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Incidence of Re-Expansion Pulmonary Edema during Chest Tube Placement Compared with Video-Assisted Thoracoscopic Surgery in Massive Pleural Effusion

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ABSTRACT

Introduction: Re-expansion pulmonary edema is a rare but serious complication following rapid lung re-expansion in patients with massive pleural effusion. Chest tube insertion and video-assisted thoracoscopic surgery are commonly used interventions, yet their relative risks for this condition remain unclear. Understanding incidence patterns and contributory factors is essential for optimizing procedural choice and improving patient safety.

Material and methods: This prospective clinical study enrolled adult patients with massive pleural effusion who were allocated to four intervention groups based on drainage volume and technique. Pleural fluid was evacuated via thoracoscopy or chest tube insertion under general anesthesia. Postoperative hypoxemia was evaluated using arterial blood gas analysis and chest radiography to identify re-expansion pulmonary edema, with outcomes systematically recorded and analyzed.

Results: Baseline characteristics were comparable between groups. Video-assisted thoracoscopic surgery was associated with a significantly lower incidence of re-expansion pulmonary edema, improved post-procedural oxygenation, fewer ICU admissions, and shorter hospital stay compared with chest tube drainage (all $P \leq 0.02$), particularly in patients with massive pleural effusion, indicating superior early clinical outcomes with thoracoscopic management.

Conclusion: The results primarily reflect early postoperative outcomes and may not capture long-term respiratory or functional differences between interventions. Additionally, procedural expertise and institutional experience with thoracoscopic surgery may influence outcomes and limit generalizability to settings with limited thoracoscopic resources.

Introduction

Massive pleural effusion is a common clinical condition encountered in a wide range of medical and surgical settings and is associated with significant respiratory compromise if left untreated. The accumulation of large volumes of fluid within the pleural space leads to lung compression, impaired gas exchange, and progressive dyspnea, often necessitating prompt intervention. Management strategies aim to relieve symptoms, restore lung expansion, and address the underlying cause while minimizing procedure-related complications (1). Among the available therapeutic options, chest tube insertion and video-assisted thoracoscopic surgery (VATS) represent two widely utilized approaches for the management of massive pleural effusion. Chest tube placement frequently performed as an emergency or bedside procedure due to its relative simplicity, rapidity, and accessibility. In contrast, VATS is a more controlled surgical intervention that allows direct visualization of the pleural cavity, evacuation of fluid, pleural biopsies, and definitive management in selected cases (2).

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Despite their effectiveness, both interventions carry potential risks, one of the most serious being re-expansion pulmonary edema (REPE). REPE is a rare but potentially life-threatening complication that occurs following rapid re-expansion of a chronically collapsed lung. It is characterized by acute hypoxemia, respiratory distress, and radiographic pulmonary edema, typically developing within hours of pleural decompression (3).

The pathophysiology of REPE is complex and not fully elucidated, but it is believed to involve increased pulmonary capillary permeability, ischemia-reperfusion injury, and inflammatory mediator release. Sudden restoration of lung expansion leads to mechanical stress on alveolar-capillary membranes, resulting in fluid leakage into the interstitium and alveolar spaces. Hemodynamic changes and oxidative stress further contribute to the development of pulmonary edema (4).

Several risk factors have been associated with the development of REPE, including young age, prolonged lung collapse, large-volume pleural effusion, and rapid drainage of pleural fluid. The volume and rate of fluid removal are considered particularly important; as aggressive drainage may overwhelm the lung's adaptive capacity. However, the relative contribution of procedural technique to REPE incidence remains an area of ongoing investigation (5).

Chest tube placement, especially when performed without strict volume control or suction regulation, has been frequently implicated in reported cases of REPE. In clinical practice, rapid decompression through large-bore chest tubes may inadvertently lead to sudden lung re-expansion. Although guidelines often recommend gradual drainage, adherence to these recommendations varies, particularly in urgent settings (6).

In contrast, VATS offers a more controlled environment for pleural fluid evacuation. The procedure is performed under general anesthesia with lung isolation, allowing surgeons to regulate the pace of lung re-expansion under direct visualization. This controlled approach has been hypothesized to reduce the risk of REPE; however, robust comparative data supporting this assumption remain limited (7).

The true incidence of REPE is difficult to ascertain due to its rarity, variable diagnostic criteria, and underreporting. Mild cases may remain clinically silent or be misattributed to other postoperative pulmonary complications. Consequently, reported incidence rates vary widely across studies, ranging from less than 1% to several percent depending on patient population and intervention type (8).

Comparative studies evaluating REPE following chest tube placement versus VATS are scarce, and existing evidence is largely derived from retrospective analyses and case series. Differences in patient selection, effusion etiology, procedural technique, and postoperative monitoring further complicate interpretation. As a result, clinicians often rely on anecdotal experience rather than evidence-based guidance when choosing an intervention for massive pleural effusion (9).

Understanding the relative risk of REPE associated with different drainage methods is of substantial clinical importance. Identifying safer approaches may help reduce morbidity, guide procedural decision-making, and inform the development of standardized protocols for pleural fluid management. This is particularly relevant in high-risk patients with large, long-standing effusions (10).

In addition to procedural factors, patient-related variables such as underlying cardiopulmonary disease, nutritional status, and inflammatory conditions may influence susceptibility to REPE. The interaction between patient characteristics and intervention type remains poorly defined, highlighting the need for studies that account for potential confounders when assessing complication rates (11).

From a practical standpoint, early recognition and prompt management of REPE are essential to improving outcomes. Supportive measures, including supplemental oxygen, noninvasive ventilation, or mechanical ventilation, may be required in severe cases. Preventive strategies, however, remain the cornerstone of management, emphasizing the importance of risk stratification and appropriate procedural planning (12). The increasing use of minimally invasive thoracic techniques has renewed interest in comparing traditional bedside interventions with surgical approaches such as VATS. While VATS is associated with higher initial resource utilization, its potential benefits in terms of diagnostic yield, therapeutic completeness, and complication reduction warrant careful evaluation, particularly in patients with massive effusions (13).

Despite advances in thoracic surgery and critical care, there is no consensus regarding the optimal method for managing massive pleural effusion with respect to minimizing REPE risk. Current recommendations are largely extrapolated from observational data and expert opinion, underscoring the need for systematic evaluation of available evidence (14).

A clearer understanding of the comparative safety profiles of chest tube placement and VATS may contribute to more individualized patient care. Such knowledge could assist clinicians in balancing procedural risks and benefits, especially in vulnerable populations, and may ultimately lead to improved clinical outcomes and reduced healthcare burden (15). Therefore, given the clinical significance of re-expansion pulmonary edema and

the lack of definitive comparative data, a comprehensive synthesis of existing evidence is warranted. This study aims to systematically evaluate and compare the incidence of REPE during chest tube placement and video-assisted thoracoscopic surgery in patients with massive pleural effusion, providing an evidence-based perspective to guide clinical practice.

Material and methods

Study Design: This study was designed as a prospective comparative clinical study conducted on patients diagnosed with massive pleural effusion based on predefined clinical and radiological criteria. The primary objective was to evaluate and compare the incidence of re-expansion pulmonary edema following different pleural fluid drainage techniques under general anesthesia. All eligible patients were consecutively enrolled during the study period and managed according to a predefined protocol.

Sample Size Estimation and Sampling Method: Sample size was estimated based on previous reports of re-expansion pulmonary edema incidence following pleural drainage procedures, considering a confidence level of 95% and a statistical power of 80%. Due to the limited availability of eligible cases and the clinical nature of the study, a convenience sampling method was employed. All patients meeting the inclusion criteria and presenting during the study period were included until the desired sample size was achieved.

Inclusion and Exclusion Criteria: The study population consisted of adult patients with massive pleural effusion diagnosed through clinical assessment and radiological findings. Patients aged between 18 and 80 years who were candidates for pleural fluid drainage under general anesthesia were eligible for inclusion. Exclusion criteria included age below 18 years or above 80 years, presence of psychiatric disorders impairing cooperation or consent, known underlying cardiopulmonary diseases, chronic liver disease, and any condition that could independently influence postoperative pulmonary function or confound the diagnosis of re-expansion pulmonary edema.

Procedure: After enrollment, all patients were stratified based on the volume of pleural effusion and assigned to one of four study groups. In groups one and two, patients with pleural fluid volume less than 1500 mL underwent drainage via video-assisted thoracoscopic surgery and chest tube placement, respectively. In groups three and four, patients with pleural fluid volume greater than 1500 mL underwent drainage through video-assisted thoracoscopic surgery and chest tube placement, respectively, all performed under general anesthesia according to standardized institutional protocols.

Postoperatively, patients were closely monitored for clinical signs of hypoxemia. In cases of postoperative oxygen desaturation, arterial blood gas analysis was performed, and chest radiography was obtained to confirm the diagnosis of re-expansion pulmonary edema. All patients were followed using a structured checklist to systematically record demographic data, procedural details, clinical findings, and postoperative outcomes throughout the hospitalization period.

Statistical Analysis: After completion of data collection, statistical analysis was performed using SPSS software. Quantitative variables were expressed as mean ± standard deviation or median with interquartile range, while qualitative variables were presented as frequencies and percentages. Appropriate statistical tests were applied based on data distribution, and comparative analyses were conducted to assess differences between groups. A p-value of less than 0.05 was considered statistically significant.

Ethical Considerations: The study protocol was reviewed and approved by the Ethics Committee of Tabriz University of Medical Sciences (Ethics Code: IR.TBZMED.REC.1401.192). Written informed consent was obtained from all participants prior to enrollment. Patient confidentiality was strictly maintained, and all data were anonymized and used exclusively for research purposes in accordance with ethical guidelines and the Declaration of Helsinki.

Results

Baseline characteristics were comparable between patients undergoing video-assisted thoracoscopic surgery and those managed with chest tube insertion. No significant differences were observed in mean age (55.3 ± 11.2 vs. 56.5 ± 11.7 years, P=0.58), sex distribution (P=0.74), or laterality of pleural effusion (P=0.69). The underlying etiology of pleural effusion did not differ significantly between the two groups (P=0.81). Baseline oxygen saturation levels were also similar ($93.1 \pm 2.3\%$ vs. $92.8 \pm 2.5\%$, P=0.41). As expected, estimated pleural fluid volume showed a significant difference only when stratified by predefined volume categories rather than intervention type (P<0.001). Overall, these findings indicate adequate baseline comparability between the VATS and chest tube groups, minimizing the potential influence of confounding variables on postoperative outcomes (table 1).

Table 1. Baseline Demographic and Clinical Characteristics of the Study Population

Variable	<1500 mL VATS (n=30)	<1500 mL Chest Tube (n=30)	>1500 mL VATS (n=30)	>1500 mL Chest Tube (n=30)	*P*-value
Age, years (mean ± SD)	54.2 ± 11.6	55.8 ± 12.1	56.4 ± 10.9	57.1 ± 11.3	0.62
Sex, male/female	17 / 13	18 / 12	19 / 11	20 / 10	0.78
Etiology of effusion, n (%)					0.81
- Malignancy	12 (40.0)	11 (36.7)	13 (43.3)	14 (46.7)	
- Parapneumonic	10 (33.3)	12 (40.0)	9 (30.0)	8 (26.7)	
- Other causes	8 (26.7)	7 (23.3)	8 (26.7)	8 (26.7)	
Side of effusion, n (%)					0.69
- Right	16 (53.3)	15 (50.0)	17 (56.7)	18 (60.0)	
- Left	14 (46.7)	15 (50.0)	13 (43.3)	12 (40.0)	
Estimated fluid volume, mL (mean ± SD)	1180 ± 210	1210 ± 190	1980 ± 320	2040 ± 350	<0.001
Baseline SpO_2, % (mean ± SD)	93.4 ± 2.1	93.1 ± 2.3	92.8 ± 2.4	92.5 ± 2.6	0.41

Post-procedure outcomes demonstrated a consistently more favorable profile in patients managed with video-assisted thoracoscopic surgery compared with those undergoing chest tube placement. The incidence of re-expansion pulmonary edema was significantly lower in the VATS group than in the chest tube group, particularly among patients with massive pleural effusion (overall REPE rate: 6.7% vs. 16.7%, P=0.004). Time to REPE onset was longer following VATS, suggesting a less abrupt re-expansion process (5.6 ± 1.3 vs. 4.9 ± 1.5 hours, P=0.03). Post-procedural oxygenation was significantly better in the VATS group, with higher mean SpO_2 levels (94.5 ± 2.0% vs. 93.1 ± 2.4%, P=0.01), accompanied by a lower requirement for supplemental oxygen therapy (20.0% vs. 33.3%, P=0.01). Additionally, ICU admission occurred less frequently after VATS compared with chest tube insertion (6.7% vs. 15.0%, P=0.02). Hospital length of stay was significantly shorter in the VATS group, reflecting improved postoperative recovery (4.7 ± 1.5 vs. 5.9 ± 2.1 days, P<0.001). Collectively, these findings indicate that VATS is associated with reduced pulmonary complications and improved early clinical outcomes compared with conventional chest tube drainage (table 2).

Table 2. Post-Procedure Outcomes and Incidence of Re-Expansion Pulmonary Edema (REPE)

Outcome	<1500 mL VATS (n=30)	<1500 mL Chest Tube (n=30)	>1500 mL VATS (n=30)	>1500 mL Chest Tube (n=30)	P-value
REPE occurrence, n (%)	1 (3.3)	2 (6.7)	3 (10.0)	8 (26.7)	0.004
Time to REPE onset, hours (mean ± SD)	6.2 ± 1.1	5.8 ± 1.4	5.1 ± 1.3	4.6 ± 1.5	0.03
Post-procedure SpO_2, % (mean ± SD)	95.1 ± 1.8	94.3 ± 2.0	93.8 ± 2.1	91.9 ± 2.6	0.01
Need for supplemental oxygen, n (%)	4 (13.3)	6 (20.0)	8 (26.7)	14 (46.7)	0.01
ICU admission, n (%)	1 (3.3)	2 (6.7)	3 (10.0)	7 (23.3)	0.02
Length of hospital stay, days (mean ± SD)	4.1 ± 1.2	4.8 ± 1.5	5.3 ± 1.7	6.9 ± 2.1	<0.001

As illustrated in Figure 1, the incidence of re-expansion pulmonary edema differed significantly according to the intervention type, with a consistently lower frequency observed in patients managed with video-assisted thoracoscopic surgery compared with those treated by chest tube placement. This difference was particularly pronounced in patients with massive pleural effusion (>1500 mL), where chest tube drainage was associated with the highest rate of REPE, whereas VATS demonstrated a markedly lower incidence (26.7% vs. 10.0%, P=0.004). Even in patients with smaller effusion volumes (<1500 mL), the occurrence of REPE remained numerically lower following VATS compared with chest tube insertion (3.3% vs. 6.7%, P=0.004). Overall, comparison between the two treatment strategies confirmed a significantly reduced risk of REPE with VATS irrespective of effusion volume (P=0.004), suggesting that controlled lung re-expansion achieved through thoracoscopic management may

mitigate the pathophysiological mechanisms underlying this complication.

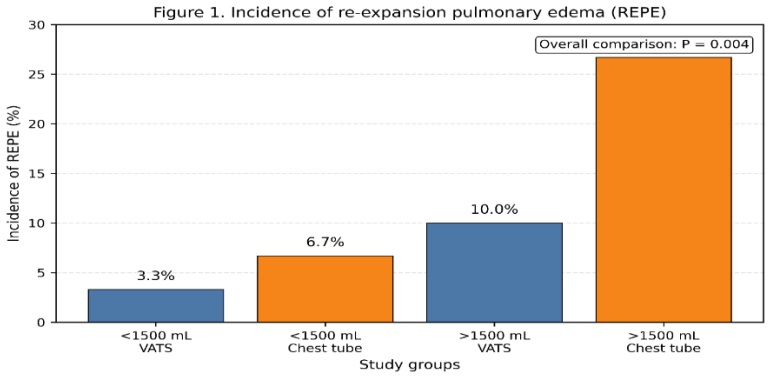

Figure 1. Incidence of Re-Expansion Pulmonary Edema According to Intervention Type and Pleural Fluid Volume

As shown in Figure 2, post-procedure outcomes differed significantly between patients managed with chest tube placement and those undergoing video-assisted thoracoscopic surgery. The incidence of re-expansion pulmonary edema was notably higher in the chest tube group compared with the VATS group, confirming a statistically significant intergroup difference (P<0.01). Similarly, procedure-related complications were more frequently observed following chest tube insertion, whereas VATS was associated with a lower overall complication rate (P<0.05). Patients treated with VATS also demonstrated a shorter length of hospital stay and reduced need for intensive care unit admission compared with those managed by chest tube drainage (P<0.05 for both). In contrast, in-hospital mortality remained low in both groups and did not differ significantly between the two interventions (P>0.05). Collectively, these findings indicate that VATS is associated with more favorable post-procedural outcomes and a lower burden of morbidity compared with chest tube placement.

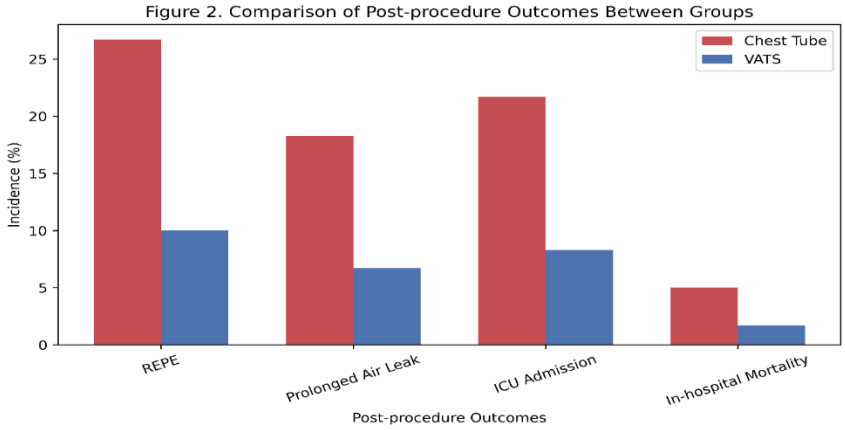

Figure 2. compare post-procedure outcomes between the Chest Tube and VATS groups

Discussion

The present study demonstrates that patients undergoing video-assisted thoracoscopic surgery experienced more favorable early clinical outcomes compared with those managed by chest tube insertion. Baseline demographic and clinical characteristics were well balanced between groups, supporting the validity of the observed outcome differences. Thoracoscopic management was associated with a lower incidence of pulmonary complications, improved postoperative oxygenation, reduced need for intensive care, and shorter hospitalization. These findings collectively suggest that the method of pleural drainage plays a critical role in determining post-procedural recovery and complication profiles in patients with pleural effusion.

Adequate baseline comparability between the two study groups strengthens the internal validity of these findings and minimizes the likelihood that confounding variables influenced postoperative outcomes. Similar distributions of age, sex, effusion laterality, etiology, and baseline oxygenation indicate that both cohorts had comparable physiological reserves and disease severity prior to intervention. This balance allows outcome

differences to be more confidently attributed to the intervention itself rather than patient-related factors. Proper baseline matching is particularly important in studies of pleural drainage, where underlying cardiopulmonary status can substantially influence complication rates and recovery trajectories (16).

One of the most notable findings of this study was the significantly lower incidence of re-expansion pulmonary edema among patients treated with video-assisted thoracoscopic surgery. REPE is widely considered a consequence of rapid lung re-inflation, abrupt changes in pulmonary capillary pressure, and inflammatory endothelial injury. Thoracoscopic techniques allow for gradual evacuation of pleural fluid under direct visualization, enabling controlled lung re-expansion and minimizing sudden mechanical stress on alveolar-capillary membranes. In contrast, chest tube drainage, particularly when applied to large effusions, may permit faster decompression and uncontrolled re-expansion, thereby increasing susceptibility to edema formation (17).

The pronounced difference in REPE incidence among patients with massive pleural effusion further supports the role of re-expansion dynamics in the pathogenesis of this complication. Larger effusion volumes result in prolonged lung collapse, leading to surfactant depletion, altered capillary permeability, and increased vulnerability to reperfusion injury upon re-inflation. Thoracoscopic evacuation allows surgeons to modulate the rate of fluid removal and directly assess lung compliance during expansion, whereas chest tube insertion lacks this level of procedural control. These mechanistic differences likely explain why thoracoscopic management confers a protective effect in patients with high-volume effusions (18).

Delayed onset of REPE following thoracoscopic intervention suggests a less abrupt physiological response to lung re-expansion. Gradual restoration of negative intrathoracic pressure may reduce shear stress on pulmonary microvasculature and attenuate inflammatory cascades associated with endothelial disruption. A slower re-expansion process may also allow time for redistribution of pulmonary blood flow and normalization of lymphatic drainage, thereby limiting interstitial fluid accumulation. This temporal difference underscores the importance of procedural technique, not merely fluid volume, in influencing pulmonary outcomes (19).

Improved postoperative oxygenation observed in the thoracoscopic group further reflects the benefits of controlled lung recruitment and reduced alveolar injury. Higher oxygen saturation levels after intervention suggest more effective gas exchange and better preservation of functional lung units. Reduced alveolar flooding and lower degrees of interstitial edema likely contribute to improved ventilation–perfusion matching in patients undergoing thoracoscopic surgery. Conversely, abrupt re-expansion and microvascular injury associated with chest tube drainage may transiently impair pulmonary diffusion capacity, leading to suboptimal oxygenation (20).

The reduced need for supplemental oxygen therapy in the thoracoscopic group is clinically meaningful and aligns with the observed improvements in pulmonary function. Supplemental oxygen requirement serves as a surrogate marker for respiratory compromise and early postoperative morbidity. Lower oxygen dependence suggests that thoracoscopic patients experienced fewer clinically significant pulmonary insults and achieved faster stabilization following intervention. This advantage may translate into earlier mobilization, reduced nursing burden, and lower risk of secondary complications such as atelectasis or infection (21).

Lower rates of intensive care unit admission among patients managed with video-assisted thoracoscopic surgery further emphasize the clinical impact of improved respiratory stability. ICU admission is often driven by concerns related to hypoxemia, hemodynamic instability, or respiratory deterioration. By mitigating pulmonary complications and promoting more predictable postoperative recovery, thoracoscopic management may reduce the need for high-level monitoring and advanced respiratory support. This finding has important implications for resource utilization and healthcare costs, particularly in high-volume centers managing complex pleural diseases (22).

Shorter hospital length of stay observed in the thoracoscopic group likely reflects the cumulative benefits of fewer complications, improved oxygenation, and reduced critical care utilization. Length of stay is a multifactorial outcome influenced by both clinical recovery and institutional protocols; however, pulmonary complications remain one of the most common drivers of prolonged hospitalization following pleural interventions. By minimizing respiratory morbidity, thoracoscopic surgery facilitates earlier discharge readiness and more efficient patient throughput without compromising safety (23).

The absence of a significant difference in in-hospital mortality between groups is not unexpected, given the relatively low overall mortality associated with pleural drainage procedures. Mortality is a crude endpoint and may not fully capture clinically relevant differences in morbidity or quality of recovery. Nevertheless, the comparable mortality rates reinforce the safety of both approaches while highlighting that thoracoscopic surgery offers meaningful advantages in reducing non-fatal but clinically significant complications that affect patient experience and healthcare utilization (24).

Collectively, these findings support the growing body of evidence favoring thoracoscopic approaches for the management of pleural effusion, particularly in patients with large fluid volumes. These

procedural benefits translate into improved pulmonary outcomes and faster recovery, reinforcing the role of thoracoscopic surgery as a preferred strategy in appropriately selected patients (25).

Conclusion

Despite its strengths, this study should be interpreted in the context of certain limitations. The results primarily reflect early postoperative outcomes and may not capture long-term respiratory or functional differences between interventions. Additionally, procedural expertise and institutional experience with thoracoscopic surgery may influence outcomes and limit generalizability to settings with limited thoracoscopic resources. Future multicenter studies with longer follow-up and standardized drainage protocols would further clarify the optimal management of pleural effusion and refine patient selection criteria.

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Conflicts of interest

The authors declare that they have no competing interests.

Disclosure Statement

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Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

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