Postoperative Air Leaks After Lung Surgery

Predictors, Intraoperative Techniques, and Postoperative Management

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KEYWORDS

• Lung resection • Air leak • Chest tube management • Surgical technique • Postoperative care • Outcomes

KEY POINTS

- Air leaks after elective pulmonary resection occur in approximately 28% to 60% of patients, with most of them resolving by postoperative day four.
- Risk factors for air leak and prolonged air leak include emphysema, low forced expiratory volume in 1 second, obesity, male sex, steroid use, nutritional status, pleural adhesions, and upper lobectomy or bilobectomy.
- Intraoperative techniques such as proper tissue handling, fissure-less surgery, and select use of surgical sealants can reduce the risk of postoperative air leak.

INTRODUCTION

Postoperative air leak is one of the most common complications after pulmonary resection, occurring in 30% to 50% of patients.[1] An air leak is the egress of air from a break in the lung parenchyma or defect in a lung or bronchial staple line. Although most of the air leaks resolve spontaneously, even a minor air leak will postpone chest tube removal, contributing to prolonged postoperative pain, delayed functional status, and increased hospital length of stay. Severe or prolonged air leaks may also require intervention, including reoperation in select refractory cases.

Prevention and/or treatment of postoperative air leaks is a crucial component of perioperative care for patients undergoing pulmonary resection. This review details the management of air leaks, including predictors, intraoperative techniques, and postoperative management. Concomitant with the advancement in minimally invasive techniques for pulmonary resection, developing technologies and new enhanced recovery algorithms are challenging existing dogma regarding the management of postoperative air leak.

DEFINITIONS AND RISK FACTORS

Alveolar-Pleural Fistula

Most of the air leaks result from an alveolar-pleural fistula, which is a communication between the pulmonary parenchyma distal to a segmental bronchus and the pleural space. Alveolar-pleural fistulas are reported to occur in 28% to 60% of patients after elective, uncomplicated, pulmonary resection and are distinct from broncho-pleural fistulas.[2] Classic postoperative air leaks are described by type and size. The Robert David Cerfolio (named after RJC's father) classification system uses the traditional analog scale to codify air leaks into 4 types: forced expiratory leaks, an expiratory leak, an inspiratory leak, and a continuous

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air leak.[3] Forced expiratory leaks are those leaks elicited during patient coughing. Current digital systems are now able to quantify air leaks to double digit (Thopaz, Medela, Barr, Switzerland) or single digit mL/min (Thoraguard, Centese, Omaha, NE, USA) (Fig. 1).

Risk Factors for Air Leak

Numerous risk factors contribute to the development of air leaks. The most consistent risk factor is chronic obstructive pulmonary disease (COPD), with a strong correlation between the degree of emphysema and risk of developing an air leak.[4] Specifically, reduced preoperative forced expiratory volume in 1 second (FEV_1) and reduced FEV_1/forced vital capacity ratio are significant predictors of air leak.[5,6] The incidence of air leak is highest in patients with an FEV_1 less than 70%. Other risk factors include steroid use, smoking history, male sex, pleural adhesions, and decreased carbon monoxide lung diffusion capacity (DLCO).[7] Patients undergoing a lobectomy—compared with a wedge resection or segmentectomy—have a higher risk of air leak, specifically a right upper lobectomy or bilobectomy.[5,7] In a study by Isowa and colleagues,[8] poor nutritional status, indicated by low serum albumin and cholinesterase, was predictive of air leak.

Prolonged Air Leak

Most air leaks (26%–48%) will spontaneously resolve by the morning of postoperative day (POD) 1, with most of the air leaks resolving by POD 5.[9–11] In up to 6% to 18% of patients, the air leak may fail to resolve within 5 days, which the Society of Thoracic Surgeons (STS) defines as a prolonged air leak (PAL). At our institution, given the reduction of postoperative length of stay with minimally invasive techniques, we consider any air leak that delays hospital discharge as "prolonged," regardless of the number of PODs. PAL can be the result of a sizable injury to the lung parenchyma/airway or delayed adherence of the visceral pleura to the parietal pleura due to lower postresection lung volume that is unable to fill the hemithorax. PAL is associated with increased length of stay, increased cost, increased incidence of empyema, readmission, and other postoperative complications.[12] Following lung volume reduction surgery (LVRS), the incidence of PAL is significantly higher and often prolonged for a much longer duration.[13]

Risk Factors for Prolonged Air Leak

Air leaks on POD 1 with a higher likelihood of becoming PALs are those with higher volumes of air loss (grade 4 or greater), expiratory in nature, and leaks associated with pneumothorax.[9] Using a cohort of patients with a PAL rate of 8.6%, Attaar and colleagues[14] formulated a prediction model for PAL with 76% accuracy. The model also stratifies patients into low-, intermediate-, and high-risk categories, with a PAL rate of 2%, 8.8%, and 19%, respectively. The prediction nomogram scored risk factors, including FEV_1, procedure type, smoking status, Zubrod score, preoperative hospitalization, reoperation, and procedures via thoracotomy. In an STS General Thoracic Database cohort of 50,000 patients after lung resection for lung cancer, the rate of PAL was 10.4%. On multivariate analysis, Seder and colleagues[15] determined that increased body mass index, lobectomy or bilobectomy, FEV_1 less than or equal to 70%, male sex, and right upper lobe procedures are risk factors, with their risk model correctly classifying 79% of patients at high- or low-risk of PAL.

INTRAOPERATIVE MANAGEMENT

Assessment of Air Leak

The most common method for the intraoperative evaluation of air leak is the submersion test. The chest is filled with saline and the operative lung is ventilated, with air bubbles identifying sources

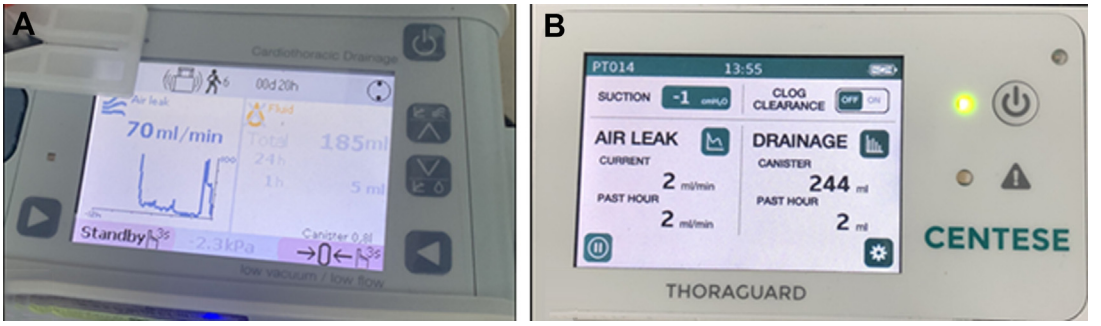

Fig. 1. Interface display of digital drainage systems. (*A*) Thopaz system demonstrating a 70 mL/min air leak. (*B*) Thoraguard system, demonstrating a 2 mL/min air leak.

of air leak. Air leaks can also be quantified by assessment of tidal volume loss on the ventilator. Tidal volume loss can be separated into mild (<100 mL/min), moderate (100–400 mL/min), or severe (>400 mL/min). Mild leaks are often self-limited and not treated, whereas severe air leaks should be reexplored. After lung resection, if a patient is difficult to ventilate at closure and there is a large air leak, the chest tube should be taken off suction while on positive ventilation. Once extubated, the tube can be returned to suction as clinically indicated.

Prevention of Air Leak

Several surgical strategies help prevent air leaks. The most important approach is appropriate tissue handling to avoid parenchymal tearing during tissue manipulation and retraction. Not enough can be said about this if fissure diving is used. The robotic platform allows a magnified view of the fissure, which can help identify where one lobe starts and another lobe ends. If early chest tube removal is planned, meticulous technique in the fissure is required. In addition, the use of fissure-less dissection has been reported to result in decreased incidence and severity of air leaks in patients with fused or incomplete fissures.[16] Traditionally, exposure of the pulmonary artery occurs with dissection at the fissure. However, in the fissure-less technique, the lung parenchyma is divided using surgical staplers after the separation of the lobar bronchus, in order to reduce the potential air leak,[17] which often entails dissection posteriorly to identify the bronchus and/or artery from the back.

During a minimally invasive pulmonary resection, it is imperative to avoid puncturing the lung during initial port placement. Despite single lung ventilation, the lung may remain adherent to the chest wall by physiologic pleural apposition or from pleural adhesions secondary to prior surgery, tube thoracostomy, neoadjuvant therapy, or an inflammatory pleural process. If a puncture occurs, the defect should be repaired with an interrupted suture (**Fig. 2**). After the initial trocar is placed, the remaining ports or incisions should be placed under direct visualization.

Treatment of Air Leak

When air leaks are identified during pulmonary resection, several operative techniques may help decrease air leak severity and duration.

Increased pleural-pleural apposition

Obliteration of the pleural space reduces the potential of air leak, by increasing pleural-pleural apposition. Pulmonary mobilization by lysis of intrapleural adhesions, division of the inferior pulmonary ligament, and/or incising the mediastinal pleura may help the lung achieve pleural apposition. An apical pleural tent, which is performed by releasing the apical parietal pleura from the endothoracic fascia circumferentially, allows the parietal pleural to drape over and adhere to the remaining lung. This technique creates a small cavity with a fully drained space.[18] In a prospective randomized study of 48 patients with COPD undergoing right upper lobectomy, a pleural tent was performed in 23 patients with reduced incidence, severity, and duration of air leak, albeit with a significantly higher volume of pleural drainage in the pleural tent cohort.[19] However, in this trial, there was no difference in overall chest tube duration or hospital length of stay.

For patients undergoing a right middle lobe and lower lobe bilobectomy, creation of pneumoperitoneum at the time of surgery has been reported as a strategy to reduce the residual pleural space. At the time of operation, 1200 mL of air is injected under the right hemidiaphragm through a small diaphragmatic opening. Cerfolio and colleagues[20] demonstrated this method to be safe, reporting decreased incidence of air leaks and pneumothoraces, thereby shortening hospital length of stay. This method is not routinely used but can be considered with patients with minimal residual lung. Our current practice is to treat the bilobectomy space similar to a lobectomy: placement of a chest tube, with or without the application of a surgical sealant.

Surgical sealants

Surgical sealants, such as glues or patches, can be applied along the visceral pleural surface and

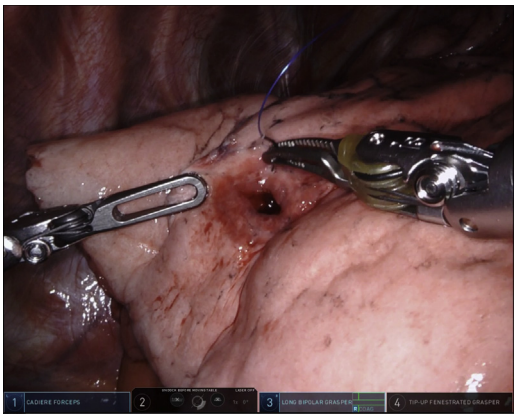

Fig. 2. Suture repair (3-0 nonabsorbable suture) of a lung laceration of the left lower lobe sustained during insertion of the initial robotic trocar.

parenchymal staple lines to prevent or reduce air leak. However, the efficacy of surgical sealants is mixed. In a 2010 Cochrane Database Review assessing 16 randomized trials, most of the studies demonstrated significant prevention or reduction of postoperative air leak, but only 3 trials reported a significant reduction in time to chest tube removal.[21] Similarly, a clear association between the use of sealants and hospital length of stay was not established, with only 3 trials demonstrating decreased hospital length of stay by a median of 1.5 days with the use of surgical sealants. In a meta-analysis of 13 trials, the use of surgical sealants had a statistically significant pooled effect size of 0.55 for reducing PAL (defined in the trials as greater than 7 days).[22] Despite these positive findings, the investigators warn that the results "should be interpreted with caution," given the heterogeneity of the studies and publication bias of those selected for analysis.

At our institution, we do not routinely use sealants. However, in select high-risk patients with wide patches of denuded or injured visceral pleura or if a minor leak is visualized from the parenchymal staple line, we use Progel (Neomend, Irvine CA). Progel is unique among sealants, as it conforms to the lung tissue, allowing expansion and relaxation without dislodging the sealant. For patients with an identified intraoperative air leak, Progel has been shown to reduce the number of patients with air leak and decrease hospital length stay.[23] The ability of Progel to seal an air leak correlated to the severity of the leak.

CHEST TUBES AND MANAGEMENT OF AIR LEAKS

Chest tubes are placed after pulmonary resection to drain fluid and/or air from the pleural space. Chest tube drainage helps maintain visceral-to-parietal pleural apposition while decreasing postoperative effusion and pneumothoraces. Our current practice is placement of a single straight 24 or 28 Fr chest tube posteriorly to the apex of the chest, with routine use of a digital drainage system. If no leak is present and the postoperative radiograph reveals a fully expanded lung, the chest tube is removed on the day of surgery, regardless of fluid output. Patients routinely have a high fat meal (usually ice cream) before removal as a provocative test for chylothorax. Chest tube removal is performed at end of expiration, which has a lower incidence of nonclinically significant pneumothorax than at end of inspiration.[24]

It is important to distinguish true air leaks from false air leaks. In patients with large or continuous air leaks, the chest tube, tubing, and drainage system should be evaluated for loose connections or breaks, which may result in the "air leak." To test for a system leak, the chest tube should be clamped at the chest wall. If air continues to leak and there is no hole in the chest tube, the drainage system should be replaced. In addition, in patients with a fixed pleural space deficit due to low-volume residual lung parenchyma, a small volume of air may be expressed through the chest tube with forced expiration, mimicking an air leak.[10] A clamp trial—where the chest tube is clamped for 2 to 4 hours with assessment for dyspnea and obtaining a chest radiograph to determine the stability or progression of pneumothorax—helps differentiate a fixed space versus a true air leak.

Reviewing 153 robotic anatomic pulmonary resections, we have discharged 12% of patients home with a chest tube and digital drainage device on POD 1 with a median duration of 4 days until the chest tube is removed in clinic.[25] In patients with a leak that does not resolve after 2 weeks, the chest tube may still be removed, even with a concomitant pneumothorax. In a retrospective study by Cerfolio and colleagues,[26] 199 patients (3.8%) were discharged home with a chest tube after pulmonary resection. After a median of 16 days, 57 patients had their chest tube removed while still having an air leak, including 26 with a nonexpanding pneumothorax. We believe chest tube removal in patients with an air leak is safe, provided they are asymptomatic, have no subcutaneous emphysema, and there is no increase in the pleural space deficit. Prophylactic antibiotics are recommended in order to avoid empyema.

Avoiding Chest Tubes

With a focus on enhanced recovery, select surgeons have questioned the necessity of postoperative chest tubes after elective pulmonary resection. Chest tubes after pulmonary resection increase pain, reduce pulmonary and functional capacity, and increase hospital length of stay. Several studies have revealed that omitting chest tubes after minimally invasive pulmonary wedge resection is feasible and safe.[27,28] In these trials, the rate of postoperative pneumothorax was 10% to 13.3%, but no patients required chest tube placement. In 162 patients who underwent thoracoscopic anatomic lung resection, Murakami and colleagues[29] identified intraoperative air leaks with a water submersion test in 112 (69%) patients and sealed them with a combination of bioabsorbable mesh and fibrin glue. After confirming no air leak after extubation, the chest tube was removed in the operating room in 102 patients (91%). No patients required placement of a chest

tube for subsequent air leak or pleural effusion. In another study by Ueda and colleagues,[30] a postoperative chest tube was omitted in 53 patients (46%) after minimally invasive anatomic lung resection, with associated reduction in pain and analgesic use and improvement in pulmonary and functional capacity. Of note, these trials did not include patients undergoing LVRS, and the practice of omitting a postoperative chest tube in these patients is not recommended due to the high incidence of air leak.

Digital Drainage Systems

The use of digital chest tube drainage systems has advanced the management of air leak by introducing the advantages of objective assessment, continuous data gathering, and portability. Digital systems record air leak and pleural fluid volumes accurately and are able to adjust levels of suction with precision. Most notably, the objective nature of these systems reduces interobserver variability, allowing all members of the team to accurately assess an air leak. Digital systems also collect data continuously, allowing interpretation of data trends over time and can capture of intermittent leaks.

In prospective trials, the use of digital drainage systems has reduced the duration of chest tubes and decreased hospital length of stay when compared with traditional analog systems.[31–33] Earlier removal of chest tubes is associated with improved pulmonary function, reduced postoperative pain, and fewer overall complications.[32–34] The use of digital drainage systems are also associated with superior patient satisfaction, including the ability to ambulate and convenience of use in the outpatient setting.

The threshold volume of air leak for chest tube removal differs across trials from 0 mL/min to 50 mL/min, over a period of 6 to 12 hours. In our practice, we use 20 mL/min as signifying resolution of air leak and routinely remove chest tubes at this level. In patients with a low-grade volume loss of 10 to 20 mL/min, before removal, we perform a provocative test, which can determine the presence or absence of air leak: the system suction is increased to 40 to 60 mm Hg, with the volume increasing to approximately 50 to 100 mL/min while evacuating the pleural space. After 20 to 30 seconds, the volume of air leak will then reduce to 0 mL/min, indicating no air leak, or will stay greater than zero (10–30 mL/min), indicating the presence of an air leak.

Data trends on digital systems can also guide chest tube management. In a cohort of patients undergoing pulmonary resection with a 5.8% rate of PAL,Takamochi and colleagues[35] reported that the incidence of PAL was significantly higher in patients with a peak air leak greater than or equal to 100 mL/min compared with less than 100 mL/min. Furthermore, they described 2 patterns of air leak over the initial 72 hours after surgery that are associated with PAL: repeated exacerbation and remission of air leak and an air leak without a progressive trend toward improvement.

POSTOPERATIVE INTERVENTIONS FOR AIR LEAK

There are several interventional treatment options to address a prolonged air leak.[4] Although our preference is to manage the pleural space using outpatient chest tubes, other options include chemical pleurodesis, autologous blood patch, placement of endobronchial valves, or reoperative strategies including topical sealants or focal wedge resection, which can be combined with chemical or mechanical pleurodesis (**Fig. 3**). More aggressive surgical strategies, such as muscle-flap obliteration of the pleural space or omentopexy, are often unnecessary for standard PAL and more frequently used for management of bronchopleural fistulas.

Pleurodesis

Instillation of a sclerosing agent into the pleural space promotes pleural apposition by forming inflammatory adhesions, leading to air leak closure. Chemical pleurodesis is used selectively in patients with a significantly prolonged air leak (greater than 20 days) in the context of a well-positioned chest tube and/or when the lung drops significantly when placed to water seal. Several agents have shown to be effective, including tetracycline, doxycycline, and talc, with success rates between 60% and 90%.[5] Successful pleurodesis via a chest tube requires pleural symphysis; therefore, chemical pleurodesis may not be effective in patients with a large pleural deficit or pneumothorax.

Blood Patch

Although at our institution, we do not perform an autologous blood patch for air leak, this method has shown success in resolving PAL in several small prospective studies. In a randomized trial, 10 patients with PAL after lobectomy were randomized to treatment with a blood patch: instillation of 120 mL of autologous blood via an apical chest drain and repeated if necessary.[36] Air leaks were sealed within 24 hours of blood patch instillation in 60% of patients, with significant reductions

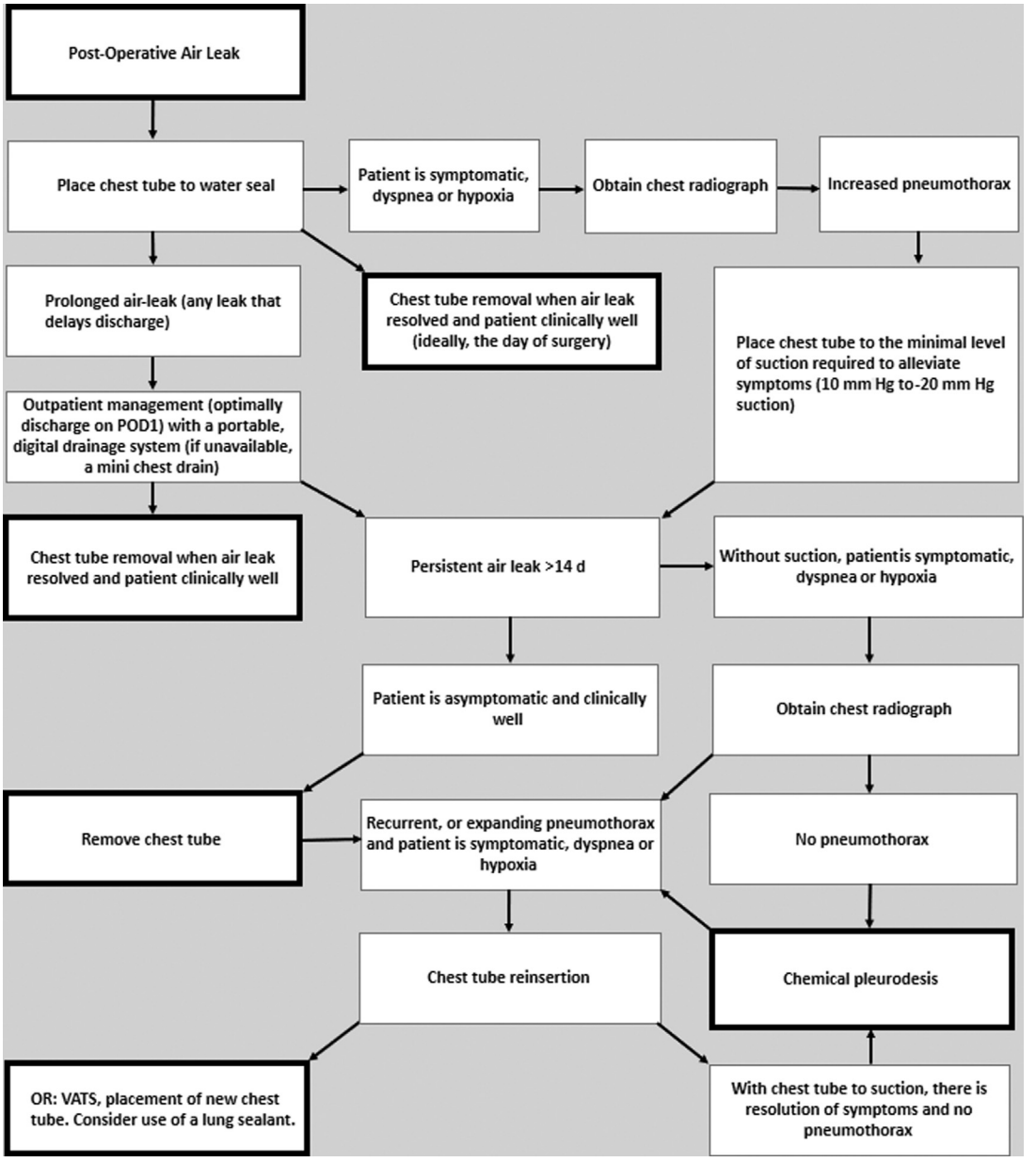

Fig. 3. Flow diagram of our preferred algorithm for management of a postoperative air leak from an aleveolar-pleural fistula. Of note, this management plan is not applicable for a segmental or bronchopleural fistula.

in chest tube dwell time and hospital length of stay. Periprocedural antibiotics have been suggested to decrease pleural contamination and reduce the incidence of empyema, which occurred in one patient (10%). A larger volume of blood seems to be more effective than smaller dose, as shown by Andretti and colleagues[37] in a randomized trial. Twenty-five patients were assigned to a 50 mL or 100 mL blood patch, with resolved air leak in 2.3 days versus 1.5 days postprocedure, respectively.

Endobronchial Valves

Patients with severe PAL or leaks refractory to other methods of control may benefit from bronchoscopic placement of a unidirectional endobronchial valve (EBV) in the segmental bronchi, occluding distal airflow while allowing drainage of secretions and trapped air. Distal parenchymal atelectasis induces tissue apposition and subsequent healing of parenchymal defects. In a series of 7 patients, Gillespie and colleagues[38] demonstrated the safety

and feasibility of EBV placement in patients with a median duration of air leak of 4 weeks. All patients had a reduction in air leak, with a mean duration of 4.5 days until resolution. Discharge within 2 to 3 days was achieved in 57% of patients, and all valves were eventually removed without procedural or valve-related complications. In a series of 21 patients, Reed and colleagues[39] reported that EBV placement resulted in a median duration of chest tube removal of 15 days and a median length of stay of 5 days. For the postoperative air leak cohort (8 patients), the median length of stay was 3 days after EBV, with a mean valve dwell time of 47 days until removal.

AIR LEAK AFTER LUNG VOLUME REDUCTION SURGERY

LVRS is a palliative procedure for select patients with severe emphysema and can lead to significant functional improvement.[40,41] Emphysematous lung parenchyma is associated with increased postoperative air leaks, with up to 90% of LVRS patients in the National Emphysema Treatment Trial (NETT) experiencing an air leak within 30 days of surgery.[40] Ciccone and colleagues[41] noted that among 250 patients, PAL (>7 days) occurred in 45% (n = 113) patients, with 3.2% (n = 8) requiring reexploration for air leaks. A study evaluating postoperative air leaks in NETT showed a median air leak duration of 7 days, with increased air leak duration associated with lower DLCO, pleural adhesions, predominantly upper lobe disease, inhaled steroid usage, and Caucasians.[13] Although there was no difference in mortality for patients who experienced air leak after LVRS versus those who did not, patients with air leaks were more likely to have postoperative pneumonia and admission to the intensive care unit.

Given the high rate of postoperative air leaks following LVRS, many methods have been used in an attempt to prevent this complication. Analysis of NETT demonstrated that development of postoperative air leak was not affected by use of pleural tents, fibrin glue, or concurrent chemical pleurodesis.[13] In a randomized prospective study, Moser and colleagues[42] evaluated 25 patients who underwent bilateral LVRS, with fibrin sealant placed on the staple lines on one side and no intervention on the other side. PAL was decreased in the treatment group (4.5% treated vs 31.8% untreated), as was mean chest tube duration (2.8 days treated vs 5.9 days untreated). Reported by Tacconi and colleagues,[43] unilateral plication of the most emphysematous lung parenchyma under epidural anesthesia is another proposed technique to reduce air leak during LVRS. In this study, the plication group had a lower incidence of PAL (18% vs 40%), shorter air leak duration (5.2 days vs 7.9 days), and shorter hospital stay (6.3 days vs 9.2 days) when compared with the traditional resection group.

SUMMARY

Alveolar air leaks after pulmonary resection remain a common complication, increasing postoperative complications and length of hospital stay. Developing technologies such as digital drainage systems combined with enhanced recovery pathways of care, however, are moving the management of air leak to the outpatient setting. Further study is warranted to define the role of avoiding chest tubes for patients after pulmonary resection.

CLINICS CARE POINTS

- Air leak after elective pulmonary resection occurs in 28% to 60% of patients and are more likely to develop in patients with limited pulmonary function (low FEV1), obesity, steroid use or immunosuppression, malnutrition, and in those undergoing an upper lobe lobectomy.
- Intraoperative techniques such as proper tissue handling, fissureless surgery, and the select use of surgical sealants can reduce the risk of postoperative air leak.
- Most of the postoperative air leaks will resolve with chest tube drainage alone by POD 4. There are several methods to address an air leak that persists beyond 5 days, including outpatient chest tube management and chemical pleurodesis.
- Digital drainage systems offer several advantages over analog systems such as an accurate digital interface, portability with suction, and precision adjustment of settings. Digital drainage systems have shown to limit interobserver variability regarding decision-making for chest tube management and had equally shown to reduce length of stay after pulmonary resection.
- LVRS for select patients with severe emphysema has a high rate of postoperative air leak (up to 90%). Using a buttressed technique and/or surgical fibrin sealants have both shown to reduce the rate of postoperative air leak in this population.

DISCLOSURE

Dr T.C. Geraci, Mr S.K. Shah, Dr S.H. Chang, and Dr A. Kent have no disclosures. Dr R.J. Cerfolio

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