Combined Thoracoscopic Surgery and High-Frequency Ventilation Induce Severe Traumatic Brain Injury and Chest Trauma Recovery

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Abstract

Background: Traumatic injuries, especially combined injuries involving multiple body regions, have become a significant concern in industrialized nations due to their rising frequency and severity. Among these, chest injuries, particularly closed chest injuries, present critical challenges due to their high mortality rates and frequent occurrence in combined trauma cases. Effective management of such injuries is crucial to improving patient outcomes. Methods: This study analyzed the outcomes of 107 patients with combined severe traumatic brain injury (TBI) and chest trauma treated at the Russian Research Center for Emergency Medicine between 2017 and 2022. Patients were categorized based on respiratory support methods: Group I (52 patients) received artificial pulmonary ventilation (APV) with synchronized intermittent mandatory ventilation volume-controlled (SIMV VC), while Group II (55 patients) was managed with a combination of SIMV VC and high-frequency jet ventilation (sHFJV). Diagnostic and clinical assessments included neurological examinations, radiological imaging, and invasive monitoring. Surgical interventions involved video-assisted thoracoscopy (VATS) for managing chest injuries. Results: Initial assessments revealed severe conditions across both groups. After 12 hours of respiratory support, Group II patients exhibited significant improvements in oxygenation, blood gas parameters, and reduced pulmonary shunt compared to Group I. Group II also experienced shorter durations of respiratory support and ICU stays, and a lower mortality rate (5.45% vs. 17.3% in Group I). Thoracoscopic interventions were successfully performed with reduced postoperative complications and shorter hospital stays in Group II. Conclusion: The combination of SIMV VC and sHFJV significantly improves respiratory outcomes, reduces the duration of mechanical ventilation, and shortens ICU stays compared to SIMV VC alone. Thoracoscopic procedures prove effective for managing select cases of chest trauma. Careful patient evaluation is essential to ensure hemodynamic stability before opting for thoracoscopic interventions. This study underscores the importance of advanced diagnostic tools and minimally invasive techniques in optimizing the management of severe chest trauma and improving overall patient outcomes.

Keywords: videothoracoscopy, rib fixation, chest trauma, combined trauma, high-frequency artificial ventilation.

Significance | This study demonstrated that combining video-assisted thoracoscopic surgery with high-frequency ventilation improves outcomes in patients with severe traumatic brain injury and chest trauma by enhancing respiratory function and reducing ICU stay and mortality.

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Introduction

Traumatic injuries represent a significant medical and social concern in industrialized countries, posing an increasing challenge that demands substantial economic resources. In recent years, these injuries have steadily risen in frequency and severity, becoming

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one of the leading causes of mortality among people of working age (20-40 years). Among the various types of traumatic injuries, mechanical injuries are particularly prevalent and account for a significant portion of the overall mortality. However, it is the combined injuries—those involving multiple trauma to different body regions—that present the most formidable challenge, contributing to over 60% of trauma-related deaths (Bagnenko & Tulupov, 2009; Naimov et al., 2023; Styazhkina et al., 2021; Tseymakh et al., 2017).

Combined injuries are often a consequence of man-made and natural disasters, such as industrial and transport accidents, or military conflicts, where the incidence of multiple injuries can range from 50% to 60% (Agadzhanyan, 2015; Zelyanin et al., 2020; Vladimirova et al., 2022; Trishkin et al., 2022; Zaitsev et al., 2023). Given this high incidence, the problem of polytrauma is receiving increased attention globally. Mortality rates for patients suffering from multiple and combined injuries can reach up to 40%, with disability rates ranging from 25% to 45% (Sabirov et al., 2019; Zaitsev et al., 2023; Savushkina et al., 2022). Among the various forms of trauma, chest injuries are particularly concerning due to their severity and high mortality rate (Clinical recommendations, 2021). Closed chest injuries, in particular, are recognized as some of the most life-threatening and critical conditions in trauma care (Styazhkina et al., 2021; Savushkina et al., 2022). Despite advancements in medical care, the frequency of closed chest injuries remains persistently high.

Data from peacetime studies reveal that chest injuries are a common component of combined injuries, with the frequency of cases involving chest trauma varying from 20% to 83% (Bagnenko & Tulupov, 2009; Tseymakh et al., 2017). These injuries often present as multiple rib fractures, occurring in 82% of cases, and are frequently accompanied by closed craniocerebral injuries (50-60%), closed injuries of other skeletal bones (57%), and fractures of the limbs (up to 30%). The persistence of these injuries is notable; in peacetime, they account for 35-50% of all trauma cases (Bagnenko & Tulupov, 2009). During wartime, chest injuries occur in 10-11% of the wounded, with 5-8% resulting in fatalities (Clinical recommendations, 2021; Trishkin et al., 2022). Moreover, the incidence of combined chest and craniocerebral injuries can range from 17% to 50% (Tseymakh et al., 2017).

The challenges associated with the diagnosis and treatment of chest injuries make it one of the most critical issues in emergency medicine today. According to scientific literature, chest injuries rank third after limb injuries and traumatic brain injuries (TBI) and account for 10% to 30% of all hospitalizations for trauma (Agadzhanyan, 2015; Clinical recommendations, 2021). Furthermore, 25% of patients with severe chest injuries require immediate surgical intervention. Approximately 90% of victims with combined injuries are of working age (Sabirov et al., 2018), and when combined with chest trauma, these cases often involve prolonged treatment, extended rehabilitation periods, a high rate of purulent-septic complications (up to 20%), and an elevated mortality rate (17% to 35%) (Avdeev et al., 2022; Bulava, 2023; Chuchalin et al., 2023; Makhutov et al., 2017; Tarabrin et al., 2023). The outcomes of intensive care for patients with chest trauma are significantly influenced by factors beyond the severity of the injury itself. Key determinants include the surgeon's ability to promptly diagnose the injury's nature, identify complications early, and implement an optimal clinical approach. However, when relying solely on clinical, laboratory, and radiological studies, diagnostic errors can range from 16% to 56% (Savushkina et al., 2022; Savushkina et al., 2022). These diagnostic challenges often lead to prolonged patient observation and conservative treatment at times when active surgical intervention is required. This delay in appropriate intervention can result in unnecessary thoracotomies, which occur in 10% to 58% of cases (Makhutov et al., 2017; Pankratov et al., 2015; Tarabrin et al., 2023).

Effective patient management in the intensive care unit, particularly the strategies for respiratory support, is crucial for this group of patients. Choosing the correct ventilation parameters and mode is vital, and high-frequency ventilation is emerging as a promising alternative for various critical conditions (Akalaev et al., 2013; Rostalnaya et al., 2023).

Given these challenges, the use of video-assisted mini-thoracotomy interventions (VATS - video-assisted thoracic surgery) for chest injuries is becoming increasingly promising. VATS offers several advantages, including a minimal incision length, a shorter operation duration, reduced postoperative pain, less limitation of arm movement on the operated side, and better preservation of lung respiratory mechanics during the postoperative period (Makhutov et al., 2017; Pankratov et al., 2015; Tarabrin et al., 2023; Trishkin et al., 2022). These benefits are especially important for patients with concurrent traumatic brain injuries, as they reduce the risks associated with extended surgical recovery and improve overall patient outcomes.

The aim of this study is to improve the outcomes of surgical treatment for patients with chest trauma by expanding the diagnostic and therapeutic capabilities of video thoracoscopy and optimizing methods of respiratory support during the postoperative period.

By leveraging advanced diagnostic tools and minimally invasive surgical techniques, such as VATS, along with enhanced respiratory management strategies, this study seeks to address the persistent challenges associated with chest trauma. The ultimate goal is to reduce mortality and morbidity rates, minimize complications, and promote faster recovery for patients suffering from these severe and life-threatening injuries.

Material and Methods

Analysis of Surgical and Resuscitation Treatment for Combined Severe Traumatic Brain Injury and Chest Trauma

This study analyzed the outcomes of 107 patients with combined severe traumatic brain injury (TBI) and chest trauma treated at the Russian Research Center for Emergency Medicine between 2017 and 2022. The patient cohort included individuals aged 18 to 65 years, with 80.77% men (n=86) and 19.63% women (n=21). The severity of each patient's condition upon admission was assessed using the APACHE II scale, with an average score of 21 ± 0.9, indicating a high severity of illness. The average number of broken ribs per patient was 7 ± 0.6, and 27% of patients presented with bilateral rib injuries. The Murray Lung Injury score was >2.5 at admission, reflecting severe lung injury. This study was conducted with the approval of the Institutional Review Board (IRB) at the Russian Research Center for Emergency Medicine. All procedures were performed in accordance with ethical standards outlined in the Declaration of Helsinki. The study was reviewed and approved by the ethics committee to ensure compliance with ethical guidelines and the protection of patient rights.

Diagnostic and Clinical Assessments

To establish the diagnosis and assess the extent of brain and chest injuries, a combination of clinical neurological examinations, radiological assessments, computed tomography (CT) scans, and intracranial pressure (ICP) monitoring were employed. The degree of oxygenation was evaluated by determining the acid-base status and calculating the PaO_2/FiO_2 ratio. The diagnostic evaluations identified hemopneumothorax in 51 patients, pneumothorax in 36 patients, hemothorax in 24 patients, subcutaneous emphysema in 12 patients, clinical signs of profuse intrapleural bleeding in 7 patients, and a combination of hemothorax with subcutaneous emphysema in 8 patients.

Based on the clinical and radiological findings, indications for emergency thoracoscopy were identified, including hemopneumothorax (48 cases), pneumothorax (31 cases), hemothorax (22 cases), and hemothorax with subcutaneous emphysema (6 cases).

Surgical Intervention: Thoracoscopy Procedure

Thoracoscopy was performed on 107 patients following initial clinical and radiological examinations. Of these, 18 patients underwent the procedure under local anesthesia, while 89 patients received general endotracheal anesthesia. Neurosurgical interventions were not carried out, and conservative therapy was administered according to standard medical protocols.

The operations were conducted using a video endoscopic complex (Karl Storz, Germany). Patients were positioned on their healthy side with their arm abducted upward, and a transverse bolster was placed under the chest at the level of the IV-V intercostal space to facilitate access. The insertion of thoracoports followed a specific technique: a 5-mm thoracoport was placed outside the fracture zone, typically in the V-VI intercostal spaces along the mid-axillary line under video camera guidance. Depending on the identified pathology and the anticipated extent of the surgical intervention, an additional 2-3 ports for endoscopic instruments were introduced under monitor control to enable effective visualization and management during the procedure.

During the operation, the chest organs were inspected in a specific sequence: pericardium, lung root, mediastinum, diaphragm, lung, and chest wall. This process allowed for a prompt decision to abandon endoscopic attempts if necessary. After the revision of the pleural cavity, necessary procedures to manage intrapulmonary and intrapleural complications were performed, such as hemostasis, suturing of lung and diaphragm wounds, and pleural cavity sanitation.

Rib Fixation Technique

The procedure for rib fixation involved determining the most mobile floating segments and rib fragments protruding into the pleural cavity. A 2 mm skin incision was made 1-2 cm from the fracture line at the center of a stable rib segment. A needle without a thread was inserted through the incision, passed perpendicularly through the intercostal soft tissue, turned upward under the rib, and controlled by water-thoracoscopy. At the upper edge, the needle end emerged through the skin, where a similar 2 mm incision was made. A nylon thread (No. 5) was passed through the needle hole and extracted back under the rib to the lower edge. The ligatures were fixed to a metal plate (patent FAP 01003 Device for fixing ribs) at the site of the cut for the ligature. Rib fragment fixation and repositioning were achieved by pressing the fragments against a rubber sponge attached to the inner surface of the metal plate.

Outcomes of Thoracoscopy

Thoracoscopy proved to be highly informative in identifying lung wounds, thoracoabdominal wounds, and sources of ongoing intrapleural bleeding or coagulated hemothorax. Performing thoracoscopy within the first hours post-injury allowed for timely surgical intervention, lung expansion, and pleural cavity sanitation.

Additional Surgical Procedures

Urgent thoracotomies without preliminary thoracoscopy were performed in 8 patients due to deep lung wounds and bleeding (4 cases), heart wounds (3 cases), and post-traumatic diaphragmatic hernia (1 case). For spontaneous pneumothorax, all patients underwent thoracoscopy, and 6 patients received video-assisted excision and suturing of bullous lung tissue, followed by electro- or chemical coagulation of the parietal pleura.

In cases with rib fractures or penetrating wounds accompanied by subcutaneous emphysema, where no radiological signs of pneumothorax or hemothorax were observed, active interventions were avoided. Instead, dynamic radiological monitoring was performed for 13 patients. For 9 patients with complicated chest

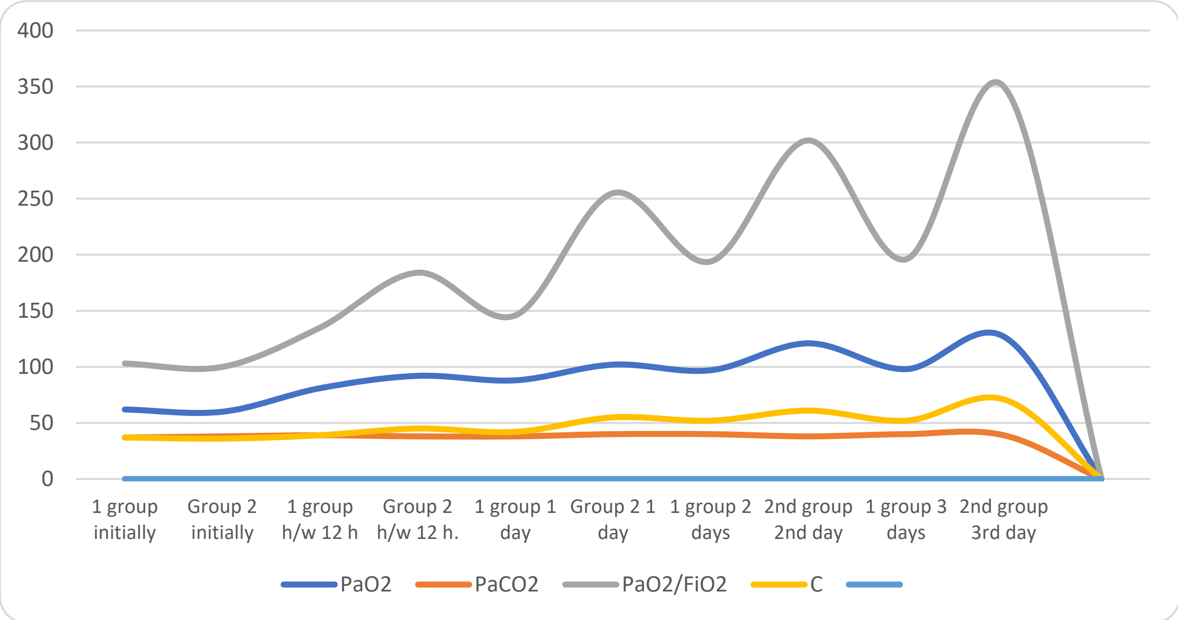

Figure 1. Dynamics of blood gas parameters during respiratory support. For Group I patients on SIMV VC mode, the observed parameter values were as follows: PaO2/FiO2 (135±1.4 mmHg), SaO2 (92±1.2%), Qs/Qt (20.1±1.7%), heart rate (76±1.4 beats per minute), stroke index (SI, 3.2±0.7 l/min/m²), lung compliance (C, 39±1.2 ml/cm H2O), PaO2 (81.2±1.1 mmHg), and PaCO2 (39±1.7 mmHg). Meanwhile, patients in Group II who received combined SIMV VC and sHFJV demonstrated superior outcomes: PaO2/FiO2 (184.1±1.8 mmHg), SaO2 (96±1.2%), Qs/Qt (16±1.4%), heart rate (78±1.8 beats per minute), SI (3.6±1.3 l/min/m²), C (45±1.1 ml/cm H2O), PaO2 (92.2±1.3 mmHg), and PaCO2 (38.4±1.4 mmHg).

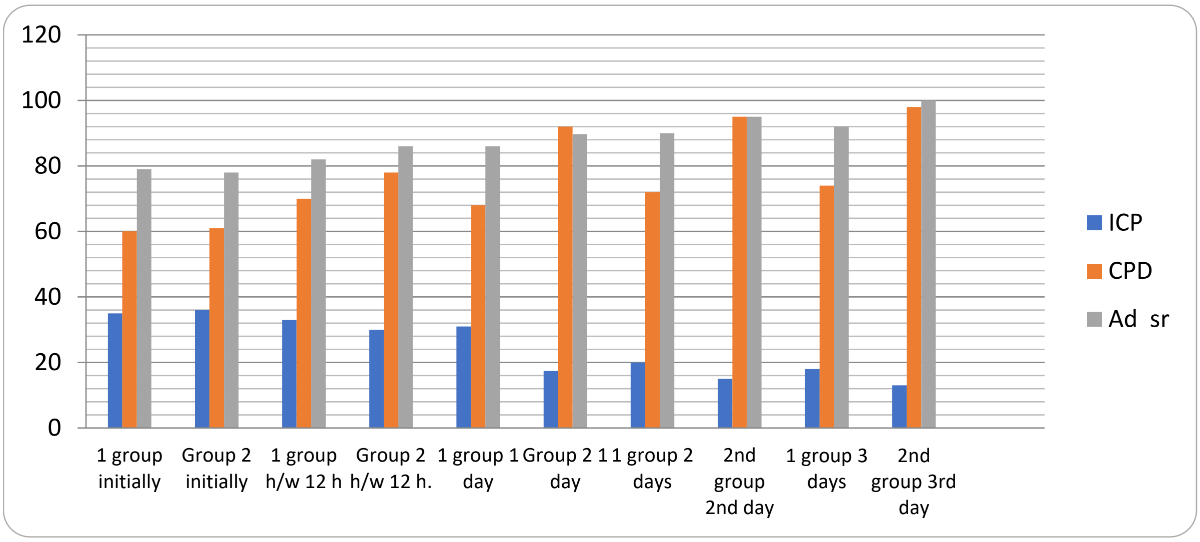

Figure 2. Dynamics of central hemodynamic parameters during respiratory support. The average duration of coma following surgery in all patients was 2.4±1.9 days. By day 4.1±1.1 of ICU stay, 21 patients in Group II were extubated, compared to only 5 patients in Group I. The duration of respiratory support was notably shorter in Group II (5.1±1.4 days) compared to Group I (7.8±1.2 days), a statistically significant difference (p<0.01).

injuries, pleural cavity punctures or drainage was conducted, considering the delayed presentation of these patients.

Postoperative Care and Respiratory Support

Following surgery, all patients were transferred to the neurosurgical intensive care unit (ICU). Upon admission, the patients' condition was assessed using the Glasgow Coma Scale (GCS), with an average score of 25 ± 3.1 points. The main inclusion criteria for the study required patients to have sustained combined trauma with specific conditions, such as disruption of the chest frame and lungs, complications including hemo- or pneumothorax, fractures of more than four ribs, respiratory failure of grade II-III, and a respiratory index below 200 mm Hg.

All patients received intensive and respiratory therapy as part of their treatment regimen. The therapeutic approach included antibacterial therapy with ceftriaxone sodium (1 g twice daily) and levofloxacin (500 mg twice daily), anticonvulsant treatment with carbamazepine (0.1 g three times daily), and the administration of hemostatic agents like sodium etamsylate as needed. Additionally, a cerebroselective calcium antagonist, nimodipine (30 mg twice daily), was prescribed to manage cerebral conditions. Analgosedation was provided using fentanyl, morphine, or promedol as required, alongside other symptomatic therapies to address individual patient needs.

Division of Patients Based on Respiratory Support

Patients were divided into two groups based on the method of respiratory support they received. Group I consisted of 52 patients who were administered artificial pulmonary ventilation (APV) using the synchronized intermittent mandatory ventilation volume-controlled (SIMV VC) mode. Group II included 55 patients who were managed with a combination of mechanical ventilation modes, specifically SIMV VC and high-frequency jet ventilation (sHFJV).

Data for both groups were systematically recorded during the period of mechanical ventilation at specific intervals: 10-15 minutes after admission to the intensive care unit (ICU), and subsequently at 12 hours, and on the 1st, 2nd, and 3rd days following the injury.

Statistical Analysis

Data were processed using Microsoft Excel and analyzed using standard methods of variation statistics in the biomedical field. The STATISTICA 10 software (StatSoft, Inc., 2011) was employed for statistical analysis. The significance level was calculated using the Pearson chi-square test.

This comprehensive approach enabled an in-depth analysis of the efficacy of various surgical and resuscitation treatments for patients with severe TBI and chest trauma, providing critical insights into optimal management strategies.

Results and Discussion

The analysis of patient data before and after the initiation of respiratory support reveals that the severity of the patients' condition remained consistently severe in both groups during the initial six hours of observation in the intensive care unit (ICU), with no significant differences observed between the groups. However, after 12 hours of respiratory support, notable improvements in various physiological parameters were observed, particularly in Group II patients who received a combination of synchronized intermittent mandatory ventilation with volume control (SIMV VC) and superimposed high-frequency jet ventilation (sHFJV).

For Group I patients on SIMV VC mode, the observed parameter values were as follows: PaO_2/FiO_2 (135±1.4 mmHg), SaO_2 (92±1.2%), Qs/Qt (20.1±1.7%), heart rate (76±1.4 beats per minute), stroke index (SI, 3.2±0.7 l/min/m²), lung compliance (C, 39±1.2 ml/cm H_2O), PaO_2 (81.2±1.1 mmHg), and $PaCO_2$ (39±1.7 mmHg). Meanwhile, patients in Group II who received combined SIMV VC and sHFJV demonstrated superior outcomes: PaO_2/FiO_2 (184.1±1.8 mmHg), SaO_2 (96±1.2%), Qs/Qt (16±1.4%), heart rate (78±1.8 beats per minute), SI (3.6±1.3 l/min/m²), C (45±1.1 ml/cm H_2O), PaO_2 (92.2±1.3 mmHg), and $PaCO_2$ (38.4±1.4 mmHg) (Figure 1). These findings indicate a statistically significant improvement in oxygenation, blood gas parameters, and a reduction in pulmonary shunt among patients in Group II (Avdeev et al., 2022; Agadzhanyan, 2015).

Further daily monitoring from the first to the third day showed continued significant improvements in respiratory therapy outcomes for Group II (Akalaev et al., 2013). The average duration of coma following surgery in all patients was 2.4±1.9 days. By day 4.1±1.1 of ICU stay, 21 patients in Group II were extubated, compared to only 5 patients in Group I. The duration of respiratory support was notably shorter in Group II (5.1±1.4 days) compared to Group I (7.8±1.2 days), a statistically significant difference ($p<0.01$) (Figure 2). Additionally, the length of ICU stay was shorter in Group II (10.4±1.6 days) than in Group I (13.8±1.6 days), again with statistical significance ($p<0.01$) (Bagnenko & Tulupov, 2009; Zaitsev et al., 2023).

Patient mortality was observed to be 10.3% (11 patients) overall, but differed significantly between the groups. Group I experienced a higher mortality rate of 17.3% (9 patients), compared to 5.45% (3 patients) in Group II. The predominant cause of mortality in both groups was nosocomial pneumonia and secondary infections, underscoring the importance of infection control measures in critical care settings (Bulava, 2023; Vladimirova et al., 2022).

For patients who underwent thoracoscopic interventions, all were discharged without postoperative complications, indicating the effectiveness of minimally invasive procedures for select cases. The average hospital stay for thoracoscopic patients in Group I was 6.8±1.2 days, while it was significantly reduced to 4.5±1.4 days in Group II (Zelyanin et al., 2020).

Our findings suggest that combining SIMV VC with sHFJV may offer significant advantages over SIMV VC alone in managing severe respiratory distress, particularly in cases of combined trauma with chest involvement. These results are consistent with previous research indicating the efficacy of high-frequency ventilation methods in enhancing oxygenation and reducing shunt fractions (Rostalnaya & Makhsudov, 2023; Sabirov et al., 2018).

Based on our clinical experience, we have identified specific indications for emergency thoracoscopy in cases of chest trauma, such as tension pneumothorax, hemothorax, hemopneumothorax, and injuries to the "heart zone" or diaphragm. Conversely, we recommend against thoracoscopic operations for patients with unstable hemodynamics due to the potential for undetectable injuries to the heart or major vessels that may necessitate a transition to thoracotomy (Pankratov et al., 2015; Savushkina et al., 2022).

Conclusion

In conclusion, the combination of SIMV VC with sHFJV appears to improve patient outcomes by reducing the duration of respiratory support and ICU stay, as well as lowering mortality rates. However, it is important to carefully evaluate the patient's hemodynamic status and ensure stability before opting for thoracoscopic procedures, as traditional thoracotomy remains essential in certain critical scenarios (Styazhkina et al., 2021; Trishkin et al., 2022).

Author contributions

A.R. led the study's conceptualization and design. D.S. contributed to data collection and analysis. R.R. provided critical revisions and interpretations of the results. A.T. supervised the project and ensured the accuracy of the final manuscript. All authors discussed the results and approved the final version of the manuscript.

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Competing financial interests

The authors have no conflict of interest.

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