malformations. It also appears to be an appropriate option in patients who are deemed inoperable or are poor surgical candidates. Typically, arteriography is performed after the bleeding is localized by bronchoscopy. The limitations of arterial embolization depend on the experience of the provider, anatomic variance of the bronchial arterial tree, and inability to appreciate extravasation of contrast secondary to slow bleeding rates. If the cause of the hemoptysis is a chronic inflammatory condition such as bronchiectasis, any systemic artery in the thorax could potentially be the source of the bleeding. Should hemoptysis recur, repeat embolization can be performed safely. A potential complication of arterial embolization is accidental embolization of the anterior spinal artery, which originates from a bronchial artery in about 5% of the population.

Emergent surgery for massive hemoptysis is associated with a very high mortality rate and is typically used as a last resort. It is best to first stabilize the patient before proceeding with surgery. Surgery for massive hemoptysis after institution of control measures has mortality rates as low as 0% as opposed to 38% for emergent surgery. Surgical resection should be considered (1) when arterial embolization is unavailable or is deemed technically impossible; (2) when bleeding continues despite embolization; (3) when the volumes of expectorated blood or the cardiopulmonary sequelae of massive hemoptysis are so extreme as to be an imminent threat to survival; or (4) when the putative cause of massive hemoptysis is unlikely to be controlled by embolization, as in patients with suspected pulmonary artery perforation. Relative contraindications include poor underlying lung function, inoperable cancer, and active tuberculosis. Definitive treatment options for massive hemoptysis depend on the underlying cause. Lung cancer may be amenable to surgical resection or radiation therapy. Patients with massive hemoptysis resulting from infection may ultimately respond to antibiotic therapy. Patients with diffuse alveolar hemorrhage from disorders such as Goodpasture syndrome or systemic lupus erythematosus may respond to immunotherapy.

PNEUMOTHORAX

Pneumothorax is a relatively common disorder and is defined as air within the pleural space. It can be an incidental finding on a chest radiograph and cause few or no symptoms, or it can result in acute respiratory failure. The most common way air enters the pleural space is from the lung. However, air can also enter the pleural space through the chest wall because of penetrating trauma, by gas-producing organisms within the pleural space, or from air initiating in the abdomen. A pneumothorax can occur because of underlying lung disease or trauma or can be iatrogenically induced. **Table 2** lists some common causes of pneumothorax.

Table 2. Common Causes of Pneumothorax

Primary Spontaneous (from subpleural blebs)
Associated With Underlying Lung Disease (Secondary)

- Chronic obstructive pulmonary disease
- Asthma
- Lung cancer
- Sarcoidosis
- Infections (pneumocystis, tuberculosis, necrotizing pneumonia)
- Endometriosis
- Cystic fibrosis
- Rheumatoid arthritis, Sjögren syndrome, ankylosing spondylitis
- Interstitial lung disease
- Genetic conditions (Marfan syndrome, Birt-Hogg-Dubé syndrome)
- Lymphangioleiomyomatosis
- Anorexia nervosa

Traumatic

- Penetrating chest trauma
- Blunt chest trauma
- Tracheal or bronchial rupture

Iatrogenic

- Transthoracic needle biopsy
- Subclavian central venous catheters
- Thoracentesis
- Transbronchial biopsy
- Lung resection
- Positive pressure ventilation
- Cardiopulmonary resuscitation

Information taken from Cremaschi P, Nascimbene C, Vitulo P, et al. Therapeutic embolization of bronchial artery: a successful treatment in 209 cases of relapse hemoptysis. *Angiology*. 1993;44:295-299 and Bintcliffe, OJ, et al. Spontaneous pneumothorax: time to rethink management? *The Lancet Respiratory Medicine*. 2015;3:578-588.

Spontaneous Pneumothorax

The term *spontaneous pneumothorax* refers to a pneumothorax of nontraumatic origin. It may be a primary spontaneous pneumothorax that occurs in otherwise healthy individuals and is linked to the presence of subpleural blebs. A secondary spontaneous pneumothorax is linked to an underlying lung disease and is also described in **Table 2**. Smoking has been reported to increase the risk of primary spontaneous pneumothorax in up to 12% of healthy male smokers. Secondary atraumatic pneumothoraces carry a higher mortality than primary spontaneous pneumothoraces and may be more difficult to manage. One of the most common causes of secondary pneumothorax is chronic obstructive pulmonary disease.

Symptomatic primary or secondary spontaneous pneumothoraces require intervention. Secondary pneumothoraces are most likely to require intervention. Large-bore chest tubes are usually not required for management. Small-bore tubes of 14F or smaller are adequate. Smaller bore tubes are also better tolerated. Routine suction is usually not required. A persistent air leak after 2 to 4 days merits evaluation for thoracic surgery.

Traumatic Pneumothorax

Pneumothorax associated with blunt or penetrating chest trauma is common. In one published series, up to 26% of patients with blunt trauma sustained a pneumothorax and 76% of the pneumothoraces were occult. A pneumothorax seen on chest CT but not on chest radiograph is referred to as an *occult pneumothorax*. Frequently the patient has associated rib fractures. Blunt chest trauma can cause a pneumothorax by parenchymal injury with rib fracture, parenchymal injury from deceleration forces, alveolar rupture from crush forces, and alveolar rupture from increased intrathoracic pressure. A pneumothorax can develop without significant signs of external injury. Penetrating trauma involves direct injury to lung and the pleura. Occult pneumothoraces are commonly recognized with the use of chest CT scans and bedside ultrasonography. These pneumothoraces are typically very small and asymptomatic. Patients with occult pneumothorax who do not require positive pressure ventilation usually can be safely observed. Recommendations are mixed for the management of occult pneumothoraces in patients receiving positive pressure ventilation and include a conservative approach of observation or a more invasive approach involving placement of thoracostomy tubes. Patients with larger pneumothoraces may present with symptoms of pleuritic chest pain or dyspnea. On examination, patients may have tachypnea, hypoxia, or decreased or absent breath sounds on the side of the pneumothorax. The presence of subcutaneous emphysema in the neck or hemoptysis should raise concern for a traumatic injury to the trachea, mainstem bronchus, or esophagus. Patients should be evaluated for evidence of displaced rib fractures and a flail chest. Absent breath sounds with the trachea deviated to the contralateral side should raise concerns for a tension pneumothorax.

Most patients with significant trauma undergo multiple body CT scans, which are very sensitive at diagnosing a pneumothorax. Upright chest radiographs are less sensitive and can miss up to 30% of pneumothoraces. Ultrasound has a higher reported sensitivity to detect a pneumothorax. A recent meta-analysis showed that ultrasound had 76% sensitivity for detecting pneumothoraces as opposed to 39.8% for chest radiograph. Placement of a chest tube is indicated if the patient is symptomatic or unstable, there is an associated hemothorax, the patient requires positive pressure ventilation, there is evidence of tracheobronchial rupture, or there is evidence of a tension pneumothorax. Tension pneumothorax should first be treated with immediate needle decompression followed by placement of the chest tube. A chest tube size of at least 32F has been recommended; however, smaller chest tubes may be considered. Up to 20% of traumatic pneumothoraces can have associated hemothoraces. There is some support in the literature for prophylactic doses of a first-generation cephalosporin for 24 hours to decrease the incidence of pneumonia or empyema in patients who require chest tubes for the management of a traumatic pneumothorax.

Iatrogenic Pneumothorax

An iatrogenic pneumothorax is not uncommon in the ICU. It is often due to a complication from placement of a central venous catheter, thoracentesis, transthoracic needle biopsy, cardiopulmonary resuscitation, or positive pressure ventilation. Pacemaker placement and bronchoscopy have been associated with pneumothorax but are uncommon causes. The incidence of pneumothorax complicating the placement of a subclavian venous catheter is about 1.5%, whereas the risk associated with transthoracic needle biopsy can be as high as 25%. Risk of pneumothorax is highest when the procedure is performed by less experienced providers. Most pneumothoraces that complicate procedures are small and are detected immediately after the procedure. However, some may develop up to 24 hours after the procedure. If the pneumothorax is small and the patient is asymptomatic and not receiving positive pressure ventilation, the patient can likely be treated with increased FIO_2 and observed. Placing the patient on humidified 100% oxygen potentially increases the rate of reabsorption 4 times faster compared with room air. Serial chest radiographs are needed to ensure that the pneumothorax is not expanding. Expansion suggests an ongoing air leak from the lung, and in such cases a chest tube should be placed. Needle aspiration remains an option for select iatrogenic and noniatrogenic pneumothoraces. Asymptomatic patients with a larger pneumothorax (>20% on chest radiograph) or presenting with symptoms such as dyspnea post procedure may benefit from needle aspiration. This is performed by inserting a 16- or 18-gauge catheter over a needle into the pleural space at the level of the second intercostal space in the midclavicular line. Air is aspirated through the catheter with a syringe once the needle is removed. This is best accomplished by using a 3-way stopcock and a 50- to 60 mL-syringe. Ultrasound may facilitate pneumothorax location and limit complications. Needle aspiration has been associated with a resolution rate as high 90%. If more than 2.5 L of air is removed without the development of resistance to withdrawal, this suggests the presence of a persistent air leak. Some literature suggests that the aspiration of air greater than 550 mL predicts the need for chest thoracostomy. The catheter is typically removed when resistance is detected with aspiration. Postprocedure serial chest radiographs should be performed. Increasing pneumothorax suggests the presence of an air leak and requires placement of a chest tube. A meta-analysis comparing needle aspiration versus chest tube in the management of spontaneous pneumothoraces showed no difference in outcome but a decreased hospital length of stay when aspiration was used. Needle aspiration has been used successfully for small iatrogenic pneumothoraces. For patients with persistent air leaks, patients receiving positive pressure ventilation, or those with signs of hypoxia, respiratory distress, or respiratory failure, a chest tube should be placed.

Pneumothorax From Positive Pressure Ventilation

Pneumothorax is one of several manifestations of pulmonary barotrauma from positive pressure ventilation and can result in severe hypoxia, hypotension, and even cardiac arrest due to the development of a tension pneumothorax. Other repercussions of barotrauma include pneumomediastinum, pneumoperitoneum, subcutaneous emphysema, and gas embolism. The risk of pneumothorax with positive pressure ventilation has been estimated to range from 3% to 10%. Risk factors for developing a pneumothorax with positive pressure ventilation include chronic obstructive pulmonary disease, asthma, chronic interstitial lung disease, right mainstem intubation, and acute respiratory distress syndrome (ARDS). Patients receiving high-frequency oscillatory ventilation appear to be at a much higher risk for developing pulmonary barotrauma, with an incidence as high as 26%.

The appearance of signs such as sudden tachycardia, worsening hypoxia, tachypnea, and/or subcutaneous emphysema may suggest the presence of a pneumothorax. If the patient develops sudden hypotension with evidence of tracheal deviation, a tension pneumothorax should be suspected. A sudden increase in both peak and plateau airway pressures should also raise the concern for a pneumothorax. Other findings that suggest a pneumothorax include pulsus paradoxus on arterial line tracings, decreased ipsilateral breath sounds, or hyperresonance on percussion. The challenge in care is that clinical findings in a ventilated patient can be highly unreliable. In one case series review, mechanically ventilated patients with tension pneumothorax rarely exhibited jugular venous distention or tracheal deviation. Primary findings were an increase oxygen requirement and hypotension. Detection of a pneumothorax in a mechanically vented patient often requires vigilance, clinical suspicion, and frequent reevaluation.

A chest radiograph and/or ultrasound study should be performed immediately if a pneumothorax is suspected. However, if the patient is unstable and evidence suggests a tension pneumothorax (absent breath sounds, contralateral tracheal deviation, and hypotension), needle decompression should be performed immediately without waiting for diagnostic studies. The chest radiograph should be performed with the patient sitting upright if possible. A better option than a chest radiograph is a bedside ultrasound. Bedside ultrasound has a documented superior sensitivity to chest radiograph for occult pneumothorax detection. The bedside ultrasound offers the advantage of immediate point of care access. In trained hands, bedside ultrasound has been shown to diagnose 92% of occult pneumothoraces found on chest CT. If chest radiography or ultrasonography is inconclusive, chest CT should be considered.

Efforts should be made to prevent the development of barotrauma in patients receiving positive pressure ventilation. The best approach appears to be keeping plateau airway pressures below 30 cm H_2O. Elevated peak airway pressures do not predict the risk of barotrauma, and barotrauma appears unlikely to develop at peak airway pressures less than 50 cm H_2O.

INHALATIONAL INJURIES

Inhalational injuries can be divided into 3 categories: thermal injuries to the