase the likelihood of localizing the source of bleeding. Bronchoscopy performed within 48 hours of bleeding onset successfully localized bleeding in 34% to 91% of patients, depending on the case series, as compared to successful localization in 11% to 52% of patients if delayed bronchoscopy was performed (38). Bronchoscopy performed within 12 to 24 hours may provide an even higher yield. Besides flexible bronchoscopy should not be performed to establish a diagnosis of a tracheoarterial fistula such as a tracheostinominiate fistula (39,40). Bronchoscopy may be performed in the patient with a tracheostomy tube and hemothysis to exclude bleeding from suction trauma, tracheitis, granulation tissue, and lower respiratory tract disorders. If no other causes for hemoptysis
can be found, or if the observation that anterior and downward pressure on the cannula at the level of the stoma site or over-inflation of the tracheostomy tube slows down the bleeding, a surgical consultation should be obtained. The tracheostomy balloon should not be deflated, and the tracheostomy tube should not be removed without protecting the airway below the tracheostomy tube. The patient should be brought to the operating room for further examination with preparations for surgical repair in place.

**Bronchoscopic Therapies to Control Hemoptysis**

Endobronchial tamponade via flexible bronchoscopy can prevent aspiration of blood into the contralateral lung and preserve gas exchange in patients with massive hemoptysis. Endobronchial tamponade can be achieved with a 4 French Fogarty balloon-tipped catheter. The catheter may be passed directly through the working channel of the bronchoscope, or the catheter can be grasped with biopsy forceps placed though the working channel of the bronchoscope prior to introduction into the airway of the bronchoscope and catheter. The catheter is held in place adjacent to the bronchoscope by the biopsy forceps, and both are then inserted as a unit into the airway. Care must be taken not to perforate the catheter or balloon by the forceps. The catheter tip is inserted into the bleeding segmental orifice, and the balloon is inflated. If passed through the suction channel, the proximal end of the catheter is clamped with the hub cut off, and a straight pin inserted into the catheter channel proximal to the hemostat to maintain inflation of the balloon catheter. The clamp is removed, and the bronchoscope is carefully withdrawn from the bronchus with the Fogarty catheter remaining in position, thus providing endobronchial hemostasis (41–43). The catheter can safely remain in position until hemostasis is ensured by surgical resection of the bleeding segment or bronchial artery embolization. Right heart balloon catheters have been used in a similar fashion (44). A modified technique for placement of a balloon catheter has been described using a guidewire for insertion. A 0.035-inch soft-tipped guidewire is inserted through the working channel of the bronchoscope into the bleeding segment. The bronchoscope is withdrawn, leaving the guidewire in place. A balloon catheter is then inserted over the guidewire and placed under direct visualization after reintroduction of the bronchoscope (45). The use of endobronchial blockers developed for unilateral lung ventilation during surgery may hold promise for management of massive hemoptysis in tamponading bleeding and preventing contralateral aspiration of blood (46). The Arndt endobronchial blocker is placed through a standard ET and directly positioned with a pediatric bronchoscope. Suctioning and injection of medications can be performed through the lumens of the catheter after placement. The Cohen tip-deflecting endobronchial blocker is also placed through a standard ET and directed into place with a self-contained steering mechanism under bronchoscopic visualization. At this time, there is limited published experience with these blockers in the setting of massive hemoptysis, although the author has successfully used them for this application. The prolonged use of endobronchial blockers may cause mucosal ischemic injury and postobstructive pneumonia.

Additional bronchoscopic techniques may be useful as temporizing measures in patients with massive hemoptysis. Bronchoscopically administered topical therapies, such as iced sterile saline lavage or topical 1:10,000 or 1:20,000 epiinephrine solution, may be helpful (47). Direct application of a solution of thrombin or a fibrinogen-thrombin combination solution has been used (48). The use of bronchoscopy-guided topical hemostatic tamponade therapy using oxidized regenerated cellulose mesh has recently been described (49). Although anecdotal, the author has had success with topical application of a sodium bicarbonate solution.

For patients who have hemoptysis due to endobronchial lesions, particularly endobronchial tumors, hemostasis may be achieved with the use of neodymium-yttrium-aluminum-garnet (Nd:YAG) laser phototherpay, electrocautery, or cryotherapy via the bronchoscope.

**Angiography and Embolization**

Angiography can identify the bleeding site in more than 90% of cases. As noted, the bronchial arteries are the most frequent source of bleeding in massive hemoptysis. In some cases, systemic vessels other than the bronchial arteries can be the source of bleeding (50). The pulmonary arteries may be the source for massive hemoptysis in 8% to 10% of cases (9). Visualization of extravasated dye from a vessel is relatively uncommon. Signs that suggest a particular vessel is the source of bleeding include vessel tortuosity, increased vessel diameter, and aneurysmal dilatation.

Bronchial artery embolization is considered the most effective nonsurgical modality for treatment of massive hemoptysis. The immediate success rates from bronchial artery embolization range from 51% to 80.00% (3,51–65). Embolization has been performed with Gelfoam, polyurethane particles, polyvinyl alcohol particles, and vascular coils. Sclerosing agents may cause subsequent lung necrosis and should be avoided. Recurrence of bleeding, although usually nonmassive, has been noted in 16% to 46% of patients (51,52). Repeat embolization may be required in some patients (57,60,62,66). Complications include chest pain, fever, vessel perforation and intimal tears, and embolization of material to mesenteric and extremity arteries. The most serious complication is embolization of the anterior spinal artery, which may arise from the bronchial artery, with subsequent spinal artery infarction and paraparesis. The risk of this occurrence is less than 1%.

**Rupture of the Pulmonary Artery**

The pulmonary artery may potentially be ruptured from right heart catheterization. This complication should be suspected in patients who develop hemoptysis with a pulmonary artery catheter in place. Balloon tamponade and contralateral selective intubation should be performed (67). The catheter should be withdrawn 5 cm with the balloon deflated, and the balloon is then inflated with 2 ml of airway and allowed to float back into the ruptured vessel to occlude it. Patients who stop bleeding should undergo angiographic evaluation to localize the tear and identify the formation of a pseudoaneurysm (32,68). If a pseudoaneurysm is identified, embolization of the affected vessel should be considered to prevent subsequent hemorrhage.
Surgery

Emergency surgery for control of massive hemoptysis is performed less often due to the advent of bronchial artery embolization. Mortality rates for surgical management of massive hemoptysis range from 1% to 50% (3,69–74). Surgical resection of the source of bleeding offers definitive treatment as long as the lesion can be completely resected and the patient is able to tolerate resectional surgery. It is often difficult to accurately determine if these patients will be able to tolerate surgery, as they are often too ill to undergo pulmonary function tests, or are intubated and thus unable to perform pulmonary function tests. Surgical resection may be considered in patients when bronchial artery embolization is unavailable, if bleeding continues despite embolization, or if the cause of the hemoptysis is unlikely to be controlled with embolization.

Diffuse Alveolar Hemorrhage

Patients with diffuse alveolar hemorrhage syndromes are not candidates for bronchial artery embolization or surgery. Treatment for these groups of patients is pharmacologic. Corticosteroids are typically used and are effective for a wide range of the alveolar hemorrhage syndromes (75). Doses of 1 to 2 mg/kg per day of methylprednisolone have been most commonly used. For life-threatening alveolar hemorrhage, initial doses of 500 to 1,000 mg per day of methylprednisolone have been recommended. For Goodpasture disease, Wegener granulomatosis, and other vasculitides, adjunctive cytotoxic therapy has been recommended. For Goodpasture disease, cyclophosphamide is typically used. For life-threatening alveolar hemorrhage, initial doses of 500 to 1,000 mg per day of methylprednisolone have been recommended. For Goodpasture disease, Wegener granulomatosis, and other vasculitides, adjunctive cytotoxic therapy may be recommended. However, there are limited data regarding the optimal treatment approach for these conditions. The use of corticosteroids and other immunosuppressive agents, such as cyclophosphamide, azathioprine, and mycophenolate mofetil, is recommended. In addition, plasma exchange has been used for the treatment of diffuse alveolar hemorrhage in patients with systemic lupus erythematosus (76).

References

3. Cooper K, Ha KM. Major and massive hemoptysis: management of conserva-
25. Marshall TJ, Faust CD, Jackson JE. The role of radiology in the in-
44. Jolliet P, Soccal P, Cherelinger J. Control of massive hemoptysis by endo-
Section XIII: Respiratory Disorders


