Article

Risk Factors of Postoperative Atelectasis and the Preventive Effect of a Risk-Stratified Nursing Model in Elderly Patients With Severe Polytrauma

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Na Zhu[1], Fang Gu[1], Liting Zou[1]

[1]Emergency Intensive Care Unit, Affiliated Hospital of Jiangnan University, 214000 Wuxi, Jiangsu, China

AIM: To investigate the incidence and independent risk factors for postoperative atelectasis in elderly patients with severe polytrauma, and to evaluate the preventive effect of a risk-stratified nursing model developed based on these factors.

METHODS: This retrospective study comprised two components. The first component included 108 elderly patients with severe polytrauma who underwent surgery between March 2021 and March 2024. Based on postoperative atelectasis, patients were categorized into an atelectasis group (n = 31) and a non-atelectasis group (n = 77). Baseline characteristics, injury- and surgery-related variables, and preoperative laboratory parameters were collected from both groups. Univariable analysis and multivariate logistic regression were performed to identify independent risk factors and to estimate their odds ratios (ORs) with 95% confidence intervals (CIs). The combined predictive performance of these factors was evaluated using receiver operating characteristic (ROC) curve analysis. The second component was an intervention analysis to evaluate the effectiveness of a stratified nursing protocol established based on the derived risk scoring system. Using a before–after design, the incidence of postoperative atelectasis was retrospectively analyzed in a subsequent cohort of 48 elderly patients with severe polytrauma who received this nursing intervention between June 2024 and June 2025.

RESULTS: The incidence of postoperative atelectasis in elderly patients with severe polytrauma was 28.70% (31/108). Multivariate logistic regression analysis identified advanced age (>75 years), elevated body mass index (BMI) (>24 kg/m^2), concomitant pulmonary injury, substantial blood loss volume (≥3000 mL), prolonged time from injury to surgery (≥6 h), and extended operative time (≥2 h) as independent risk factors (all $p < 0.05$). The combined predictive model incorporating these factors yielded an area under the curve (AUC) of 0.924 (95% CI: 0.876–0.971), with a sensitivity of 83.9% and specificity of 87.0%. A risk-scoring system derived from regression coefficients stratified patients into low- (0–2 points), moderate- (3–4 points), and high-risk (≥5 points) groups. Implementation of the corresponding risk-stratified nursing model was associated with a reduction in postoperative atelectasis incidence to 10.42% (5/48) in the subsequent intervention cohort.

CONCLUSIONS: Postoperative atelectasis is common among elderly patients with severe polytrauma and is influenced by multiple clinical factors. A risk-stratified nursing model based on identified independent predictors demonstrates potential to reduce the incidence of atelectasis in clinical practice and warrants further validation.

Keywords: aged; multiple trauma; atelectasis; risk factors; prevention; risk stratification

Introduction

Against the backdrop of accelerating global population ageing, the elderly are at a significantly increased risk of high-energy trauma events, including traffic accidents and falls from height, partly due to increased social participation and expanded range of activities [1,2,3]. According to established international standards, trauma with an Abbreviated Injury Scale-1990 Revision (AIS90)-injury severity score (ISS) ≥16 is defined as severe polytrauma. This condition is characterized by multi-organ injury, metabolic dysregulation, and immunosuppression, resulting in higher mortality among elderly patients compared with younger populations and significantly impaired postoperative recovery capacity, thereby posing a major challenge in emergency and critical care medicine [4,5]. The prevention and management of postoperative complications are therefore critical determinants of the prognosis of patients with severe polytrauma [6,7]. Atelectasis, a common postoperative pulmonary complication, occurs more frequently in elderly and trauma populations, representing a serious threat to recovery in this vulnerable group [8,9].

Currently, factors associated with atelectasis have been reported across a range of clinical contexts. However, the evidence remains heterogeneous and lacks systematic integration. In trauma intensive care unit (ICU) patients requiring mechanical ventilation, chest trauma has been identified as a primary trigger, with additional contributors including abdominal injury, Acute Physiology and Chronic Health Eval-

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Correspondence to: Liting Zou, Emergency Intensive Care Unit, Affiliated Hospital of Jiangnan University, 214000 Wuxi, Jiangsu, China (e-mail: carthise2@163.com).

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uation II (APACHE II) score ≥15, prior surgical history, comorbidities, and prolonged duration of ventilation [10]. Following endoscopic resection, radiographically identified atelectasis occurs in approximately 20% of cases and has been associated with obesity, prolonged operative time, and increased propofol exposure [11]. Rounded atelectasis has been linked to hepatic hydrothorax, asbestos exposure, pleurisy, heart failure, and end-stage renal disease [12]. In patients with traumatic brain injury, postoperative acute atelectasis has been independently associated with vomiting or aspiration, mechanical ventilation, and hypoalbuminemia [13]. Paediatric studies have identified age <1 year and tracheobronchial stenosis during cardiac magnetic resonance imaging (MRI) anaesthesia [14], and supplemental oxygen administration during sedation [15], as key risk factors. Among surgical populations, the retroperitoneal approach and elevated body mass index (BMI) have been associated with increased risk following robot-assisted partial nephrectomy [16], while following right upper lobectomy, anatomical features such as a reduced middle lobe bronchial diameter and a fused interlobar fissure predispose to middle lobe atelectasis [17]. Additionally, baseline characteristics, including age, sex, and smoking exposure, may also influence risk [18].

Overall, although previous studies have revealed multiple factors associated with atelectasis, evidence specific to elderly patients with severe polytrauma remains limited, and clinical nursing practice is largely based on conventional, non-stratified approaches. Furthermore, there is a lack of integrated risk assessment models tailored to this high-risk population. Therefore, this study aimed to systematically identify independent risk factors for postoperative atelectasis in elderly patients with severe polytrauma, develop a risk-stratified nursing model based on these factors, and evaluate its clinical effectiveness in preventing atelectasis. This approach is expected to provide a scientific basis for early risk identification, targeted nursing interventions, and the optimization of clinical outcomes.

Methods

Study Population

The study cohort for the analysis of influencing factors consisted of 108 elderly patients with severe polytrauma who underwent surgery at Affiliated Hospital of Jiangnan University between March 2021 and March 2024. Based on postoperative imaging findings, patients were categorized into an atelectasis group (n = 31) and a non-atelectasis group (n = 77). The cohort used to evaluate the effectiveness of the nursing model comprised a separate group of 48 elderly patients with severe polytrauma admitted between June 2024 and June 2025 who received the risk-stratified nursing intervention.

The diagnosis of atelectasis was established according to predefined imaging criteria: chest computed tomography (CT) or X-ray showing focal pulmonary opacity accompanied by at least one of the following features: (1) displacement of the hilum, mediastinum, or diaphragm toward the affected region; (2) compensatory hyperinflation of adjacent normal lung tissue.

The inclusion criteria were as follows: (1) age 65–85 years; (2) American Society of Anesthesiologists (ASA) physical status classification I–III; (3) meeting diagnostic criteria for severe polytrauma with an ISS ≥16; (4) initial presentation at

Affiliated Hospital of Jiangnan University within 24 hours after trauma; and (5) meeting surgical indications and successfully undergoing surgery at our institution.

Exclusion criteria: (1) preoperative moderate-to-severe obstructive or restrictive ventilatory dysfunction, moderate-to-severe chronic pulmonary disease requiring ongoing treatment, pulmonary infection, pleural effusion, pneumothorax, pulmonary bullae, chest deformity, or previous thoracic surgery; (2) concomitant severe cardiovascular disease (e.g., chronic myocardial ischemia, uncorrected hypotensive shock), severe hepatic or renal dysfunction, intracranial hypertension, or neuromuscular diseases; (3) comorbid malignancy, coagulation disorders, immune-related disorders; (4) history of organ transplantation; (5) presence of atelectasis before admission or surgery; and (6) history of mechanical ventilation within the preceding 2 weeks.

Data Collection

This study collected data from 108 patients admitted to Affiliated Hospital of Jiangnan University between March 2021 and March 2024, including baseline characteristics, injury- and surgery-related indicators, and preoperative laboratory results for all eligible patients. Baseline variables included age, sex, BMI, smoking history, alcohol consumption history, and comorbidities [hypertension, diabetes mellitus, coronary heart disease, and chronic obstructive pulmonary disease (COPD)]. Injury-related indicators comprise ISS, cause of injury, number of injured body regions, presence of open injury, abdominal trauma, abdominal organ injury, pulmonary injury, type of surgery performed (classified as abdominal surgery, thoracic surgery, and other types based on intraoperative records), volume of blood loss, time from injury to surgery, and results of thoracoabdominal puncture. The primary surgery-related variable was operative time.

Laboratory indicators included preoperative white blood cell count, neutrophil percentage, platelet count, C-reactive protein (CRP), haemoglobin, and albumin levels. All data were uniformly extracted from the hospital's electronic medical record system. Laboratory tests were performed by the hospital laboratory department following standardized operating procedures. Routine haematological parameters (white blood cell count, neutrophil percentage, platelet count, etc.) were measured using an automated haematology analyser (model BC-6800, Shenzhen Mindray Bio-Medical Electronics Co., Ltd., Shenzhen, China). CRP levels were determined using a specific protein immunoanalyzer (model: CRP-M100, Shenzhen Mindray Bio-Medical Electronics Co., Ltd., Shenzhen, China). Haemoglobin and albumin were measured using an automated biochemistry analyzer (model: AU5800, Beckman Coulter, Inc.).

Perioperative Management and Nursing Protocols

Standard Perioperative Respiratory Care

Perioperative respiratory management: All enrolled patients received standard postoperative respiratory care according to Affiliated Hospital of Jiangnan University's cardiothoracic surgery and intensive care unit protocols. This included routine oxygen therapy and monitoring, encouragement and assistance with coughing and deep breathing exercises, and aseptic suctioning to clear airway secretions when indicated. For suspected or confirmed atelectasis, additional bronchoscopic intervention or intensified physiotherapy was provided at the attending physician's discretion. The aim of this analysis was to evaluate the incremental value of the identified risk factors and the stratified nursing model beyond this baseline standard care.

Risk Stratification and Corresponding Tiered Nursing Protocol

Risk Stratification Scoring Criteria and Corresponding Tiered Nursing Protocol: Based on the regression coefficients (β) of six significant independent risk factors identified through multivariable logistic regression, a risk scoring system was developed. The scoring weights were derived from the β coefficients (representing log odds) rather than odds ratios. The smallest non-zero coefficient (operation duration, $|\beta| = 1.438$) was used as the baseline reference and assigned 1 point. Scores for the remaining variables were calculated proportionally relative to this reference and subsequently rounded to the nearest integer.

Based on the distribution of total scores for postoperative atelectasis in the study population, patients were categorized into three risk levels: low (0–2 points), moderate (3–4 points), and high (≥5 points). A corresponding risk-stratified nursing protocol was developed and implemented as follows:

Low-risk group (0–2 points): Maintain adequate ward ventilation; perform breath sound auscultation and Peripheral Capillary Oxygen Saturation (SpO_2) monitoring each shift; provide structured health education using visual guides and bedside demonstrations to facilitate mastery of deep breathing, effective coughing, and early mobilization; schedule diaphragmatic breathing exercises 3–4 times daily for 5–10 minutes per session; instruct correct wound support techniques during coughing combined with daily balloon-blowing exercises; promote progressive rehabilitation from in-bed activity to sitting, standing, and indoor ambulation within 24 hours postoperatively.

Moderate-risk group (3–4 points): In addition to low-risk measures, implement enhanced interventions including daily nebulization therapy followed by 4–6 sessions of back percussion to facilitate sputum expulsion; apply alternating semi-Fowler's and lateral positioning combined with incentive spirometry training to promote lung re-expansion; strengthen psychological support and optimize analgesia to maintain effective coughing while avoiding respiratory depression.

High-risk group (≥5 points): Transfer patients to the emergency intensive care unit (EICU) for advanced monitoring; prophylactically apply non-invasive ventilation or high-flow oxygen therapy to maintain alveolar recruitment; ensure respiratory therapist-guided chest physiotherapy at least twice daily, including postural drainage, vibration percussion, and assisted sputum expulsion; assess breath sounds, sputum characteristics, and respiratory muscle strength each shift; guide active and passive limb functional exercises in bed three times daily for 10–15 minutes per session, combined with regular repositioning (e.g., every 2 hours) to facilitate pulmonary secretion drainage and lung re-expansion; establish a multidisciplinary collaboration mechanism led by emergency intensive care and respiratory teams, with individualized management plans involving nutritionists and rehabilitation therapists; implement daily sedation and analgesia assessments with planned awakening, optimize ventilation parameters, and ensure effective implementation of respiratory training.

Study Design for Phase II Intervention Effectiveness Evaluation

Second-phase study design: The second phase of this study was designed as an evaluation of intervention effectiveness rather than validation of the predictive model itself. To assess the preventive effect of the risk-stratified nursing model, a before–after comparison (historical control) design was adopted. The model, derived from the first-phase cohort (March 2021–March 2024), was applied to an independent subsequent cohort (June 2024–June 2025). The primary outcome was the incidence of postoperative atelectasis. This design aimed to determine whether the implementation of targeted nursing interventions was associated with improved clinical outcomes, independent of the statistical performance of the risk prediction model.

Statistical Analysis

All statistical analyses in this study were performed using SPSS version 21.0 statistical software (IBM SPSS Corp., Armonk, NY, USA). Categorical variables are presented as counts and percentages, and intergroup comparisons were performed using the chi-square test or continuity-corrected chi-square test, as appropriate. Continuous variables were initially assessed for normality using the Shapiro-Wilk test. Variables conforming to a normal distribution are expressed as mean ± standard deviation and were compared using the independent-samples *t*-test. Variables not conforming to a normal distribution were expressed as median (interquartile range, IQR) and compared using the Mann-Whitney *U* test. To enhance clinical interpretability, selected continuous variables were categorized based on clinically relevant thresholds or previously reported cutoffs. Specifically, age ≥75 years was used based on the definition of the oldest-old; BMI ≥24 kg/m^2 was defined according to Asia-Pacific obesity criteria; ISS ≥30 was applied based on severe trauma stratification; and blood loss ≥3000 mL was defined as severe intraoperative blood loss based on previously reported criteria and clinical practice. Time from injury to surgery and operative time were dichotomized at 6 hours and 2 hours, respectively. The remaining continuous variables were retained in their original scale.

To identify independent factors associated with postoperative atelectasis and to quantify their effects, variables with $p < 0.05$ in univariable analysis were entered into a multivariate logistic regression model. In addition, although smoking history was not statistically significant in the univariate analysis, it was included in the multivariate model as a confounder based on previous evidence indicating its clinical relevance to postoperative pulmonary complications. Results are presented as adjusted odds ratios (ORs) with corresponding 95% confidence intervals (CIs).

The predictive performance of the identified independent risk factors, both individually and in combination, was evaluated using receiver operating characteristic (ROC) curve analysis. The area under the curve (AUC), along with its 95% CI, sensitivity, and specificity, was calculated to quantify the discriminative performance of the model. All statistical tests were two-sided, and *p*-values < 0.05 were considered statistically significant. Additionally, a sensitivity analysis was performed by incorporating sex as an additional covariate into the multivariate logistic regression model to assess the robustness of the findings.

Results

Incidence of Postoperative Atelectasis in Elderly Patients With Severe Polytrauma

A retrospective analysis of 108 patients admitted to Affiliated Hospital of Jiangnan University between March 2021 and March 2024 showed that 31 patients developed postoperative atelectasis, corresponding to an incidence of 28.70% (31/108). Regarding clinical management of atelectasis, among the 31 patients with postoperative atelectasis, 8 (25.81%) underwent bronchoscopic intervention, of whom 3 required repeated procedures (≥2 times). In contrast, no patients in the non-atelectasis group underwent bronchoscopy.

Univariable Analysis of Postoperative Atelectasis

Univariable analysis demonstrated that the occurrence of postoperative atelectasis was not significantly associated (all $p > 0.05$) with sex, smoking history, history of alcohol consumption, hypertension, diabetes, coronary heart disease, cause of injury, number of injured body regions, presence of open injury, abdominal trauma, thoracoabdominal puncture findings, or preoperative laboratory indices, including white blood cell count, neutrophil percentage, platelet count, C-reactive protein, haemoglobin, albumin levels and other relevant indicators. In contrast, several variables showed statistically significant associations with postoperative atelectasis. Notably, age >75 years ($p = 0.004$), body mass index >24 kg/m^2 ($p = 0.001$), ISS <30 ($p = 0.011$), concomitant abdominal organ injury ($p < 0.001$), concomitant pulmonary injury ($p = 0.001$), substantial blood loss volume ≥3000 mL ($p = 0.031$), time from injury to surgery ≥6 hours ($p = 0.003$), and operative time ≥2 hours ($p = 0.002$) were significantly associated with the occurrence of postoperative atelectasis (Table 1).

Multivariable Logistic Regression Analysis of Risk Factors for Postoperative Atelectasis in Elderly Patients With Severe Polytrauma.

Logistic regression analysis was performed with postoperative atelectasis as the dependent variable. Independent variables included age (65–75 years = 0, >75 years = 1), body mass index (≤24 kg/m^2 = 0, >24 kg/m^2 = 1), smoking history (no = 0, yes = 1), ISS score (<30 = 0, ≥30 = 1), abdominal organ injury (no = 0, yes = 1), pulmonary injury (no = 0, yes = 1), substantial blood loss volume (<3000 mL = 0, ≥3000 mL = 1), time from injury to surgery (<6 h = 0, ≥6 h = 1), and operative time (<2 h = 0, ≥2 h = 1). The analysis showed that advanced age ($p = 0.003$), elevated body mass index ($p = 0.009$), pulmonary injury ($p = 0.049$), substantial blood loss volume ($p = 0.024$), prolonged time from injury to surgery ($p = 0.001$), and extended operative time ($p = 0.026$) were significant influencing factors for postoperative atelectasis in elderly patients with severe polytrauma (Table 2).

Predictive Performance of the Models

ROC analysis demonstrated that the combined predictive model incorporating age, body mass index, pulmonary injury, substantial blood loss volume, time from injury to surgery, and operative time yielded an AUC of 0.924, a sensitivity of 83.9%, a specificity of 87.0%, and a Youden index of 0.709 (Table 3, Fig. 1).

Risk Stratification for Postoperative Atelectasis in Elderly Patients With Severe Polytrauma

In this study, operative time ($|\beta| = 4.213$) was used as the reference factor and assigned a score of 1 point. The corresponding risk score for each remaining factor was calculated based on the proportional relationship between its β coefficient (regression coefficient) and that of the operative time, with values rounded to the nearest integer. This approach yielded a risk scoring system for postoperative atelectasis in elderly patients with severe polytrauma (Table 4).

Table 1. Univariable analysis of factors associated with postoperative atelectasis in elderly patients with severe polytrauma.

Variable	*n*	Atelectasis group (n = 31)	Non-atelectasis Group (n = 77)	Statistics ($t/\chi^2/Z$)	*p*-value
Age, n (%)				8.340	0.004
65–75 years	55	9 (29.03)	46 (59.74)		
>75 years	53	22 (70.97)	31 (40.26)		
Sex, n (%)				0.052	0.819
Male	68	19 (61.29)	49 (63.64)		
Female	40	12 (38.71)	28 (36.36)		
Body mass index, n (%)				10.380	0.001
≤24 kg/m^2	61	10 (32.26)	51 (66.23)		
>24 kg/m^2	47	21 (67.74)	26 (33.77)		
Smoking history, n (%)				0.117	0.732
Yes	62	17 (54.84)	45 (58.44)		
No	46	14 (45.16)	32 (41.56)		
History of alcohol consumption, n (%)				0.808	0.369
Yes	63	16 (51.61)	47 (61.04)		
No	45	15 (48.39)	30 (38.96)		
COPD history, n (%)				3.322	0.068
Yes	17	8 (25.81)	9 (11.69)		
No	91	23 (74.19)	68 (88.31)		
Hypertension, n (%)				0.052	0.819
Yes	40	12 (38.71)	28 (36.36)		
No	68	19 (61.29)	49 (63.64)		
Diabetes, n (%)				0.746	0.388
Yes	19	7 (22.58)	12 (15.58)		
No	89	24 (77.42)	65 (84.42)		
Coronary heart disease, n (%)				0.031	0.861
Yes	13	4 (12.90)	9 (11.69)		
No	95	27 (87.10)	68 (88.31)		
ISS score, n (%)				6.538	0.011
<30 points	36	16 (51.61)	20 (25.97)		
≥30 points	72	15 (48.39)	57 (74.03)		
Cause of injury, n (%)				0.417	0.981
Traffic accident	45	14 (45.16)	31 (40.26)		
Fall from height	26	7 (22.58)	19 (24.68)		
Tumble	17	4 (12.90)	13 (16.88)		
Blunt force injury	13	4 (12.90)	9 (11.69)		
Crush injury	7	2 (6.45)	5 (6.49)		
Number of injured body regions, n (%)				0.077	0.962
2 regions	28	8 (25.81)	20 (25.97)		
3 regions	54	15 (48.39)	39 (50.65)		
≥4 regions	26	8 (25.81)	18 (23.38)		
Open injury, n (%)				0.074	0.785
Yes	57	17 (54.84)	40 (51.95)		
No	51	14 (45.16)	37 (48.05)		
Abdominal trauma, n (%)				0.082	0.775
Yes	43	13 (41.94)	30 (38.96)		
No	65	18 (58.06)	47 (61.04)		
Pulmonary injury, n (%)				10.483	0.001
Yes	16	10 (32.26)	6 (7.79)		
No	92	21 (67.74)	71 (92.21)		

Table 1. Continued.

Variable	n	Atelectasis group (n = 31)	Non-atelectasis Group (n = 77)	Statistics ($t/\chi^2/Z$)	p-value
Type of surgery, n (%)				5.466	0.065
Abdominal		18 (58.06)	26 (33.77)		
Thoracic		10 (32.26)	41 (53.25)		
Other		3 (9.68)	10 (12.99)		
Abdominal organ injury, n (%)				14.042	<0.001
Yes	21	13 (41.94)	8 (10.39)		
No	87	18 (58.06)	69 (89.61)		
Blood loss volume, n (%)				4.654	0.031
<3000 mL	66	14 (45.16)	52 (67.53)		
≥3000 mL	42	17 (54.84)	25 (32.47)		
Time from injury to surgery, n (%)				8.780	0.003
<6 h	59	10 (32.26)	49 (63.64)		
≥6 h	49	21 (67.74)	28 (36.36)		
Thoracoabdominal puncture results, n (%)				0.170	0.680
Positive	66	18 (58.06)	48 (62.34)		
Negative	42	13 (41.94)	29 (37.66)		
Preoperative WBC (×10^9/L)		6.52 ± 1.18	6.22 ± 1.12	1.265	0.209
Preoperative neutrophil percentage (%)		55.84 ± 9.43	57.61 ± 8.78	–0.930	0.354
Preoperative platelet count (×10^9/L)		238.62 ± 36.02	240.29 ± 39.79	–0.202	0.841
Preoperative C-reactive protein (mg/L)		1.55 (1.09–2.30)	1.64 (0.88–2.35)	0.204	0.839
Preoperative haemoglobin (g/L)		127.57 ± 16.16	124.08 ± 13.97	1.120	0.265
Preoperative albumin (g/L)		42.39 ± 6.27	44.49 ± 5.63	–1.704	0.091
Operative time, n (%)				9.588	0.002
<2 h	60	10 (32.26)	50 (64.94)		
≥2 h	48	21 (67.74)	27 (35.06)		

Notes: COPD, chronic obstructive pulmonary disease; ISS, injury severity score; WBC, white blood cell count.

Table 2. Multivariate logistic regression analysis of factors associated with postoperative atelectasis in elderly patients with severe polytrauma.

Variable	β	SE	Wald χ^2	p-value	OR	95% CI	
						Lower	Upper
Age	2.182	0.731	8.919	0.003	8.865	2.117	37.120
Body mass index	1.912	0.728	6.903	0.009	6.767	1.625	28.171
Smoking history	–0.076	0.628	0.015	0.904	0.927	0.271	3.175
ISS score	–1.155	0.707	2.667	0.102	0.315	0.079	1.260
Abdominal organ injury	0.644	0.763	0.714	0.398	1.905	0.427	8.490
Pulmonary injury	2.146	1.088	3.888	0.049	8.548	1.013	72.130
Blood loss volume	1.516	0.673	5.073	0.024	4.555	1.218	17.041
Time from injury to surgery	2.551	0.743	11.784	0.001	12.824	2.988	55.040
Operative time	1.438	0.647	4.944	0.026	4.213	1.186	14.967
Constant	–5.586	1.352	17.081	<0.001	0.004		

Notes: OR, odds ratio.

Preventive Effect of the Risk-Stratified Nursing Model

Following implementation of the risk-stratified nursing model, the incidence of postoperative atelectasis among the 48 elderly patients with severe polytrauma admitted between June 2024 and June 2025 was 10.42% (5/48). This incidence was significantly lower than the 28.70% (31/108) observed in the historical control cohort from the first phase (χ^2 = 6.260, p = 0.012).

Discussion

This study found that the incidence of postoperative atelectasis in elderly patients with severe polytrauma was 28.70% (31/108). Through univariable and logistic regression analyses, we identified advanced age (>75 years), elevated body mass index (>24 kg/m^2), concomitant pulmonary injury, substantial blood loss (≥3000 mL), prolonged time from injury to surgery (≥6 h), and extended operative time (≥2 h) as independent risk factors for postoperative atelectasis

Table 3. Predictive performance of individual indicators and their combination for postoperative atelectasis in elderly patients with severe polytrauma.

Variable	AUC	*p*-value	Sensitivity	Specificity	Youden index	95% CI
Age	0.654	0.013	71.0	59.7	0.307	0.540–0.767
Body mass index	0.670	0.006	67.7	66.2	0.340	0.556–0.783
Pulmonary injury	0.622	0.047	58.1	66.2	0.243	0.498–0.747
Blood loss volume	0.612	0.070	54.8	67.5	0.224	0.493–0.731
Time from injury to surgery	0.657	0.011	67.7	63.6	0.314	0.543–0.771
Operative time	0.663	0.008	67.7	64.9	0.327	0.550–0.777
Combined model	0.924	0.000	83.9	87.0	0.709	0.876–0.971

Notes: AUC, area under the curve.

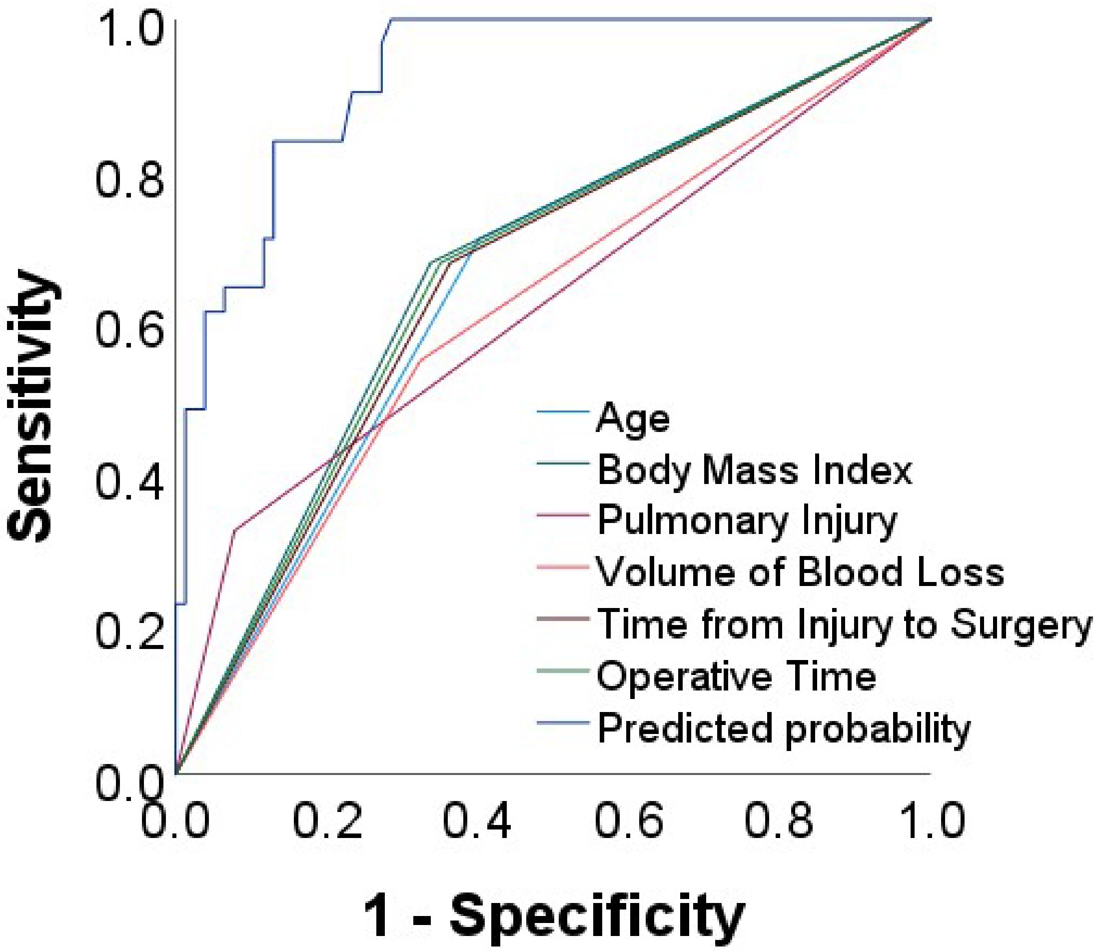

Fig. 1. ROC curve of the multivariable model for predicting postoperative atelectasis in elderly patients with severe polytrauma. Notes: ROC, receiver operating characteristic; AUC, area under the curve.

in this population. More importantly, by translating these factors into a practical risk-scoring system, we developed and preliminarily evaluated a corresponding risk-stratified nursing protocol. Application of this model in a subsequent patient cohort was associated with a significant reduction in postoperative atelectasis (10.42% vs. 28.70%). However, this observed reduction should be interpreted with caution. The evaluation of the nursing model was based on a historical control design, comparing cohorts from different time periods. Although consistent inclusion and exclusion criteria were applied, the analysis primarily compared the atelectasis incidence without a detailed assessment of cohort comparability in terms of baseline injury severity, specific surgical procedures, or potential temporal changes in perioperative management. Therefore, the potential influence of time-related bias and unmeasured confounding factors cannot be fully excluded. These findings not only delineate the risk profile of this vulnerable population but also highlight the potential clinical value of a targeted, evidence-based prevention strategy. The study thus provides a fea-

Table 4. Risk scoring system for postoperative atelectasis in elderly patients with severe polytrauma.

Risk factor	High-risk criterion	Risk score	Basis for score assignment
Operative time	≥2 h	1 point	Reference factor with the smallest non-zero β coefficient (β = 4.213); used as baseline for scaling.
Blood loss volume	≥3000 mL	1 point	β coefficient comparable to the baseline; rounded to 1 point.
Body mass index	>24 kg/m^2	1 point	β coefficient approximately 1.33-fold that of the baseline; rounded to 1 point.
Pulmonary injury	Yes	1 point	β coefficient approximately 1.49-fold that of the baseline; rounded to 1 point.
Age	>75 years	2 points	Larger β coefficient (~1.52-fold baseline), indicating a stronger contribution to risk.
Time from injury to surgery	≥6 h	2 points	Largest β coefficient among predictors, representing the strongest independent risk factor.

sible framework for early risk identification and stratified intervention, which may contribute to improved postoperative respiratory outcomes in elderly patients with severe polytrauma. Notably, postoperative atelectasis was closely associated with the need for bronchoscopic intervention. As described in the Results section, 8 patients (25.81%) in the atelectasis group underwent bronchoscopy, among whom 3 required repeated procedures (≥2 times). In contrast, no patients in the non-atelectasis group underwent bronchoscopy, suggesting that a subset of patients with postoperative atelectasis may require invasive intervention.

Regarding model stability, several risk factors in the final model were associated with relatively large odds ratios and wide confidence intervals (e.g., time from injury to surgery: OR 12.82, 95% CI: 2.99–55.04). This imprecision in effect estimates likely reflects the limited number of outcome events (n = 31) relative to the number of candidate predictors. With approximately 3.4 events per variable, the model is susceptible to overfitting, indicating that the estimated coefficients may be unstable. Consequently, the derived risk score should be considered preliminary, and its predictive performance requires validation in larger, independent cohorts before routine clinical application can be recommended.

The relationship between ISS and atelectasis also warrants further discussion. Contrary to the intuitive expectation that "more severe injury implies higher risk", this study observed a trend toward a lower incidence of atelectasis in patients with ISS ≥30. Although this variable did not reach independent significance in the multivariable model, the finding may reflect the specific injury patterns and clinical management characteristics of this cohort. It is plausible that patients with lower ISS predominantly present with limb or abdominal injuries, allowing earlier mobilization or differing perioperative care. In contrast, patients with higher ISS often present with severe craniocerebral or thoracic trauma, frequently requiring immediate postoperative ICU admission and more intensive respiratory monitoring and support, which may partially mitigate the risk of atelectasis. Furthermore, as a composite injury score, ISS may not fully capture the pathophysiological impact of localized pulmonary injury, highlighting the limitations of using a global severity index to predict organ-specific complications.

This study identified an atelectasis incidence of 28.70% in elderly patients with severe polytrauma. Direct comparison with existing literature should be interpreted cautiously, as most published studies involve distinct populations, including pediatric patients under sedation, elective cardiac or thoracic surgery cohorts, or individuals with isolated traumatic brain injury. These populations differ substantially from the present cohort in terms of demographics, injury mechanisms, anesthetic approaches, and surgical contexts. For example, Bang YJ et al. [19] reported atelectasis rates of 58.5%–88.9% in children undergoing MRI under sedation, while Ji SH et al. [20] observed a rate of 73.3% in infants during general anaesthesia induction with routine bag-mask ventilation. Among adult surgical populations, Sweity EM et al. [21] reported postoperative atelectasis rates of 20%–42.5% following coronary artery bypass grafting, Setlers K et al. [22] observed 14.0% in cardiac surgery patients, Zhou T et al. [23] reported a 9.3% after video-assisted thoracoscopic lobectomy, Licker M et al. [24] reported 36.4% in lung cancer surgery, and Choe JW et al. [11] observed 19.5% after endoscopic procedures. In trauma populations, Hongrattana G et al. [10] reported 14.0% in mechanically ventilated ICU patients, and Wu H et al. [13] identified a rate of 23.66% following craniocerebral injury surgery. In comparison, the incidence observed in this study is at a moderate-to-high level, highlighting the novelty of systematically evaluating atelectasis risk in a population characterized by the dual high-risk features of advanced age and severe polytrauma.

The findings of this study suggest that advanced age, elevated body mass index, pulmonary injury, substantial blood loss, delayed surgery, and prolonged operative time are independent risk factors for postoperative atelectasis in elderly patients with severe polytrauma. The underlying mechanisms may be interpreted as follows: In elderly patients, age-related degeneration of pulmonary elastic fibres, reduced respiratory muscle strength, and diminished cough reflex sensitivity collectively impair postoperative airway clearance, thereby increasing the likelihood of secretion retention. In obese individuals, excessive thoracoabdominal adipose tissue limits diaphragmatic excursion and chest wall expansion, resulting in reduced lung-thorax system compliance and a decrease in functional residual capacity below closing volume, which predisposes to small airway collapse. In patients with concomitant pulmonary injury, direct damage to the pulmonary surfactant system and increased capillary permeability provide a pathophysiological basis for atelectasis formation. Substantial blood loss leading to hypovolaemia may reduce pulmonary perfusion, contribute to ventilation-perfusion mismatch, and impair tissue oxygenation, thereby promoting alveolar collapse. Delayed surgery may prolong the systemic inflammatory response following trauma, with increased release of inflammatory mediators increasing pulmonary capillary permeability and impairing alveolar stability and lung compliance. Furthermore, prolonged operative time, often accompanied by sustained mechanical ventilation, high inspired oxygen concentrations, and deep sedation, may inhibit surfactant synthesis, impair mucociliary clearance, and promote absorption atelectasis and local lung unit hypoventilation.

Based on these risk factors, this study developed a corresponding risk-stratified nursing intervention model and implemented it in clinical practice. The results preliminarily indicate that this model may effectively reduce the incidence of postoperative atelectasis in elderly patients with severe polytrauma. Notably, although univariable analysis in this study did not reveal a statistically significant association between smoking history and the incidence of atelectasis ($p > 0.05$), substantial clinical evidence has consistently identified smoking as an independent risk factor for atelectasis and pneumonia. Consequently, the potential impact of smoking history on postoperative pulmonary complications was considered during the construction of the regression model. However, the results showed that smoking history was not an independent predictor of postoperative atelectasis in this cohort. This finding suggests that, among elderly patients with severe polytrauma, the direct influence of smoking history on the development of postoperative atelectasis may be attenuated or relatively weaker compared with the confirmed injury-related factors. Nevertheless, in clinical practice, patients with a significant smoking history may have compromised baseline pulmonary function. Therefore, when applying the risk-scoring system, clinicians may consider cautiously adjusting the risk estimates for such individuals (e.g., by 0.5–1 points) to better reflect their overall risk profile, although this approach requires further validation in future studies.

This study has several limitations. First, as a single-centre retrospective study, the sample source is relatively homogeneous, and the overall sample size (n = 108) is limited, particularly the small number of cases in the atelectasis group (n = 31). With approximately 3.4 events per variable (EPV), the model is susceptible to overfitting, which may affect model stability and the precision of effect estimates, reduce statistical power, and limit the generalizability of the findings. Second, although the risk-scoring system was derived from regression analysis, its construction (e.g., integer rounding) and the selection of stratification cutoff points involve a degree of subjectivity. The predictive model was evaluated only within the current dataset, and external validation in independent cohorts is necessary to strengthen its robustness and general applicability. Third, in evaluating the effectiveness of the nursing model, a historical control design was used rather than a randomized controlled approach; thus, whether the pre- and post-intervention groups were fully comparable in terms of baseline injury severity and surgical characteristics cannot be definitively ensured. Additionally, this study primarily focused on the occurrence of atelectasis during hospitalization and did not quantify its severity or assess long-term outcomes such as pulmonary function. Future studies should expand the sample size, incorporate multicentre collaborations, and further validate and refine both the risk model and the nursing intervention through prospective study designs.

Conclusions

In summary, the incidence of postoperative atelectasis is high in elderly patients with severe polytrauma, warranting increased clinical attention. Advanced age (>75 years), elevated body mass index (>24 kg/m^2), concomitant pulmonary injury, substantial blood loss (≥3000 mL), prolonged time from injury to surgery (≥6 h), and extended operative time (≥2 h) are independent risk factors. The risk-stratified nursing model constructed based on these factors was implemented in clinical practice, and its application was associated with a reduced incidence of atelectasis in a subsequent cohort, suggesting its potential value in preventing complications in this high-risk population. Further prospective studies are warranted to confirm its efficacy.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

NZ and LTZ designed the research study and wrote the first draft. NZ and FG performed the research. NZ, FG and LTZ analyzed the data. All authors have been involved in revising the manuscript critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study was approved by the Medical Ethics Committee of Affiliated Hospital of Jiangnan University (Approval No.: LS2025184). Written informed consent was obtained from each participant. All procedures were conducted in strict adherence to principles of confidentiality, anonymity, and the tenets of the Declaration of Helsinki.

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Conflict of Interest

The authors declare no conflict of interest.

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