Pneumothorax, Bullous Disease, and Emphysema

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KEYWORDS

- Pneumothorax • Bullous disease • Emphysema
- Pulmonary conditions

This article discusses several conditions that are distinct entities but share the common thread of abnormal lung parenchyma that regularly leads to patient referral for surgical consideration. The article summarizes key aspects of the 3 conditions and provides advice and recommendations for evaluation and treatment based on published reports in the medical literature.

PNEUMOTHORAX

Definition

A pneumothorax is defined as air in the pleural space, between the parietal and visceral pleura. This condition may be caused by trauma or underlying lung disease, but sometimes happens spontaneously without obvious cause. When a pneumothorax develops, there is loss of the negative intrapleural pressure that is needed for lung inflation, and the lung on the affected side collapses and cannot expand properly. This collapse leads to a ventilation-perfusion mismatch because there is continued perfusion of a poorly ventilated lung. Arterial hypoxemia can occur with 50% collapse of the lung. If there is a continued air leak with increasing positive intrapleural pressure, this can lead to a tension pneumothorax and can lead to compromise of venous return to the heart, decreasing cardiac output, and causing hemodynamic collapse.

Causes

Pneumothorax can be spontaneous, traumatic, or iatrogenic. Primary spontaneous pneumothorax typically occurs in young, healthy, tall, thin, male smokers and is

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usually caused by rupture of apical subpleural blebs in otherwise normal lungs. The reported incidence varies from 7.4 per 100,000 per year in the United States to 24 per 100,000 per year in the United Kingdom. The incidence in women is lower: 1.2 per 1000,000 per year in the United States and 9.8 per 100,000 per year in the United Kingdom.[1–4] In the United States, primary spontaneous pneumothoraces affect more than 20,000 patients per year and may account for as much as $130,000,000 in health care expenditures annually.[2,5] Compared with nonsmokers, the relative risk of pneumothorax in smokers is 22 times greater for men and 9 times greater for women.[6]

When a spontaneous pneumothorax occurs in patients with known underlying lung disease, it is referred to as secondary spontaneous pneumothorax. Causes include bullous diseases (chronic obstructive pulmonary disease [COPD] and emphysema), cystic diseases (cystic fibrosis, lymphangioleiomyomatosis), infectious causes (pneumonia, severe acute respiratory syndrome), catamenial, connective tissue disorders (Marfan syndrome), and malignancy (primary lung cancer, metastatic disease). The incidence of secondary spontaneous pneumothorax in the United States is 6.3 per 1000,000 per year in men and 2 per 100,000 per year in women.[2] Most of these cases are caused by hyperinflation and rupture of bullae.

Traumatic pneumothoraces can result from both blunt and penetrating injuries to the chest wall, bronchi, lung, or esophagus. Iatrogenic pneumothoraces can occur after diagnostic or therapeutic interventions.

Patient Presentation

Patients who develop a pneumothorax usually complain of sudden onset of dyspnea and pleuritic chest pain. However, the condition may be asymptomatic in 10% of cases. Forty-six percent of patients with primary pneumothorax wait more than 2 days after onset of symptoms before seeing a physician.[4] Patients with secondary spontaneous pneumothorax may have more severe symptoms because they have less pulmonary reserve because of their underlying lung disease. On physical examination, patients typically have decreased breath sounds, decreased chest excursions, and hyperresonant percussion on the affected side. Subcutaneous emphysema may also be present. If the patient has any hemodynamic instability, the concern for a tension pneumothorax must be raised. Additional signs of a tension pneumothorax include significant respiratory distress, tachypnea, distended neck veins, pulsus paradoxus, displacement of the point of maximal cardiac impulse, and trachea shift. These signs are often late and emergency treatment must be initiated with an urgent thoracostomy tube or temporary decompression of the chest with a 14- to 16-gauge needle or catheter placed in the second intercostal space in the midclavicular line on the affected side.

Clinical Findings

Chest radiographs can show the pneumothorax as a hyperlucent area with an absence of pulmonary markings. A white visceral pleural line can be seen outlining the collapsed lung border (**Fig. 1**). Lateral displacement of the mediastinum and/or trachea and downward displacement of the diaphragm can be seen with a tension pneumothorax. According to the British Thoracic Society guidelines, a pneumothorax is defined as small if the distance from the chest wall to the visceral pleural line is less than 2 cm, or large if the distance is greater than 2 cm.[4] However, the American College of Chest Physicians defines small pneumothoraces as those in which the visceral pleura is less than 3 cm from the chest wall and large pneumothoraces as those more than 3 cm.[3] The chest cavity is a three-dimensional space and it is difficult to accurately calculate the size of the pneumothorax using plain chest films. It has

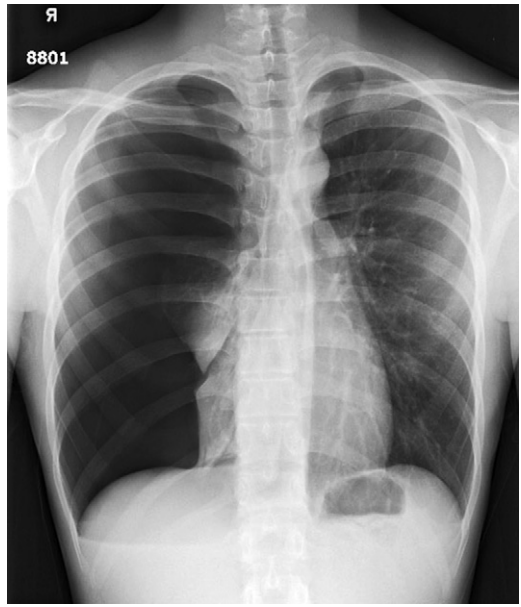

Fig. 1. Twenty-year-old man with a right-sided spontaneous pneumothorax. The compressed and collapsed right lung, and the widened intercostal distance on the right side, all suggest a degree of tension pneumothorax is present. Successful management took place with a 19 French percutaneous chest catheter.

been estimated that, if the pneumothorax is 1 cm wide, it accounts for 25% of the hemithorax volume. A 2-cm pneumothorax can occupy up to 50% of the chest cavity. In patients with COPD, a large apical bulla can be misdiagnosed as a pneumothorax because of a similar appearance on chest radiograph. Chest computed tomography (CT) can help differentiate between these two conditions and provide information on underlying lung pathology. A large left-sided pneumothorax may lead to a right-sided shift in the QRS axis on an electrocardiogram, with a decrease in the precordial R wave voltage. In general, once the pneumothorax is treated, the electrocardiogram reading will return to normal.[7]

Nonoperative Management

There are 3 principles for treatment of a pneumothorax: (1) eliminate the intrapleural air collection, (2) facilitate pleural healing, and (3) prevent recurrence. Initial treatment options include one or more of the following options: observation, supplemental oxygen, needle aspiration of intrapleural air, chest tube insertion, and thoracoscopic or thoracotomy interventions. The patient's clinical status is the most important factor to consider in proper management.

An asymptomatic patient in good health with a small (less than 2 cm) pneumothorax can be managed expectantly with observation. Spontaneous reabsorption of pneumothoraces has been estimated at 1.25% to 1.8% (about 50–70 mL) of the total volume of air in the pleural space per day.[8] The administration of supplemental oxygen reduces the partial pressure of nitrogen in the pleural capillaries and increases air reabsorption from the pleural space.[4,9] If patients are treated expectantly with observation, it is important to follow them closely with serial chest radiographs to make sure

the pneumothorax is resolving. With observation, a 25% pneumothorax can take as long as 20 days to reabsorb.

In patients with mild to moderate respiratory symptoms and a moderate or large first-time pneumothorax, a trial of needle aspiration should be considered. Two recent randomized controlled studies have been conducted evaluating needle aspiration versus chest tube insertion. One study consisted of 60 participants with either a first episode of primary spontaneous pneumothorax, or a pneumothorax greater than 20%. The patients were randomized into one of 2 treatment groups: manual pleural aspiration with a small-caliber 16-gauge intravenous catheter under local anesthesia, or chest tube drainage with a 16 to 20 French chest tube. Patients with underlying lung disease, previous pneumothorax, or tension pneumothorax were excluded from the study. The results showed no difference in the immediate success rate, early failure rate, 1-year success rate, or complication rate of simple aspiration versus intercostal tube drainage. Simple aspiration had an immediate success rate of 60%, and resulted in a significant reduction in the proportion of patients hospitalized compared with intercostal tube drainage.[10]

The second study enrolled 137 patients with a first episode of primary spontaneous pneumothorax at a single center. Patients were included if they were symptomatic or had greater than a 20% pneumothorax. Once again, patients were randomized to simple aspiration versus tube thoracostomy. The results showed no difference in immediate success rate, 1-week success rate, complication rate, recurrence at 3-month follow-up, or recurrence at 1 and 2 years. Only 26% of the patients treated with simple aspiration required hospital admission, versus 100% of those receiving chest tubes.[11] A Cochrane Review of this topic concurred with the British Thoracic Surgery guidelines recommending simple aspiration as a first-line treatment of primary spontaneous pneumothoraces requiring intervention.[4,12]

Conventional tube thoracostomy should be used in patients with large pneumothoraces who fail needle aspiration, who have underlying lung pathology, or who are very symptomatic. Chest tubes are inserted in the anterior or midaxillary line in the fourth or fifth interspace and should be guided posteriorly and cephalad. This tube positioning allows drainage of both fluid and air. If the patient has an isolated pneumothorax with no pleural effusion, a small chest tube (16–20 French) can be used to minimize discomfort to the patient. With proper tube drainage, the lung should re-expand rapidly. Negative pressure (-10 to -20 cm H_2O) on the chest tube or underwater seal can be used to maintain lung re-expansion. The chest tube can be removed after the air leak has stopped. If the air leak is prolonged and the patient can maintain full lung expansion on underwater seal drainage, a 1-way valve can be placed at the end of the tube and the patient discharged and followed as an outpatient.

Surgical Treatment

Most cases of primary spontaneous pneumothorax resolve with nonoperative management; however, some require surgical intervention. The indications for operative intervention include persistent air leak, failure of the lung to fully expand with chest tube drainage, hemothorax, recurrent pneumothorax, bilateral pneumothorax, first occurrence of contralateral pneumothorax, high-risk activities/professions, and poor access to medical treatment or follow-up.

Most air leaks seal within 48 hours after placement of a chest tube, but up to 5% have a prolonged air leak lasting more than 4 days.[13] Recurrence rates vary widely depending on the treatment applied and the follow-up period. In general, recurrence rates of primary pneumothorax range from 16% to 52% with follow-up of 10 years.

Recurrence rates for secondary pneumothorax range from 40% to 56%.[14–16] Recurrence most often occurred within 6 months following the first episode. Sadikot and colleagues[17] followed 154 patients with primary pneumothorax for 54 months and observed a recurrence rate of 39% within the first year.

Patients who are involved in professions or recreations that involve rapid changes in atmospheric pressure, such as scuba divers or airline personnel, should have their pneumothoraces treated surgically at initial presentation, given their increased risk should they have a recurrence. The British Thoracic Society recommends that patients with a pneumothorax should not fly for 72 hours after a pleural drainage tube is removed, and only then if a chest radiograph at 48 hours after tube removal confirms resolution of the pneumothorax.[4] Patients with limited access to medical services should be offered surgical treatment because of the dangers of developing a recurrent pneumothorax and not being able to get it treated in a timely fashion.

The principles of surgical intervention are to resect any blebs or bullae and to obliterate the pleural space to avoid recurrences. Chest CT scans can help delineate the surgical anatomy. For patients with a primary spontaneous pneumothorax, 30% to 40% of patients have single or multiple blebs. These blebs are often found at the apex of the upper lobe or the superior segment of the lower lobe. An additional 5% to 10% of patients have bullae that are larger than 2 cm. However, 12% to 15% of patients have normal lung with adhesions suggesting previous pneumothoraces. Between 30% and 40% have no obvious pathologic explanation for their pneumothorax and normal lungs.

Resection of blebs with stapling has been shown to decrease the recurrence rate from 23% to 1.8%. Even if no abnormalities were found in the lung, resection of the apex decreased the recurrence rate.[18] It is important to combine a resection with a technique that locally fuses the pleural space to reduce the recurrence rate. This fusion can be achieved by pleurectomy, pleural abrasion, or pleurodesis. All these methods create an inflammatory reaction causing the lung to adhere to the chest wall, thus precluding collapse of the lung in the event of another parenchymal air leak. Thus, the procedure does not prevent an air leak from occurring; instead it is aimed at preventing a significant pneumothorax from developing. When used alone, the recurrence rate after pleurectomy is 1% to 5%.[19] Pleural abrasion is technically easier and is associated with fewer hemorrhagic complications than pleurectomy. In a review of 9 case series, the recurrence rate of pneumothorax after pleural abrasion alone was 2.3%.[20] Chemical pleurodesis can be used at the time of surgery, or via a chest tube in patients who are not candidates for surgical intervention. Talc is most often used for chemical pleurodesis, but autologous blood, bleomycin, tetracycline, and doxycycline have all been used.[21,22] Talc is a powder of hydrous magnesium silicate and is extremely effective in inducing pleural adhesions. Talc pleurodesis is effective, with recurrence rates of 5% to 8% when patients are treated with talc pleurodesis alone.[23,24] However, it induces fever and pain and, in up to 2% of patients, the associated pneumonitis can induce respiratory failure.[25] In addition, there is concern about the long-term consequences of leaving foreign material (talc crystals) in the chest cavity in young patients. Intrapleural injection of tetracycline alone is less effective and has been associated with recurrence rates of 16%.[26] Injection of tetracycline or doxycycline can be painful and it is important to premedicate patients with analgesics. Intrapleural lidocaine injection can be added to help with analgesia.

Traditionally, a posterolateral or transaxillary thoracotomy was used for the surgical approach. However, the development of video-assisted thoracoscopic surgery (VATS) has greatly decreased the morbidity associated with the surgical treatment of

pneumothoraces. VATS provides excellent visualization and is associated with decreased pain and length of hospital stay. With VATS, an endoscopic stapler can be used to resect diseased lung tissue, and a pleurectomy, pleural abrasion, and chemical pleurodesis can be performed at the same time. In a prospective, controlled, randomized study of 60 patients with spontaneous pneumothorax who were treated with either VATS or posterolateral thoracotomy, VATS was associated with decreased analgesic requirement and a shorter hospitalization. There were no significant differences between operative failures, duration of chest tube drainage, treatment failures, or recurrences with the two approaches.[27] A systematic review of the literature comparing VATS with traditional surgical approaches also found decreased use of pain medication and shorter hospital stay in the patients having VATS.[28] Whenever possible, a VATS approach should be used to treat pneumothoraces when surgical intervention is indicated.

Pneumothorax Summary

Pneumothoraces are among the more common problems that the thoracic surgeon is asked to manage. Most primary pneumothoraces can be managed with minimal, if any, intervention. For more complicated patients, a surgical bleb resection with pleurodesis provides reproducibly good results. Similar results can be obtained via VATS, with shorter hospital stays and less pain for the patient.

BULLOUS DISEASE

Definition

A bulla is defined as an air-filled space, 1 cm or more in distended diameter, that forms within the lung parenchyma, typically as a result of emphysematous destruction. Anatomically, bullae have a thin outer wall consisting of the visceral pleura and an inner wall consisting of the remnants of emphysematous lung. The inside of the bullae can be either smooth or crossed with fibrous bands, which are likely the remnants of alveolar and interlobular septa.[29] Multiple dilated, thin-walled vessels can pass through the walls of bullae, or be suspended within the fibrous septa. Rarely, bullae may enlarge to a degree that they occupy more than one-third of the hemithorax; in this circumstance, the term giant bulla is applied.

Patients with bullae have traditionally been divided into 2 groups: those in whom the remaining lung parenchyma is structurally normal, and those in whom the rest of the lung exhibits emphysematous change. The latter group can be described as having bullous emphysema. There have been several proposed classification systems for giant bullae, based on the number, shape, and position of the bullae, combined with the condition of the underlying lung.[30–32] Although such classification systems are potentially useful, the lack of widespread usage limits their clinical usefulness.

Natural History of Bullae

In 1968, Boushy reported on 49 patients with bullous emphysema who were followed with serial chest radiographs and pulmonary function tests.[33] Of the 49 patients reported, 27 had giant bullae. The investigators noted a consistent tendency toward growth of the bullae over time, with concomitant worsening pulmonary function. Some of these patients had a gradual worsening, whereas some were stable for several years before worsening. There were 4 notable patients whose bullae decreased in size; in all 4, the bullae had become infected. Although giant bullae may be asymptomatic on presentation, they typically do not remain so.[34] There

have been some case reports of bullae regressing,[35–37] but the natural history of bullae seems to show a pattern of progressive, if unpredictable, enlargement.

Evaluation and Decision Making

Initial investigation is directed toward identifying patients who are most likely to benefit from resection of bullae. This investigation includes an evaluation of the overall medical status of the patient for the assessment of any major comorbidities that would preclude a resection. The patient's cardiac status is considered for the presence of cor pulmonale, right-sided heart failure, as well as for risk stratification for other perioperative cardiac events. For operative planning, and determination of operability, pulmonary function tests and a CT scan of the chest are usually sufficient.

Pulmonary function testing

In patients with a localized giant bulla and normal-appearing underlying lung, FitzGerald and colleagues[38] showed a strong correlation between the patient's decline in forced expiratory volume in the first second of expiration (FEV_1), the size of the bulla, and the improvement in postoperative FEV_1. In an additional longitudinal study, Ohta and colleagues[39] followed 25 patients having bullectomy for 4 years. They identified 20 patients with durable improvement in symptoms, and 5 patients whose symptoms worsened after 1 year. Only a higher initial FEV_1 and a uniform distribution of ventilation were able to predict the sustained postoperative improvement.[39]

It is difficult to determine whether a patient's reduced FEV_1 is secondary to the presence of the bulla or to the emphysema in the underlying lung. This distinction is important, because performing a giant bullectomy on a patient with substantial underlying emphysema has been associated with higher morbidity and mortality,[40,41] as well as less-durable benefit.[38] Using CT lung density measurements, Gould and colleagues[42] found that pulmonary function testing correlates poorly with the degree of bullous change, but is strongly related to the degree of emphysema in the underlying lung. Haerens and colleagues[43] reported on 15 patients having bullectomy, 10 of whom had generalized emphysema and 5 who had normal underlying lung. Preoperatively, the FEV_1 of the patients with normal underlying lung was higher, but, on an individual patient basis, it was impossible to predict the quality of the underlying lung based solely on pulmonary function testing.[43]

A reduction in diffusion capacity of carbon monoxide in the lung (DLCO) has been noted as an indicator of underlying emphysema,[44,45] and patients with normal DLCO have been found to have better short- and long- term outcomes after bullae resection.[38,46,47] However, reversible conditions leading to extreme airway obstruction can give falsely depressed DLCO levels; as such, a low DLCO should not be the sole reason for denying a patient an operation.

There is no generally accepted absolute cutoff in pulmonary function values for which surgery is contraindicated. Even with an extremely low FEV_1, patients with preserved underlying lung tissue can obtain substantial improvement in both symptoms and pulmonary function after resection of giant bullae.[38,48] The determination of the nature of the underlying lung function is best obtained by CT scan.

Chest CT

CT provides valuable information about the architecture of the diseased lung parenchyma, and should be obtained for all patients being considered for bullectomy.[49,50] The size, location, and number of bullae can be well visualized, in addition to any other abnormalities such as masses or infiltrates. The consistency of the underlying lung can also be assessed (**Fig. 2**). Morgan and colleagues[49] used CT to evaluate 43 patients

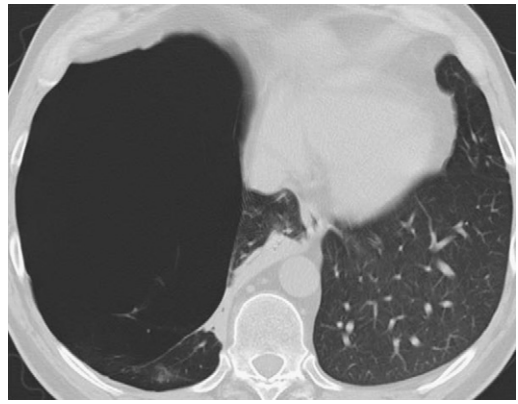

Fig. 2. Several different states of lung disease present in a patient with giant bulla. The large right-sided bulla is evident as the homogeneous hypodense region in the right hemithorax. Some residual septae are evident posteriorly and medially. There is comparatively normal lung on the opposite side. There is compressed and atelectatic lung adjacent to the mediastinum, likely caused by the pressure of the bulla.

with apparent bullous disease. CT differentiated 20 patients whose bullae were merely local exaggerations of generalized emphysema from 23 patients who had well-defined bullae with relatively normal underlying lung. There was no statistical difference in the pulmonary function tests between these groups.

Indications for Operation

In 1950, Baldwin and colleagues[51] suggested that ventilatory insufficiency and the absence of generalized emphysema were the criteria predicting the need for, and success of, bullectomy. Sixty years later, the standard criteria have not significantly changed: isolated bullae occupying more than 30% of the hemothorax, the preservation of underlying lung parenchyma, and a patient who has dyspnea.

Although the first 2 criteria are best evaluated via chest CT, the presence of symptoms is subjective. Dyspnea can be measured using either the modified Hugh-Jones Criteria[52] or the Medical Research Council Dyspnea Scale[53]; any grade of dyspnea greater than zero on either scale is abnormal, and is considered symptomatic. For those symptomatic patients with a giant bullae and otherwise preserved lung function, there is little argument that they will benefit from surgical treatment. Patients with severe underlying emphysema are best considered in the context of lung volume reduction surgery (LVRS). Other, more controversial, indications include bullae in an asymptomatic patient, hemoptysis, and chest pain.

Asymptomatic patient

The natural history of bullous disease is progressive enlargement of the bullae, with concomitant worsening of pulmonary function. Some have advocated that surgery is indicated in the absence of symptoms, provided a giant bulla occupies more than 50% of the hemithorax, the adjacent lung is compressed, or the bulla has enlarged during a period of years.[54,55] Others think that the incidence of postoperative complications is too high to justify operating on an asymptomatic patient.[34,40,56]

Hemoptysis

Massive hemoptysis has rarely been associated with rupture of vessels in a giant bulla.[57] In their extended series, Gaensler and colleagues[46] noted only 1 bullectomy that was performed because of bleeding. Because of the rarity of hemoptysis solely explicable by bullous disease, hemoptysis in this patient population mandates an investigation for other potential sources, such as carcinoma, bronchiectasis, or aspergillus superinfection.[29]

Chest pain

Chest pain associated with giant bullae has been reported. It can be substernal, radiating to the arms, and exercise related. It is hypothesized to be secondary to air trapping in a bulla, with subsequent distention of the visceral or mediastinal parietal pleura. Once cardiac causes have been eliminated, surgical treatment of bullae has been performed for chest pain with good results.[46]

Surgical Approaches

Open bullectomy

The goal of bullectomy is to resect as much bullous disease as possible while minimizing resection of the spared lung. Care is taken in opening the pleural space, because injury to the underlying parenchyma can be difficult to repair, and the resulting air leak can be prolonged. A complete adhesiolysis reveals the full extent of the bullous disease, and allows the underlying lung to fully expand. Unless an operation for cancer is being performed, anatomic resections are generally unnecessary.[48] Once the bullae are clearly identified, there are several acceptable approaches.

This first open approach, perhaps of historical interest at best, involves using the wall of the bulla to buttress a staple line across the base of the bulla. The largest bulla is opened longitudinally, and its cavity is explored from within, dividing any septa. Allis clamps are used to grasp the bulla from the inside at the reflection of the bullous wall with normal lung; this interface can be identified by gently ventilating the operative lung. The wall of the bulla is folded over and used as a staple line buttress, and a linear stapler is fired completely across the base of the bulla. At completion, all raw surfaces are sealed, and the buttressed staple line consists of 4 layers of parietal pleura and bulla wall.[58]

Alternatively, a giant bulla can be excised without widely opening the bulla. The bulla is deflated by making a small incision the lateral wall, which is grasped and held up with Allis clamps, and sequential firings of a linear stapler are applied.[59–62] Compression of the area of the lung where the stapler is to be applied, with either the surgeon's fingers or a straight clamp, can ease the application of the stapler and prevent injury to the underlying lung. Again, emphasis is placed on leaving behind as much normal underlying parenchyma as possible.

Bullae may also be removed by simple excision with suturing of any air leaks. The wall of the bulla is excised down to the interface with normal lung, and any visualized air leaks at the base of the bulla are sutured closed.[63] This technique is not commonly used in modern practice.

Both thoracotomy and median sternotomy have been used as approaches for open bullectomy, without a clear advantage being shown for either approach. For patients with bilateral disease, a median sternotomy provides access to both pleural spaces, and, as such, is the preferred approach in these cases.[43] However, patients with bilateral giant bullae and preserved underlying lung function are rare, and finding such a case should raise the suspicion of more severe emphysema in the underlying lung.

Thoracoscopic bullectomy

Because thoracoscopy has the advantage of avoiding the pain and disability of a thoracotomy, many surgeons have adopted thoracoscopy for the treatment of giant bullae. Wakabayashi[64] reported the first series of thoracoscopically treated giant bullae in 1993. Both bilateral and unilateral thoracoscopic-stapled bullectomy procedures have been performed. As with open bullectomy, care must be taken when entering the pleura to avoid injuring the underlying lung, and a complete adhesiolysis is needed to visualize the bulla to be resected. The bulla can be partially opened to obtain adequate visualization. Once the bulla is identified, a stapled bullectomy can be performed with sequential firings of a buttressed endoscopic stapler, in a manner similar to the open bullectomy.[59–62] The underlying lung is reinflated under direct vision; if the underlying lung does not reinflate, bronchoscopy should be performed to suction clean the involved airways. When there has been chronic collapse of a section of lung, it can sometimes be difficult to re-expand. Typically, the airway pressure necessary to inflate the collapsed segment is high and, as a consequence, the abnormally compliant diseased lung is preferentially inflated. If this occurs, it can be useful to pass a small catheter through the working port of the bronchoscope and apply gentle jet ventilation to the airway leading to the collapsed lung segment.

Although the presence of a previous thoracotomy is a relative contraindication to subsequent thoracoscopic procedures, there have been successful series of patients in whom thoracoscopic bullectomy was performed despite previous thoracotomy.[65]

Endocavitary drainage

Monaldi originally described a technique for endocavitary drainage of tuberculous cavities in 1938,[66] and this technique was adapted for giant bullae in 1995.[67] In this technique, a small thoracotomy is made over the site of the bulla. A segment of rib is resected, and the parietal pleura adjacent to the bulla is incised. An incision is made on the lateral wall of the bulla, and any septae in the interior of the bulla are excised. Two purse-string sutures are placed around the hole in the bulla, and a 32 French Foley catheter is inserted into the bulla to serve as an endocavitary drain. The balloon on the Foley is inflated, the purse-string sutures are tied, and suction is applied to the Foley, collapsing the bulla. The pleural drain is discontinued after 48 hours, whereas the endocavitary drain is removed in 8 to 21 days.[67,68]

Endocavitary drainage of giant bullae offers a limited surgical approach that avoids resection of underlying lung while providing symptomatic relief and functional improvement. Most investigators reserve this treatment for patients who would not otherwise tolerate a thoracotomy,[68] but some advocate it as the first surgical choice for any patient with a giant bullae.[69]

Surgical Outcomes

Symptomatic improvement has been reported in 80% to 100% of postoperative patients in numerous studies.[39,70–74] Many studies have also shown postoperative improvement in pulmonary function, although there is a wide range (24%–200%) in the degree of improvement in FEV_1, for example.[38,73,75] Limited long-term data suggest that the postoperative increase in lung function tends to degrade with time, with the loss of function related to the condition of the underlying lung.[38]

Operative mortality is low, ranging from 0% to 5% in several studies.[38,73–75] In contrast, operative morbidity is substantial, with most postoperative complications involving a prolonged air leak. The frequency of prolonged air leak is approximately 50% in most series.[73,75]

Several studies have been performed to try to minimize the incidence and length of air leaks. Gentle handling of the lung tissue remains of paramount importance. The use of buttressed staple lines and surgical sealants has failed to show effectiveness in pulmonary resections as a whole.[60,76–78] In contrast, there is evidence that, in the particular subset of patients with emphysematous lung, the use of buttresses[59,61] and sealants[79] can decrease both the duration and severity of air leaks. Early placement of the pleural drains to water seal, rather than suction, has been shown to assist with sealing of air leaks.[80]

Summary

The best candidates for surgical resection of giant bullae are patients with an isolated bulla occupying more than 30% of the hemithorax, collapsed but otherwise normal underlying lung, and dyspnea. Several operative techniques have been used to accomplish these goals, including stapled bullectomy, excision, ligation, and endocavitary drainage. In properly selected patients, most can be expected to have subjective improvement of their dyspnea as well as demonstrable improvement in pulmonary function testing. The long-term persistence of this improvement is dependent on the quality of the underlying lung and the progression of any disease in that lung.

Emphysema

In 1993, Cooper observed that patients with COPD, in the process of undergoing a lung transplant, were able to get adequate gas exchange from an emphysematous lung if properly ventilated.[81] In addition, transplanting normal-sized lungs into a hyperexpanded chest led to restoration of a normal thoracic cavity. These observations led Cooper to resurrect the idea of lung volume reduction, with some modifications of an approach described 40 years earlier by Brantigan.[81] The procedure was considered palliative, intended to reduce dyspnea and increase exercise tolerance, and able to achieve these goals in carefully selected patients.

Following this sentinel report, LVRS enjoyed widespread application within the United States. However, analysis of patients undergoing this procedure revealed an unacceptably high mortality: 23% at 12 months.[82] This led to cessation of federal funding for the operation, and a decrease in enthusiasm for the procedure. To more rigorously evaluate the benefit of the operation, the National Institute of Health sponsored a large, multicenter trial that began enrolling patients in 1999.[83] The trial, called the National Emphysema Treatment Trial (NETT), was a prospective randomized study of 1218 patients, and it has provided strong evidence for the efficacy, safety, and durability of LVRS. The outcomes from the NETT analysis, in conjunction with data from earlier trials, help provide the criteria for defining which patients will benefit from LVRS.

Patient Selection

The goals of preoperative assessment for LVRS are to identify patients who remain disabled by emphysema despite maximal medical therapy, determine which patients will benefit from surgery with an acceptable risk, and exclude those patients with an increased risk of poor outcome.

Medical management and preparation

The first step is to assess the patient's symptoms and degree of quality-of-life impairment related to emphysema. Patients with severe, incapacitating emphysema are considered for surgical intervention. A structured pulmonary rehabilitation program is a critical first step in determining suitability for an operation. The program should

include abstinence from tobacco products, an exercise training program, optimization of medical treatment, patient education, and psychosocial assessment. Exercise training is designed to increase endurance and decrease exertional dyspnea. Patients enrolled at the authors' LVRS program are required to complete an exercise program that has a goal of 30 minutes of daily continuous exercise, 5 days a week, on a treadmill or stationary bicycle. The Joint Commission on Accreditation of Hospitals and Organizations also uses a minimal performance of 3 minutes of unloaded pedaling on a stationary bicycle as a prerequisite for LVRS surgery in the United States. A significant number of patients achieve enough improvement in their symptoms that they decline LVRS after undergoing exercise-based pulmonary rehabilitation.[84,85] Exercise tolerance also has an important postoperative predictive value: the NETT trial demonstrated that, in patients with upper lobe predominant disease, patients with high exercise tolerance (ie, less impaired by the disease) did not have the same survival benefit from surgery as those more impaired patients with low exercise tolerance.[86] However, other clinical trials have amended enrollment criteria after observing an excessive mortality in the patients with the poorest exercise abilities. It is clear that patients selected for surgical therapy must be impaired enough to merit the risks of surgery, but not so ill that they cannot participate in physical therapy.

Medical optimization includes several factors. Oxygen therapy is indicated for any patient with a Pa_{O_2} less that 55 mm Hg, or an Sa_{O_2} less than 88%. Bronchodilator therapy is useful for alleviating symptomatic airflow limitation; however, many patients use appropriately prescribed inhalers incorrectly. Assuring the correct use of inhalers should be a component of any medical evaluation. Many patients with stable COPD symptoms use long-term corticosteroid therapy, despite the absence of prospective data supporting a benefit of steroids on lung function or its rate of decline. As such, tapering the use of corticosteroids preoperatively to the lowest possible dose is advised in an effort to avoid the associated risks of poor wound healing and infection.

Cardiovascular function

As with any other major operation, assessment of cardiac function is a critical component of an evaluation for emphysema surgery. Rest and stress echocardiography, radionuclide ventriculograms, thallium imaging, and other studies can assist with cardiac risk stratification. However, the patient with COPD provides several unique challenges to these modalities, limiting the usefulness of such tests. Exercise testing is rarely useful because of the patient's inability to exercise to maximal heart rates. Chest hyperinflation can limit the visualization afforded by echocardiography, and concerns about bronchoconstriction may limit the use of dipyridimole or adenosine. As such, many otherwise acceptable surgical candidates eventually undergo right and left heart catheterization just before surgery. Any intervention must be coordinated among all physicians involved, because the placement of a drug-eluting coronary stent in a preoperative patient can have major implications on the timing and the conduct of the surgery.

Pulmonary function

Spirometry is the cornerstone of pulmonary function testing, because it provides quantifiable, reproducible assessment of several aspects of pulmonary physiology. Airflow obstruction is the most significant abnormality with emphysema; it can be accurately estimated by forced expiratory maneuvers. Lung volumes, measured by plethysmography, indicate the degree of trapped gas and residual volume. Resting and exercise arterial blood gas analyses indicate the patient's pulmonary reserve, and reflect their potential for recovery after surgery. Diffusing capacity, as measured

by DLCO values, estimates the severity of the disease within the pulmonary vascular bed. These parameters provide objective criteria for assessment of emphysema severity, and serve as markers of the patients at highest risk of a poor outcome.

Radiographic evaluation

The purpose of imaging preoperative patients is to identify those patients with findings favorable for surgical intervention. The main features to assess are the presence of hyperinflation, the severity of emphysema, and the distribution of emphysema.

The severity and distribution of emphysema correlates with clinical outcomes after surgery. The greatest improvements in FEV_1 and exercise capacity tend to occur in patients with more-severe, heterogeneous disease that predominates in the upper lobes (**Fig. 3**A, B).[87,88] The standard chest CT examination is the most accurate means of evaluating the severity and distribution of emphysema. However, there is

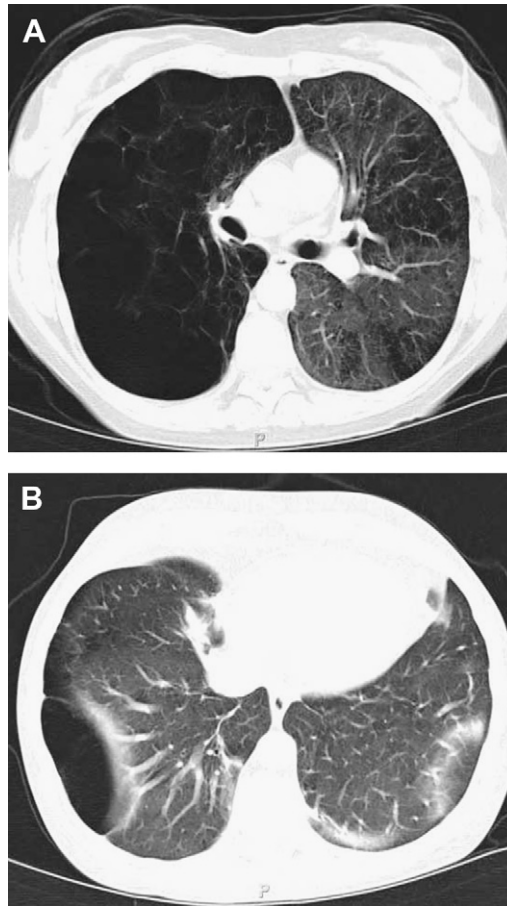

Fig. 3. (*A*) CT radiograph of a patient who underwent lung reduction surgery. Both upper lobes are diseased. The right side shows more extensive bullous changes, whereas the left side has emphysematous destruction without macroscopic bullae. (*B*) Lower cuts in the same the patient show relatively normal lung parenchyma and pulmonary vessels near the base of the lungs. This degree of heterogeneity is often seen in the patients who experience the best response to LVRS.

considerable variation in the interpretation of CT scans in these patients; the entire lung is affected to some degree by emphysema, and it may be difficult to assess the heterogeneity of the disease. Studies have found considerable interobserver variability in interpretation of the distribution of emphysema on CT.[89] Despite this, CT remains the mainstay of preoperative imaging.

Nuclear medicine ventilation-perfusion lung scans depicting regional blood flow patterns provide a valuable roadmap for surgery. As the distribution of the perfusion agent is relative, the absolute severity of emphysema cannot be assessed, but the presence of diffuse versus upper or lower lobe predominant disease can be identified. In addition, a right- or left-sided predominance of lung function may direct surgery toward a unilateral approach, if the findings are also supported by the CT.

LVRS versus Transplantation

Given the potential morbidity associated with surgical intervention, it is worth re-emphasizing that these procedure should only be considered for patients who continue to have debilitating symptoms despite maximal medical therapy. It is rare that patients are considered for surgery with an FEV_1 that is greater than 40% of predicted. The exception to this would be a patient with giant bulla as described earlier.

Similarly, significant nonpulmonary comorbidities eliminate surgery as an option for the patient. These comorbidities include extremes of body habitus, concurrent malignant processes, psychosocial instability, or advanced age. Patients who have used tobacco within the last 6 months are also excluded from surgical consideration. Previous thoracic surgical interventions, such as a wedge resection, lobectomy, or pleurodesis, are relative contraindications to ipsilateral bullectomy or LVRS, although contralateral interventions are viable options. In contrast, although previous thoracic operations increase the technical difficulty of the explant, they are not contraindications to transplantation.

With progressive pulmonary dysfunction, the morbidity and mortality associated with LVRS increases. Patients with an FEV_1 less that 20% of predicted, marked hypercarbia ($Paco_2$>55 mm Hg), severe oxygen dependence (>6 L at rest), or with pulmonary hypertension, are all relative indicators that the patient may be better served by transplantation than LVRS.

Early in the NETT experience, it was noted that patients with an FEV_1 less than 20% of predicted and either homogeneous distribution of emphysema on CT or a DLCO of less than 20% of predicted had no change in exercise tolerance, no improvement in FEV_1, no subjective improvement in quality of life, and a 16% 30-day mortality after LVRS.[90] The high mortality found in this patient cohort prompted a modification of the NETT protocol, excluding from randomization any patients who met these criteria. However, retrospective review of a patient population that met the high-risk criteria of the NETT protocol showed improved respiratory function at an acceptable risk of mortality.[91] This suggests that the presence of suitable anatomic heterogeneity of disease may be the most important determinant of outcome. In our experience, the most common reason for exclusion of a patient from consideration of LVRS is the lack of sufficient target areas for resection.[92] For these patients, lung transplantation is the only remaining surgical option.

Lung transplant is a life-saving tool available to the patient who is critically ill; patients with severe physiologic derangements and unfavorable disease anatomy have dramatic initial improvements after transplant.[93] In patients who would qualify for both transplant and LVRS, it is tempting to consider listing the patient for transplant. However, despite the improvements that have been made in lung transplants in the last 20 years, mortality remains approximately 50% at 5 years.[94]

SUMMARY

Surgical intervention is a viable option in a select group of patients with severe, incapacitating emphysema. Only those patients who have failed to progress despite optimized medical therapy and a rigorous pulmonary rehabilitation regimen should be considered for surgical intervention. Pulmonary function tests, CT, and nuclear ventilation-perfusion scans further delineate those patients who are most likely to benefit from the operation, as well as determining which intervention is most likely to have a good outcome. The surgical options available to the patient depend on the spectrum of the distribution of their disease; isolated bullae can be treated with bullectomy, heterogeneous emphysema lends itself to LVRS, whereas homogeneous disease is best treated by lung transplantation. The ideal indicators for LVRS also include hyperinflation, an FEV_1 greater that 20%, and a normal $Paco_2$. In contrast, patients with a low FEV_1, hypercapnia, and associated pulmonary hypertension are directed toward transplantation.

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