



Mastering the maze: navigating prolonged air leak in thoracic surgery

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Abstract: Despite technological advancements, prolonged air leak (PAL) remains a significant complication in thoracic surgery. PAL, indicative of an alveolar-pleural fistula (APF), impacts patient recovery, quality of life, and healthcare costs. Risk factors such as smoking and surgical techniques predispose patients to PAL, highlighting the importance of preoperative risk assessment. Segmentectomies, while beneficial for early-stage lung neoplasms, pose challenges due to increased PAL risk. Intraoperative techniques like the submersion test aid in PAL detection and categorisation. Standardising intraoperative management through initiatives like the Delphi consensus enhances PAL management. Studies on aerostatic interventions show promise in reducing PAL incidence. Postoperatively, chest drainage strategies play a crucial role, with digital chest drains offering improved monitoring and management precision. Long-term PAL management includes watchful waiting, chemical pleurodesis, and surgical interventions, with autologous blood patching emerging as a cost-effective intervention. Despite the array of interventions available, the lack of standardised guidelines underscores the multifactorial nature of PAL. In the context of visualised thoracic surgery, PAL remains a significant concern, impacting patient outcomes and healthcare costs. Visualised thoracic surgery, which encompasses minimally invasive techniques such as video-assisted thoracoscopic surgery (VATS) and robotic-assisted thoracic surgery (RATS), offers several advantages, including reduced postoperative pain, shorter hospital stays, and faster recovery. However, despite these benefits, PAL remains a common complication, particularly in procedures involving lung resection or pleural interventions. Advanced visualisation technology in thoracic surgery allows for precise identification and management of PAL intraoperatively. Techniques such as intraoperative near-infrared fluorescence imaging enable real-time visualisation of air leaks, facilitating prompt intervention and potentially reducing the risk of PAL development. Additionally, adopting enhanced recovery protocols tailored to visualised thoracic surgery may help mitigate PAL risk by optimising perioperative care and promoting early mobilisation. Addressing PAL requires a comprehensive, individualised approach and continued research efforts in thoracic surgery. This review provides an overview of the challenges and strategies in navigating PAL, particularly on APF, emphasising the need for collaborative efforts and tailored approaches to optimise patient outcomes and reduce healthcare costs.

Keywords: Lung cancer; prolonged air leak (PAL); risk factors; intraoperative management; digital chest drains

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Introduction

Despite advancements in surgical technology, prolonged air leak (PAL) remains one of the most common complications of lung surgery. Postoperative air leak indicates the presence of an alveolar-pleural fistula (APF), a pathological communication between the lung parenchyma and the pleural space. Air loss through chest drainage or postoperative pneumothorax is an indicator of APF. PAL is the persistence of air leaks for more than 5 days.

In the context of visualised thoracic surgery, PAL remains a significant concern, impacting patient outcomes and healthcare costs. Visualised thoracic surgery, which encompasses minimally invasive techniques such as video-assisted thoracoscopic surgery (VATS) and robotic-assisted thoracic surgery (RATS), offers several advantages, including reduced postoperative pain, shorter hospital stays, and faster recovery. However, despite these benefits, PAL remains a common complication, particularly in procedures involving lung resection or pleural interventions. Advanced visualisation technology in thoracic surgery allows for precise identification and management of PAL intraoperatively. Techniques such as intraoperative near-infrared fluorescence imaging enable real-time visualisation of air leaks, facilitating prompt intervention and potentially reducing the risk of PAL development. Additionally, adopting enhanced recovery protocols tailored to visualised thoracic surgery may help mitigate PAL risk by optimising perioperative care and promoting early mobilisation.

This review provides an overview of the challenges and strategies in navigating PAL, particularly on APF, emphasising the need for collaborative efforts and tailored approaches to optimise patient outcomes and reduce healthcare costs.

Definition and incidence of postoperative air leaks

Due to resource utilisation, PAL inevitably leads to diminished patient quality of life, prolonged post-operative recovery time, and increased healthcare costs (1).

A systematic review demonstrated that the incidence of PAL after lung resection is approximately 15%, excluding patients who underwent lung volume reduction surgery (LVRS), where the percentage is higher (46%). Zheng and colleagues identified five variables associated with a higher risk of PAL: smoking, steroid use, low forced expiratory volume in the first second/forced vital capacity ratio (FEV1/FVC%), non-fissureless surgical technique,

and pathological stage III/IV. Conversely, body mass index (BMI) was inversely related to PAL incidence, possibly due to obese patients having a more favourable wound-healing environment (2).

Based on the variables above, they also developed a decision curve analysis to predict PAL incidence in minimally invasive surgery (3). Preoperative analysis of these variables could provide additional information for surgeons in risk assessment but with a high rate of false positives and a low positive predictive value (4). However, most of the predisposing factors for PAL are potential targets for prehabilitation interventions, optimising patients in the preoperative phase.

Regarding the risk of PAL developing, the type of resection performed is another aspect that cannot be overlooked. Segmentectomies are increasingly used for treating early-stage lung neoplasms, as supported by CALGB140503 and JCOG0802/WJOG4607L results (5,6). In addition to technical difficulties, one of the main concerns regarding segmentectomies is the increased risk of PALs post-surgery. In this case, factors such as FEV1 value, diffusing lung capacity for carbon monoxide (DLCO), low BMI, and complex segments predispose to increased PAL risk, while the type of access (minimally invasive *vs.* open) does not. For lobectomies, the use of minimally invasive surgery is associated with a lower risk of PAL, as well as the use of the fissureless technique in the case of poorly represented fissures (grade III/IV according to Craig-Walker classification) or mechanical staplers with bovine pericardium coating (7,8).

Another aspect aiding surgeons in predicting PAL risk postoperatively is the analysis of radiological images. Patients with emphysematous alterations of the lung parenchyma are at higher risk. The lobe-specific emphysema index (LEI) was assessed using three-dimensional volumetric computed tomography (CT) scans. CT quantification of emphysema is the best predictor of PAL after lobectomy and segmentectomy (9).

Intraoperative risk factors for PAL include long staple lines, pleural adhesions and adhesiolysis causing additional parenchymal tears and PAL. Hence, the current trends include using sealants with haemostatic and aerostatic properties.

Therefore, the analysis of all these aspects during the patient's preoperative assessment should complement the usual international guidelines to guide the surgeon in selecting the type of resection, balancing risks and benefits in the most fragile patients (*Table 1*).

Table 1 Risk factors for postoperative air leaks

Risk factors	Impact on PAL
Smoking	Increased risk
Steroid use	Increased risk
Low FEV1/FVC%	Increased risk
Non-fissureless surgical technique	Increased risk
Pathological stage III/IV	Increased risk
High BMI	Decreased risk

FEV1/FVC%, forced expiratory volume in the first second/forced vital capacity ratio; BMI, body mass index; PAL, prolonged air leak.

Table 2 Intraoperative management of air leaks

Intraoperative tests	Description
Submersion test	Filling the chest cavity with sterile distilled water to identify air leaks
Ventilator test	Assessing air leaks under standardized ventilator settings to categorize the severity

Table 3 Categorisation of air leaks according to the ventilator test

Air leak categorization	Air leak rate (mL/min)	Expected resolution time
Mild	<100	Few hours
Moderate	100–400	5–8 days
Severe	>400	>15 days

Intraoperative management of air leaks

Intraoperative estimation of air leaks is mainly evaluated using the submersion and ventilator tests (*Table 2*). The submersion test involves filling the chest cavity with sterile distilled water and reventilating the parenchyma to identify any breaches or air leaks, allowing immediate treatment. The ventilator test (*Table 3*) is performed by the anaesthetist, assessing the extent of air leaks under standardised ventilator settings: 12 breaths per minute, a positive end-expiratory pressure (PEEP) of 5 mmHg, and a peak pressure of 22 cmH₂O to assess the extent of air leaks. This allows categorising patients into three categories: mild (<100 mL/min), moderate (100–400 mL/min), and severe (>400 mL/min). This categorisation also predicts the timeframe for resolution, respectively a few hours, approximately 5–8 days, and

>15 days (10). This estimation of air leaks enables surgeons to use aerostatics or minimise air leaks by resecting the affected area or applying parenchymal sutures.

A Delphi consensus among members of the Italian Society of Thoracic Surgery was reached regarding the intraoperative management of air leaks. The aim was to update surgeons with scientific information about technical and technological solutions, such as surgical sealants. This working group has recently expanded to include European and non-European collaborators, developing guidelines for better management of post-surgery air leaks (11,12).

Several studies have investigated the potential benefits of using aerostatics during surgery. These materials promote tissue adhesion and sealing of pleural defects. The main advantage of sealants and patches is their effectiveness in minimising intraoperative and early postoperative air leaks. They are versatile and can be used in various surgical scenarios and with different tissue types. Many sealants and patches are designed to be biocompatible, minimising the risk of adverse reactions. However, these materials can be expensive, adding to the overall cost of surgery. Their effectiveness can vary depending on the type of surgery and the patient's condition.

Additionally, applying these materials requires skill and precision during surgery. Sealants and patches are increasingly being adopted in thoracic surgery. Integrating these technologies involves training surgical teams and assessing cost-benefit ratios for different patient populations. Establishing standardised protocols for their use can enhance outcomes and consistency in PAL management. Routine use of fibrin sealants intraoperatively did not significantly shorten air leak duration or chest tube length (13). However, recent studies suggest that using fibrin glue or aerostatic patches reduces postoperative air leaks, decreasing drainage days and hospitalisation. For instance, using ProgelTM (BD, New York, USA) (14), a human albumin and polyethylene glycol solution, significantly reduced the length of stay. The superiority of TachoSilTM (Corza Medical, Westwood, USA) over standard stapling and suturing aerostatic techniques in reducing postoperative air leaks was demonstrated (15), as well as the benefits of using NeoveilTM (Gunze Co., Ltd., Tokyo, Japan), a polyglycolic acid sheet, in reducing air leaks after major lung surgery in patients with lung cancer (16).

Postoperative management of air leaks

Postoperative measures to prevent PAL include early

Table 4 Postoperative management of air leaks

Chest drainage strategies	Key features
Water seal	Reduces total air leak time
Gentle aspiration	Recommended when a small residual pneumothorax is present
Digital chest drains	Continuous monitoring of fluid and air leaks, objective interpretation of data

extubation, preferably on the table, and reduced mechanical ventilation time. This is especially important in sick patients undergoing extensive resections, lung-volume reduction surgery or pneumonectomy. Prevention and treatment of empyema is a vital management point of PAL, particularly in the setting of the broncho-pleural fistula (BPF) formation. Regarding postoperative management of air leaks, the chest drainage type also seems crucial (Table 4). Cerfolio *et al.* first demonstrated that using a water seal immediately after pulmonary resection reduces total air leak time (17). Literature shows that several other studies have been conducted on this topic to strengthen Cerfolio's theory, among which it is worth mentioning the work of Marshall *et al.*, which confirmed how the air leak sealing was significantly shorter in the water seal group compared to the suction group (-20 cmH₂O). To date, another clear aspect is that a gentle aspiration (-10 cmH₂O) is recommended when a small residual pneumothorax is present due to incomplete lung expansion (18).

In this regard, using digital chest drains could allow better management of the different degrees of suction (19,20). They ensure continuous monitoring of fluid and air leaks, enabling a more objective interpretation of data trends over time and capturing intermittent leaks, resulting in shorter hospital stays (21). Moreover, by evaluating differential intrapleural pressures, these systems could differentiate an active air leak from an apparent one due to a pleural space effect. The possibility of predicting the risk of PAL following pulmonary lobectomy by examining air leak rates and pleural pressure was outlined (7). Expanded on this concept, it was demonstrated how 3 hours after surgery, air leak flow ≤ 80 mL/min, surgery duration ≤ 220 minutes and right middle lobectomy are independent predictor factors of air leak cessation (ALC) and that an air leak >180 mL/min at 3 hours post-operation and a mean air leak of 73.3 mL/min or more at 1-day post-operation were risk factors for PAL (22). PAL posed a challenge during

the COVID-19 pandemic, which led to implementing infection precaution practices and safety measures such as filters on top of the drainage systems, which may still be relevant in case of infections spread via aerosolisation in future. Digital chest drain systems are advanced devices used postoperatively to manage air leaks and monitor pleural drainage. These systems utilise electronic sensors to continuously measure and record the rate of air leaks and fluid drainage. The data is displayed in real-time on a digital screen, allowing precise monitoring of intrapleural pressure and fluid dynamics. The main advantages of digital chest drains include continuous monitoring, which provides real-time data on air leaks and pleural fluid, enabling immediate detection of complications. These systems offer improved accuracy over traditional analogue systems, reducing the risk of human error. They enhance decision-making by tracking trends over time, aiding in informed decisions regarding chest tube removal and other interventions. Digital chest drains often allow for more controlled and gentle suction, improving patient comfort and reducing pain. Accurate monitoring can lead to earlier detection of leak cessation, facilitating quicker chest tube removal and shorter hospital stays. However, digital systems are more expensive than analogue ones, which may limit their use in resource-constrained settings. They also require training for healthcare staff to use and interpret the data from these systems effectively. Additionally, technical malfunctions can occur, necessitating backup systems and protocols. Integrating digital chest drains into standard practice involves training surgical teams on their use and interpretation of data. Hospitals must balance the higher upfront costs with the long-term benefits of reduced hospital stays and improved patient outcomes. Establishing protocols for using digital chest drains in various surgical scenarios can facilitate widespread adoption and standardisation.

Long-term management of PALs involves various strategies, as the lack of a standardised pathway leads to heterogeneous management (Table 5). These strategies include watchful waiting, chemical pleurodesis using agents such as tetracycline, sterile talc, or blood patch, and surgical reintervention.

Pleurodesis is indicated in patients with an air leak flow >80 mL/min at 3 hours post-operation and in high-risk patients. The choice of the best chemical sclerosing agent remains debated. Sterile talc instillation through a chest tube may be associated with side effects such as acute respiratory distress syndrome. At the same time,

Table 5 Long-term management of prolonged air leaks

Interventions	Description
Watchful waiting	Monitoring the patient without immediate intervention
Chemical pleurodesis	Using agents such as tetracycline, sterile talc, or doxycycline to promote pleural adhesion
Autologous blood patching	Instilling diluted venous blood into the pleural cavity to stimulate an inflammatory reaction and promote adhesion between the visceral and parietal pleura
Heimlich valve drainage	A portable one-way valve system that allows for early ambulation and earlier discharge from the hospital

doxycycline use is linked to chronic pain, as reported in the 2001 Consensus Statement by the American College of Chest Physicians (23).

Autologous blood patching is the safest, most effective, cost-effective, and readily available strategy; however, it has a variable efficacy. This practice has shown benefits, especially when repeated over consecutive days. Instilling diluted venous blood into the pleural cavity stimulates an inflammatory reaction, promoting adhesion formation between the visceral and parietal pleura, effectively sealing pleural defects (24).

In managing PAL, a significant focus has been placed on optimising patient outcomes while minimising hospital stays and improving the quality of life during recovery. One advanced intervention that has shown considerable promise is using a portable one-way (Heimlich) valve drainage system. This system facilitates early ambulation and allows for earlier discharge from the hospital, which are critical factors in patient recovery and overall healthcare efficiency. The Heimlich valve is a small, lightweight, portable device for managing pleural air leaks. It operates on a one-way valve mechanism that permits air to escape from the pleural cavity but prevents it from re-entering, thus ensuring adequate and continuous air drainage. One of the primary advantages of the Heimlich valve drainage system is its portability. Traditional chest tube systems require the patient to remain largely immobile and tethered to bulky suction equipment, which necessitates prolonged hospital stays.

In contrast, the Heimlich valve can be easily managed by patients, allowing them to engage in everyday activities, including walking, without being confined to a hospital bed. This not only enhances the patient's physical recovery through early ambulation but also significantly contributes to their psychological well-being by promoting a sense of autonomy and normalcy. The use of the Heimlich valve also supports earlier discharge from the hospital. For patients, early discharge reduces the risk of hospital-acquired

infections and allows them to recover in the comfort of their homes, surrounded by family and familiar surroundings.

PAL following lung resection is not only associated with increased index hospitalisation costs but also leads to higher costs after discharge. The relative costs after discharge accounted for more than half of the total 90-day costs, highlighting the importance of considering this phase when assessing the financial impact of PAL. Therefore, there is a need for healthcare providers and policymakers to address the economic implications of PAL in the management of patients undergoing lung resection surgery (25).

Lastly, chest tubes can be safely removed early, irrespective of the drainage volume of pleural effusion, in patients undergoing anatomic pulmonary resection. This approach could become a new standard in chest tube management post-surgery for patients without air leakage, hemothorax, or chylothorax. However, further validation through observational studies and daily clinical practice will be necessary (26).

Discussion

The reliance on retrospective data, small sample sizes, expert opinion, and observational designs highlights the need for further high-quality research, including well-designed randomised controlled trials (RCTs), to establish more definitive and generalisable evidence. This critical review underscores the importance of continued innovation and evidence-based practice in addressing the complexities of PALs in thoracic surgery.

PAL management strategies significantly impact long-term patient outcomes and quality of life. An expanded discussion on these effects can offer a more holistic view of PAL management, highlighting the importance of tailored interventions and continuous care. Effective management of PAL begins with preoperative risk assessment and patient optimisation. Identifying risk factors such as smoking, steroid use, and low pulmonary function allows for targeted

prehabilitation interventions. For instance, smoking cessation programs and pulmonary rehabilitation can improve lung function and overall fitness, reducing the risk of PAL and enhancing recovery. Optimised patients tend to have shorter hospital stays, lower complication rates, and better long-term respiratory function, all contributing to improved quality of life. Intraoperative strategies like submersion and ventilator tests enable early detection and management of air leaks. By accurately categorising air leaks, surgeons can apply appropriate interventions such as surgical sealants or parenchymal sutures. Digital chest drains offer precise monitoring and management of air leaks, which is crucial for the early detection of complications and timely interventions. By providing continuous data on fluid and air leakage, these devices help make informed decisions about chest tube removal and other postoperative care measures. Chemical pleurodesis and autologous blood patching are effective in sealing persistent air leaks. The Heimlich valve drainage system represents a significant outpatient tool in PAL management. The economic implications of PAL are considerable, with increased costs during hospitalisation and after discharge. Effective management strategies that reduce the duration of PAL can lower these costs significantly. Regular follow-up visits allow for the early detection of any recurrent issues and provide opportunities for continued support and intervention. Chronic respiratory problems can be managed more effectively with ongoing care, ensuring patients maintain optimal lung function and quality of life. Patient education on self-monitoring and lifestyle modifications is critical in long-term health maintenance.

Despite significant advancements in PAL management, several gaps persist, highlighting areas for future research and improvements. There needs to be more consensus on the definition and assessment of PAL, leading to variability in reported incidence rates and management strategies. Current preoperative risk prediction models for PAL are limited by their low positive predictive value and high false-positive rates. While several intraoperative management strategies for PAL have been proposed, such as using sealants and aerostatic techniques, the optimal approach remains to be determined. Future research should compare the effectiveness of different intraoperative management strategies in large, multicenter, RCTs to identify the most productive and cost-effective interventions. There needs to be more research on the long-term management of PAL and its impact on patient quality of life. Emerging technologies such as digital chest drain systems and portable

one-way valve systems show promise in PAL management but require further evaluation in clinical settings. There need to be more comprehensive cost-effectiveness analyses comparing different PAL management strategies. There is a need for more patient-centred approaches to PAL management, considering patient preferences, values, and priorities.

Limitations

While this narrative review provides a comprehensive overview of PAL management in thoracic surgery, several limitations should be acknowledged to enhance transparency and credibility.

One limitation is the potential for selection bias. The review relies on the available literature, which may inherently include studies with positive outcomes while underrepresenting studies with negative or inconclusive results. This bias can skew the overall perception of the efficacy of various interventions and management strategies.

Another limitation is the variability in study methodologies and patient populations. The studies reviewed come from different centres with varying surgical techniques, patient demographics, and definitions of PAL. This heterogeneity can make it challenging to directly compare outcomes and draw definitive conclusions about the best practices.

The review also faces the issue of publication bias. Studies showing significant results are more likely to be published, while those with negative or null results might be less readily available. This can result in an overestimation of the effectiveness of specific interventions.

Additionally, the rapid evolution of technology and surgical techniques means that some studies included in this review might need to be updated, not reflecting the latest advancements or current best practices. Emerging technologies and new research might shift current paradigms, necessitating continual updates to the information presented.

There is a need for RCTs in some areas of PAL management. RCTs are the gold standard for clinical research, providing high-quality evidence. However, many studies on PAL are observational or retrospective, which can introduce various biases and limit the strength of the conclusions drawn.

Finally, this review does not include a systematic search strategy or meta-analysis, which are often employed in systematic reviews to ensure a comprehensive and unbiased

synthesis of the literature.

Conclusions

Navigating PAL in thoracic surgery requires a multifaceted approach considering patient-specific factors, surgical techniques, and postoperative management strategies. To optimise PAL management and improve patient outcomes, clinicians should consider the following key takeaways and best practices:

- ❖ Preoperative risk assessment: conduct a thorough preoperative risk assessment to identify patients at higher risk for PAL, considering factors such as smoking history, lung function, and surgical technique. Utilise standardised risk prediction models to guide patient selection and preoperative optimisation efforts.
- ❖ Intraoperative management: implement standardised intraoperative techniques, such as the submersion and ventilator tests, to accurately assess air leaks and guide surgical decision-making. Consider using sealants and aerostatic techniques to minimise air leaks and reduce the risk of PAL.
- ❖ Postoperative chest drainage: select an appropriate chest drainage strategy based on patient-specific factors and surgical outcomes. Consider using digital chest drain systems for continuous monitoring and precise management of air leaks. Ensure early extubation and reduced mechanical ventilation time to minimise the risk of PAL development.
- ❖ Long-term PAL management: develop individualised long-term management plans based on the severity and duration of PAL. Consider watchful waiting, chemical pleurodesis, or autologous blood patching for persistent air leaks. Continuously monitor patient-reported outcomes and quality of life to guide treatment decisions and optimise patient care.
- ❖ Integration of emerging technologies: stay informed about emerging technologies and techniques, such as digital chest drain systems and portable one-way valve systems, that offer potential benefits in PAL management. Evaluate the effectiveness, safety, and cost-effectiveness of these technologies in clinical practice to inform decision-making and optimise patient care.
- ❖ Patient-centered care: involve patients in the decision-making process and consider their preferences, values, and priorities when developing PAL management

plans. Provide clear communication and education to patients and caregivers about PAL management strategies and expectations for recovery.

By implementing these actionable recommendations, clinicians can optimise PAL management approaches to improve patient outcomes and enhance the overall quality of care for patients undergoing thoracic surgery. Continued research and collaboration are essential to refine PAL management strategies further and address the evolving needs of patients and clinicians in this complex surgical domain.

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