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Original Article

Risk factors and predictive model for secondary hypoxemia following transthoracic drainage in traumatic pneumothorax

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Abstract: Objective: To analyze the risk factors for secondary hypoxemia in emergency traumatic pneumothorax (TP) patients following transthoracic drainage to provide a scientific basis for clinical prevention and treatment. Methods: This single-center retrospective study included 130 TP patients who underwent chest drainage between January 2021 and May 2024 at West China Hospital, Sichuan University. Patient demographics and clinical data were collected via the electronic medical record system. Univariate and multivariate logistic regression analyses were performed to identify independent risk factors for secondary hypoxemia. A predictive model was developed based on multifactorial logistic regression analysis and presented as a Nomogram to assess its discrimination, calibration and clinical utility. Results: Advanced age, high body mass index (BMI), history of smoking, use of conventional drains, and prolonged lung reopening time were identified as independent risk factors for secondary hypoxemia. The constructed Nomogram model demonstrated strong discrimination (AUC=0.92) and calibration (Hosmer-Lemeshow test, P=0.515). Decision curve analysis (DCA) confirmed its clinical application. Conclusion: This study identifies key risk factors for secondary hypoxemia in TP patients after transthoracic drainage and presents a validated predictive model to support clinical decision-making. These findings may help clinicians recognize high-risk patients, implement preventive measures, and reduce hypoxemia incidence, ultimately improving patient outcomes.

Keywords: Traumatic pneumothorax, transthoracic drainage, hypoxemia, risk factors, predictive model

Introduction

Pneumothorax is a common thoracic emergency characterized by the entry of gas into the chest cavity, leading to altered intrathoracic pressure and impaired lung expansion and function [1]. Traumatic pneumothorax (TP), a subtype of pneumothorax, is typically caused by trauma, such as traffic accidents, falling injuries, or penetrating injuries. Its incidence and severity are closely related to the intensity and depth of the trauma [2]. In the field of emergency medicine, TP is a frequent and life-threatening chest injury requiring urgent intervention [3]. Without timely and effective treatment, TP can lead to severe complications, including tension pneumothorax and hypoxemia [4]. In clinical practice, thoracic drainage is the preferred method for TP, as it effectively restores respiratory function by evacuating intrapleural air, reestablishing negative intrathoracic pressure, and promoting lung re-expansion [5]. However, despite its effectiveness, post-procedural complications remain a concern, with hypoxemia being among the most common [3, 5].

Hypoxemia is defined as a partial pressure of arterial oxygen (PaO_2) below the normal range (typically <60 mmHg at standard atmospheric pressure) or a significant decrease in blood oxygen saturation (SaO_2) [6]. It can delay postoperative recovery, aggravate the underlying condition, increase treatment complexity and cost, and, in severe cases, be life-threatening. In emergency TP patients, hypoxemia secondary to thoracic drainage may result from multiple factors, including but not limited to inadequate lung re-expansion, pulmonary infection,

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intrathoracic hemorrhage, pain-induced respiratory restriction, and systemic inflammation [5]. These factors not only impair respiratory function but may also exacerbate hypoxemia by affecting circulatory and metabolic systems [7].

In recent years, advancements in medical technology and improvements in emergency care systems have significantly enhanced the understanding and management of TP and its complications [8]. However, systematic and in-depth research on the risk factors for secondary hypoxemia following thoracic drainage in emergency TP patients remains limited. Therefore, this study aims to retrospectively analyze the risk factors for secondary hypoxemia after thoracic drainage in patients with emergency TP, providing a scientific basis for clinical prevention and treatment. The significance of this study is that by identifying high-risk groups and risk factors, clinicians can make more comprehensive preoperative assessments and preparations to minimize the risk of hypoxemia. In addition, elucidating the mechanisms and risk factors of hypoxemia may facilitate the development of novel therapeutic approaches and intervention measures to optimize the treatment of emergency TP and improve overall treatment outcomes.

Participants and methods

Patient population

This single-center retrospective study included patients with TP admitted to West China Hospital, Sichuan University between January 2021 and May 2024. A total of 130 patients were enrolled, with diagnosis based on clinical manifestations, physical examination, and chest imaging (X-ray or computed tomography [CT]), meeting the diagnostic criteria for pneumothorax.

Inclusion criteria: (a) age ≥18 years; (b) patients diagnosed with TP and treated with thoracic drainage; (c) absence of severe complications or life-threatening conditions at baseline; (d) availability of complete clinical data and follow-up records, including preoperative, intraoperative and postoperative examination results and treatment records. Exclusion criteria: (a) patients with non-traumatic pneumothorax; (b) patients with pre-existing hypoxemia before thoracic drainage; (c) patients who died or were transferred within 72 hours after thoracic drainage; (d) patients with other severe complications (e.g., respiratory failure and shock) that could confound study outcomes. This study was approved by the Ethics Committee of West China Hospital, Sichuan University.

Definitions and diagnostic criteria

The diagnosis of hypoxemia is based on a comprehensive assessment of the patient's clinical manifestations, auxiliary examination findings, and individual factors such as age, gender, and underlying diseases. For patients suspected of hypoxemia, timely arterial blood gas (ABG) analysis and blood oxygen saturation monitoring should be performed to confirm the diagnosis. Arterial blood gas analysis was used as the primary diagnostic criterion in this study. In healthy adults, PaO_2 ranges from 83 to 108 mmHg, with hypoxemia defined as PaO_2 <80 mmHg. Additionally, oxygen saturation monitoring and chest imaging were used as auxiliary diagnostic tools. SaO_2 in healthy individuals is typically above 95%, a value below 90% is generally indicative of hypoxemia. Imaging modalities, such as X-ray and CT, provide visual assessment of lung conditions, including lung re-expansion, pleural effusion, and lung inflammation, aiding in the evaluation of etiology and severity of hypoxemia. Finally, patients were divided into a hypoxemia group and a normal group based on whether they developed hypoxemia after treatment.

Data collection

Patient data were retrieved from the electronic medical record system, including general and clinical information. General information included age, sex, BMI, smoking and drinking history, and underlying medical conditions. Clinical data included the cause of TP (e.g., traffic accidents, falls from height), the severity of TP (mild-moderate or severe), presence of tracheal deviation, type of drainage tube (conventional catheter, central venous catheter), drainage method (conventional closed-chest drainage or minimally invasive closed-chest drainage), puncture time, pulmonary re-expansion time, extubation time, and hospital stay. In this study, smoking was defined as ≥1 cigarette per day for more than 6 months, and alcohol consumption was defined as drinking alcohol at least

Table 1. Comparison of patient demographics between the two groups

Variables	Total (n=130)	Normal group (n=102)	Hypoxemia group (n=28)	t/χ^2	*P*
Age, Mean ± SD	41.37±5.02	40.15±4.36	45.82±4.81	t=-5.97	<0.001
Gender, n (%)				χ^2=0.00	0.979
Female	56 (43.08)	44 (43.14)	12 (42.86)		
Male	74 (56.92)	58 (56.86)	16 (57.14)		
BMI, Mean ± SD	25.12±3.38	24.27±2.93	28.20±3.17	t=-6.18	<0.001
Smoking, n (%)				χ^2=4.32	0.038
No	69 (53.08)	59 (57.84)	10 (35.71)		
Yes	61 (46.92)	43 (42.16)	18 (64.29)		
Drinking, n (%)				χ^2=0.54	0.464
No	59 (45.38)	48 (47.06)	11 (39.29)		
Yes	71 (54.62)	54 (52.94)	17 (60.71)		
Underlying disease, n (%)				χ^2=1.47	0.226
No	91 (70.00)	74 (72.55)	17 (60.71)		
Yes	39 (30.00)	28 (27.45)	11 (39.29)		

Abbreviations: SD, standard deviation; BMI, body mass index.

once a week (≥50 ml of alcohol) for more than 6 months.

Statistical analysis

Kolmogorov-Smirnov test was used to evaluate the normality of all continuous variables, and the F-test was applied to evaluate the homogeneity of variance. All continuous variables included in this study met the criteria for normality and homogeneity of variance. Continuous variables were expressed as mean ± standard deviation (SD), and between-group differences were analyzed using the t-test. Categorical variables were presented as frequency and percentage, with group comparisons performed using the Chi-square test. Univariate logistic regression analysis was conducted to identify potential risk factors, and variables with P<0.05 were included in the multivariate logistic regression mode to determine independent risk factors. A nomogram model was constructed based on the results of the multivariate analysis. Receiver Operating Characteristic (ROC) curve and Area Under Curve (AUC) were used to assess the discriminatory ability of the model. The calibration curve and Hosmer-Lemeshow goodness-of-fit test were employed to evaluate the calibration degree of the model. In addition, Decision Curve Analysis (DCA) was used to evaluate the clinical application value of the prediction model. SPSS 26.0 was used for all statistical analyses in this study. All statistical tests in this study were conducted bilaterally, and P<0.05 was considered statistically significant.

Results

Demographics of included patients

A total of 130 patients with emergency TP were included in this study. Following drainage treatment, 28 cases (21.54%) developed short-term hypoxemia. The age, BMI and smoking rate in hypoxemia group were significantly higher than those in normal group (all P<0.05) (**Table 1**). No significant differences were observed between the two groups regarding other baseline characteristics.

Clinical characteristics of included patients

The utilization rate of central venous catheters was significantly lower in the hypoxemia group compared to the normal group (P=0.011) (**Table 2**). Additionally, the hypoxemia group demonstrated a significantly prolonged lung re-expansion time (P=0.002). There were no significant differences in other clinical features between the two groups.

Univariate analysis of factors associated with secondary hypoxemia in TP patients

Univariate Logistic regression analysis showed that age (OR=1.14, P=0.008), BMI (OR=1.51, P<0.001), smoking history (OR=2.04, P=0.041), drainage tube type (OR=3.03, P=0.013), and pulmonary re-expansion time (OR=7.95, P=0.024) were associated with secondary hypoxemia in TP patients (**Table 3**).

Table 2. Comparison of patient clinical data between the two groups

Variables	Total (n=130)	Normal group (n=102)	Hypoxemia group (n=28)	t/χ^2	*P*
Causes of TP, n (%)				χ^2=0.42	0.810
Traffic accident	64 (49.23)	51 (50.00)	13 (46.43)		
Fall	40 (30.77)	30 (29.41)	10 (35.71)		
Other	26 (20.00)	21 (20.59)	5 (17.86)		
Degree of TP, n (%)				χ^2=2.13	0.145
Mild to moderate	76 (58.46)	63 (61.76)	13 (46.43)		
Severe	54 (41.54)	39 (38.24)	15 (53.57)		
Tracheal migration, n (%)				χ^2=3.63	0.057
No	93 (71.54)	77 (75.49)	16 (57.14)		
Yes	37 (28.46)	25 (24.51)	12 (42.86)		
Drainage tube type, n (%)				χ^2=6.55	0.011
Central venous catheter	74 (56.92)	64 (62.75)	10 (35.71)		
Conventional catheter	56 (43.08)	38 (37.25)	18 (64.29)		
Drainage type, n (%)				χ^2=2.43	0.119
Minimally invasive	68 (52.31)	57 (55.88)	11 (39.29)		
Tradition	62 (47.69)	45 (44.12)	17 (60.71)		
Puncture time, Mean ± SD	8.14±2.01	8.12±1.93	8.21±2.31	t=-0.20	0.844
Lung re-expansion time, Mean ± SD	3.61±0.38	3.56±0.37	3.81±0.38	t=-3.21	0.002
Extubation time, Mean ± SD	6.90±1.04	6.88±1.01	6.97±1.15	t=-0.39	0.700
Hospital stays, Mean ± SD	10.11±1.96	10.17±2.03	9.90±1.72	t=0.63	0.527

Abbreviations: TP, traumatic pneumothorax; SD, standard deviation.

Univariate analysis of factors associated with secondary hypoxemia in TP patients

Multivariate Logistic regression analysis showed that old age (OR=1.34, P<0.001), high BMI (OR=1.58, P<0.001), smoking history (OR=6.99, P=0.011), traditional drainage tube (OR=4.29, P=0.025), and prolonged lung re-expansion time (OR=2.67, P=0.033) were independent risk factors for secondary hypoxemia in TP patients (**Table 4**).

Establishment of nomogram model

A prediction model was developed based on the results of multivariate Logistic regression analysis. The prediction model was presented in the form of a nomogram, incorporating five variables: age, BMI, smoking history, drainage tube type, and lung re-expansion time (**Figure 1**).

Evaluation of the predictive performance of the nomogram model

The model demonstrated strong discriminatory ability, with an AUC of 0.92 (0.87-0.97), indicating excellent predictive performance (**Figure 2A**). Calibration curve and Hosmer-Lemeshow test (P=0.515) confirmed that the predicted and observed values closely aligned, demonstrating a good model fit (**Figure 2B**). Using the Youden index to determine the optimal cut-off value, the model achieved an accuracy of 0.88 (95% CI: 0.82-0.93), a sensitivity of 0.90 (95% CI: 0.84-0.96), and a specificity of 0.82 (95% CI: 0.68-0.96), respectively.

Clinical utility of the nomogram model

A DCA was performed to evaluate the clinical applicability of the model. The DCA curve, with threshold probability on the x-axis and net benefit on the y-axis, demonstrated that when the threshold probability ranged from 5% to 95%, implementing interventions based on the nomogram would yield a positive net benefit (**Figure 2C**). This finding confirms the model's clinical utility in guiding decision-making.

Discussion

In this study, we analyzed the risk factors for secondary hypoxemia following thoracic drainage in patients with emergency TP. Through a retrospective study of clinical data from 130

Table 3. Univariate Logistic regression analysis

Variables	β	S.E	Z	*P*	OR (95% CI)
Age	0.13	0.05	2.65	0.008	1.14 (1.03-1.26)
Gender					
Female					1.00 (Reference)
Male	0.01	0.43	0.03	0.979	1.01 (0.43-2.35)
BMI	0.41	0.09	4.66	<0.001	1.51 (1.27-1.80)
Smoking					
No					1.00 (Reference)
Yes	0.90	0.44	2.04	0.041	2.47 (1.04-5.88)
Drinking					
No					1.00 (Reference)
Yes	0.32	0.43	0.73	0.465	1.37 (0.59-3.22)
Underlying disease					
No					1.00 (Reference)
Yes	0.54	0.45	1.20	0.229	1.71 (0.71-4.10)
Causes of TP					
Traffic accident					1.00 (Reference)
Fall	0.27	0.48	0.56	0.576	1.31 (0.51-3.35)
Other	-0.07	0.59	-0.12	0.907	0.93 (0.30-2.95)
Degree of TP					
Mild to moderate					1.00 (Reference)
Severe	0.62	0.43	1.45	0.148	1.86 (0.80-4.33)
Tracheal migration					
No					1.00 (Reference)
Yes	0.84	0.45	1.88	0.060	2.31 (0.96-5.54)
Drainage tube type					
Central venous catheter					1.00 (Reference)
Conventional catheter	1.11	0.44	2.50	0.013	3.03 (1.27-7.24)
Drainage type					
Minimally invasive					1.00 (Reference)
Tradition	0.67	0.44	1.54	0.123	1.96 (0.83-4.59)
Puncture time	0.02	0.11	0.20	0.843	1.02 (0.83-1.26)
Lung re-expansion time	2.07	0.92	2.26	0.024	7.95 (1.32-47.96)
Extubation time	0.08	0.21	0.39	0.698	1.08 (0.72-1.63)
Hospital stays	-0.07	0.11	-0.64	0.524	0.93 (0.75-1.16)

Abbreviations: SE, standard error; OR, odds ratio; CI, confidence interval; BMI, body mass index; TP, traumatic pneumothorax.

patients, we identified advanced age, high BMI, smoking history, use of conventional drains, and prolonged pulmonary reopening time as independent risk factors for secondary hypoxemia. These findings hold significant clinical implications for preoperative assessment, intraoperative management, and postoperative care.

Age was identified as an independent risk factor significantly associated with hypoxemia in this study. In elderly patients, the progressive decline in physiological function leads to reduced lung compliance and weakened alveolar elasticity, making lung re-expansion more challenging [9]. Gao et al. found in a retrospective study that age affects the incidence of hypoxemia after primary joint replacement [10]. However, no studies have specifically examined the effect of age on the risk of secondary hypoxemia in TP patients. Advanced age is often accompanied by diminished cardiopulmonary function, degenerative respiratory changes, and preexisting pulmonary disease, all of which

Table 4. Multivariate Logistic regression analysis

Variables	β	S.E	Z	*P*	OR (95% CI)
Age	0.29	0.08	3.52	<0.001	1.34 (1.14-1.57)
BMI	0.46	0.13	3.56	<0.001	1.58 (1.23-2.03)
Smoking					
No					1.00 (Reference)
Yes	1.95	0.76	2.55	0.011	6.99 (1.57-31.26)
Drainage tube type					
Central venous catheter					1.00 (Reference)
Conventional catheter	1.46	0.65	2.24	0.025	4.29 (1.20-15.32)
Lung re-expansion time	0.98	0.84	2.13	0.033	2.67 (1.14-13.81)

Abbreviations: SE, standard error; OR, odds ratio; CI, confidence interval; BMI, body mass index.

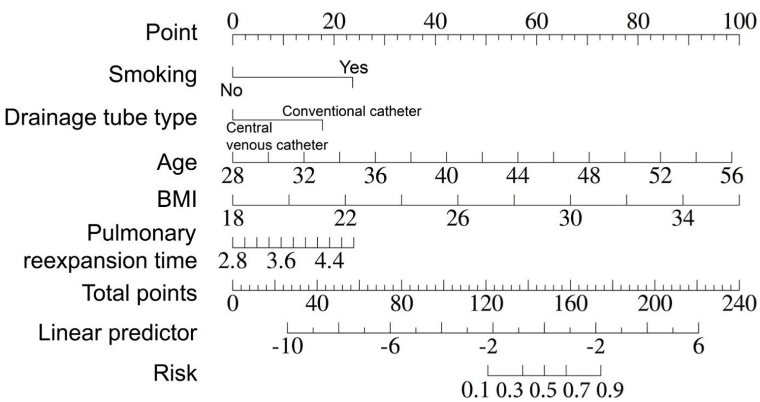

Figure 1. Nomogram prediction model. BMI, body mass index.

are key contributors to postoperative pulmonary complications [11, 12]. Interestingly, older patients may already have a degree of preoperative oxygenation deficit, potentially making them less susceptible to a relative drop in oxygenation after thoracic drainage, as their baseline oxygenation levels are already compromised. This study also found a strong association between BMI and hypoxemia. In a retrospective cohort study involving 15,238 patients, Kendale et al. found that obesity significantly increased the probability of intraoperative hypoxemia [13]. Obese patients are particularly prone to intraoperative hypoxemia after surgery due to their physiological characteristics, such as decreased lung and thoracic compliance, increased airway resistance, and altered functional residual capacity [13, 14]. In addition, obesity-related inflammatory pathways (including inflammation and insulin resistance) can further impair pulmonary and vascular function through mediators like C-reactive protein (CRP), interleukin-6 (IL-6), and insulin resistance [15]. These mechanisms may partially explain the higher risk of hypoxemia in obese patients. Therefore, emergency TP patients with obesity should be closely monitored postoperatively. Strategies such as weight control and metabolic optimization may help mitigate the risk of hypoxemia following thoracic drainage.

Smoking is a well-established risk factor for respiratory diseases, as long-term smoking can induce chronic inflammatory responses [16-18]. Harmful substances in tobacco, such as nicotine, exert vasoconstrictive effect on blood vessels, impairing blood circulation. This may impede the re-expansion of damaged lung tissue and prolong the time for lung reopening, thereby negatively impacting recovery after thoracic drainage [19, 20]. Additionally, smoking may further compromise lung expansion by increasing the likelihood of intrathoracic adhesions. Smoking produces high levels of reactive oxygen species (ROS) that can cause cellular and tissue damage, increasing the risk of intrathoracic adhesions and further affecting lung re-expansion [21, 22]. Secondly, smoking is strongly associated with hypoxemia. Smokers experience reduced gas exchange efficiency due to airway inflammation and disruption of alveolar-capillary membranes, which may be more pronounced in patients with TP, as the effects may be further exacerbated by the damage to lung tissue following thoracic drainage [23]. In addition, smoking has been shown to suppress the immune system and increase susceptibility to infections. In TP patients, this may lead to lung infections that further compromise oxygenation [24]. Therefore, for TP patients, smoking cessation is not only crucial for reducing the risk of pneumothorax but also essential for improving postoperative recovery and lowering the risk of hypoxemia.

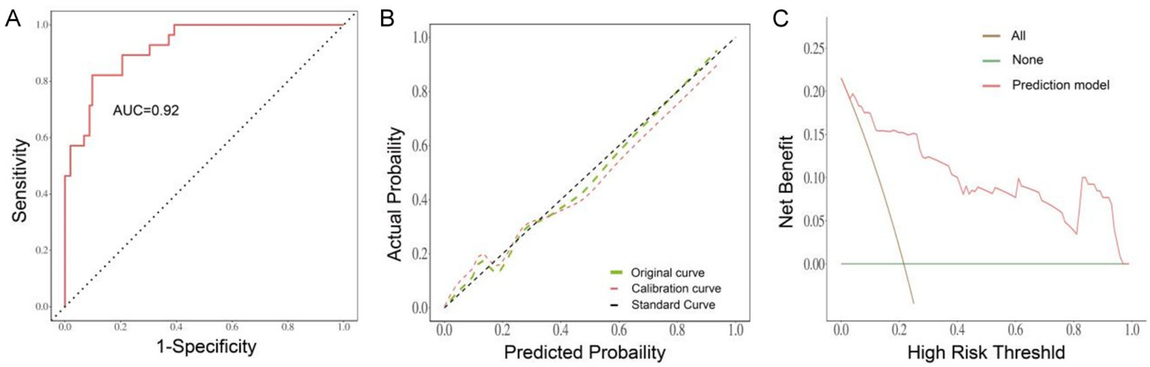

Figure 2. Evaluation of the predictive performance of the nomogram. A. ROC curve analysis; B. Calibration curve analysis; C. DCA curve. ROC, receiver operating characteristic; AUC, area under curve; DCA, decision curve analysis.

This study also found that patients who underwent central venous catheter (CVC) drainage had a significantly lower risk of secondary hypoxemia compared to those using conventional chest tubes. Yi et al. reported in a randomized controlled trial that compared with traditional large-caliber chest tubes, CVCs resulted in shorter wound healing time and lower wound infection rates [25]. Similarly, in a prospective study, Singh et al. found that using a 16G CVC effectively drained simple pleural effusions, reducing postoperative complications [26]. One possible explanation for this finding is that CVCs may lower the risk of catheter-related complications, such as catheter displacement, obstruction, or infection, which can impair thoracic drainage efficiency, thereby affecting lung re-expansion and oxygenation [27]. CVCs may be less prone to these complications due to their structural and material characteristics. In addition, CVCs provide a more stable route for hemodynamic monitoring and intervention. In some cases, hypoxemia is associated with hemodynamic instability. CVCs enable continuous central venous pressure monitoring, guiding fluid management and the administration of vasoactive medications, which can help maintain hemodynamic stability and reduce hypoxemia risk [28]. This study also found that lung re-expansion time was associated with the risk of hypoxemia. Pulmonary re-expansion has been shown to reduce postoperative pulmonary complications, including hypoxemia [29]. Studies have demonstrated that intensive alveolar re-expansion, combined with low tidal volume protective ventilation, can reduce the severity of postoperative pulmonary complications in patients with hypoxemia after cardiac surgery. This suggests that the implementation of pulmonary re-expansion strategy is important for improving postoperative oxygenation and reducing the risk of hypoxemia [29]. Prolonged lung re-expansion time may result from pleural cavity fluid or blood accumulation, or lung tissue adhesions, leading to incomplete pulmonary reopening and impaired gas exchange. To address this, post-thoracic drainage interventions should focus on promoting lung re-expansion through techniques such as negative pressure suction and postural drainage, which can shorten lung re-expansion time and further reduce the risk of hypoxemia.

Nonetheless, this study has several limitations. First, as a single-center retrospective study, it is susceptible to selection bias and information bias. Since all data were from a single hospital, the generalizability and external validity of the results may be limited. Second, the relatively sample size may have reduced the statistical power, potentially increasing the risk of random error and affecting the robustness of the findings. Finally, postoperative recovery in TP patients is influenced by multiple factors, and the presence of unrecognized or uncontrolled confounders may have affected the observed associations between hypoxemia and risk factors.

Conclusion

This study retrospectively analyzed the risk factors for secondary hypoxemia in emergency traumatic pneumothorax (TP) patients following transthoracic drainage, providing a scientific basis for clinical prevention and treatment. The findings identified advanced age, high BMI, smoking history, use of conventional drains, and prolonged lung re-expansion time as independent risk factors for secondary hypoxemia. These factors interact with each other and together affect the gas exchange function of the lungs, leading to the development of hypoxemia.

These findings underscore the importance of addressing high-risk factors during preoperative assessment, intraoperative management, and postoperative monitoring to reduce hypoxemia incidence, improve oxygenation status, and enhance patient prognosis. Future studies should further validate these results in larger, multicenter cohorts and explore additional potential risk factors to further optimize the management of TP patients.

Disclosure of conflict of interest

None.

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