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ORIGINAL RESEARCH

Analysis of Influencing Factors and Construction of a Column Chart Model for Postoperative Pulmonary Infection in Patients With Severe Traumatic Brain Injury

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Objective: To analyze the influencing factors of postoperative pulmonary infection in patients with severe traumatic brain injury, and establish and validate a column chart prediction model.

Methods: A retrospective study was conducted on 314 patients with severe traumatic brain injury in our hospital from January 2022 to March 2024. They were separated into an internal validation group of 235 cases and an external validation group of 79 cases randomly. The internal validation group was grouped into an infection group of 73 cases and an non-infection group of 162 cases. All patients underwent pathogen detection and identification.

Results: A total of 96 strains of pathogens were isolated from 73 patients with concurrent pulmonary infections. Independent risk factors for postoperative pulmonary infection in patients with severe TBI included age ≥ 60 years, diabetes, tracheotomy, operation time ≥ 4 hours, sputum excretion in the supine position, mechanical ventilation duration ≥ 7 days, and GCS score < 8 points mechanical ventilation duration ($P<0.05$). The constructed column chart prediction model had high discrimination, calibration, and clinical practical value.

Conclusion: The column chart model, incorporating age, diabetes, tracheotomy, operation time, sputum excretion position, mechanical ventilation duration and GCS score, can effectively predict pulmonary infections in severe traumatic brain injury patients.

Keywords: severe traumatic brain injury, pulmonary infection, influencing factors, column chart

Introduction

Severe craniocerebral injury is a major health and socioeconomic issue, representing a complex biochemical cascade associated with various pathophysiological processes. It not only affects the central nervous system but also impacts the function of multiple distal organs and systems.[1,2] Previous research statistics show that 53,000 people die annually from traumatic brain injury (TBI) in the United States, and currently, more than 5.3 million Americans suffer from disabilities due to TBI.[3] TBI is associated with inflammation and immune system alterations mediated by the autonomic nervous system. Patients with TBI often require endotracheal intubation and ventilator support, both of which increase the risk of ventilator-associated pneumonia.[4] Pulmonary infection ranks first among hospital-acquired infections, and the progression of pulmonary infection can lead to severe complications such as sepsis, resulting in prolonged hospital stays, increased disability rates, further affecting patient prognosis.[5,6] However, previous studies on the factors influencing pulmonary infections in patients with severe craniocerebral injury are relatively limited, and there is a lack of targeted guidance materials. Additionally, relying on a single influencing factor to predict pulmonary infection may have many limitations and biases. Establishing a mathematical model to predict postoperative pulmonary infection in patients with severe craniocerebral injury may be an important method to address this issue. Therefore, this study aims to explore the influencing factors of postoperative

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pulmonary infection in patients with severe craniocerebral injury, further constructing a nomogram model to predict the occurrence of pulmonary infection, and providing targeted guidance for clinical treatment.

Research Subjects and Methods

Research Subjects

A total of 314 patients with severe craniocerebral injury who were admitted to our hospital from January 2022 to March 2024 were retrospectively included in the study. The median age of the patients was 60 years, with 179 males and 135 females. The body mass index (BMI) was 22.95 ± 2.97kg/m^2. Causes of injury included traffic accidents (214 cases), falls from heights (65 cases), and violent assaults (35 cases). The types of severe traumatic brain injuries were as follows: According to the 3:1 principle, they were divided into an internal validation group of 235 cases and an external validation group of 79 cases randomly. The internal validation group was further divided into an infection group of 73 cases and a non-infection group of 162 cases based on the occurrence of pulmonary infection (All cases were ventilator-associated pneumonia). The study was approved by the Medical Ethics Committee of Wenzhou Central Hospital, and the patients and their families were informed and consented to the treatment plan.

Inclusion criteria: ① Pulmonary infections that meet the criteria for ventilator-associated pneumonia (VAP) established by the American Thoracic Society.[7] Pathogen testing identified infections caused by Gram-negative bacteria, Gram-positive bacteria, or fungi. The pulmonary infection must meet the hospital infection standards; ② Age > 18 years; ③ Complete case data records. Exclusion criteria: ① Patients whose condition deteriorated rapidly or who died within 24 hours of admission; ② Patients with confirmed pulmonary infection based on blood gas analysis, respiratory symptoms, and chest X-ray examination at admission; ③ Patients with malignant tumors; ④ Having other severe primary organ diseases, such as kidney, liver, or heart; ⑤ Transient ischemic attack or intracranial hemorrhage; ⑥ Having chest trauma; ⑦ Long-term use of immunosuppressants or hormonal drugs. The case collection flowchart is shown in Figure 1.

Methods

Clinical Data Collection

Collect the following patient information: age (the median age was 60 years), gender, body mass index (BMI), cause of onset, type of severe craniocerebral injury, smoking history, alcohol consumption history, diabetes, hypertension, hypoproteinemia, tracheotomy, surgery duration (the median duration was 4 hours), gastric tube retention, use of

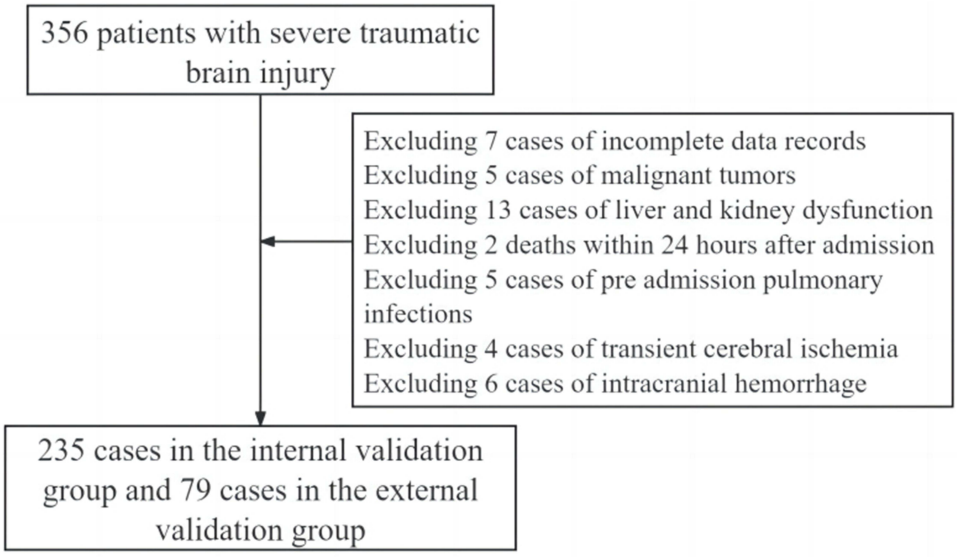

Figure 1 Case collection process diagram.

antibiotics (prophylactic cephalosporin antibiotics were administered 30 minutes before surgery), sputum drainage position, mechanical ventilation duration (the median duration was 7 days), and Glasgow Coma Scale (GCS) score (upon admission, the median score was 8 points).surgery durationmechanical ventilation duration

Pathogen Detection

After the patient gets up, they rinse their mouth with clean water, followed by a rinse with saline, and then perform a deep cough to obtain the second sputum sample. (If the patient is unable to cough autonomously, a fiberoptic bronchoscope can be used to obtain the sample). The sample is immediately sent to the laboratory for bacterial culture. Pathogen detection and identification are carried out using the Microstation automatic microbial identification system, produced by Nanjing Hengrui Bio-pharmaceutical Company.

Statistical Analysis

Using SPSS 25.0, measurement data are expressed as ($\bar{x} \pm s$) and tested using *t*-test; count data are expressed as [n (%)] and tested using $\chi 2$ test; Variables with a P-value < 0.05 in the univariate analysis were included in the multivariate logistic regression analysis as independent variables. Multivariate logistic regression analysis is used to screen for influencing factors; the nomogram prediction model is constructed using R4.3.3 software package, the Hosmer-Lemeshow test is used for goodness-of-fit, the ROC curve is drawn to analyze the predictive value and discrimination of the model, and the calibration curve is used to analyze the calibration of the model; the DCA curve is used to validate the clinical application value of the nomogram prediction model. A P < 0.05 indicates a statistically significant difference.

Results

Distribution and Composition Ratio of Pathogens in Postoperative Pulmonary Infections in Patients With Severe Craniocerebral Injury

Among 235 patients, 73 cases (73/235, 31.06%) had postoperative pulmonary infections. A total of 96 strains of pathogens were isolated from these 73 patients, including 68 strains of Gram-negative bacteria (70.83%), 21 strains of Gram-positive bacteria (21.88%), and 7 strains of fungi (7.29%). (See Table 1).

Comparison of Clinical Data Between the Internal Validation Group and the External Validation Group

There were no statistically significant differences between the internal validation group and the external validation group in terms of age, gender, BMI, cause of onset, type of severe craniocerebral injury, smoking history, alcohol consumption

Table 1 Distribution and Composition Ratio of Pathogens Causing Postoperative Pulmonary Infections in Patients With Severe Traumatic Brain Injury

Pathogenic bacteria	Number of plants	Constituent ratio
Gram negative bacteria	64	66.67
Acinetobacter baumannii	24	25.00
Pseudomonas aeruginosa	17	17.71
Klebsiella pneumoniae	15	15.63
Escherichia coli	8	8.33
Gram positive bacteria	21	21.88
Staphylococcus aureus	11	11.46
Staphylococcus epidermidis	7	7.29
Enterococcus	3	3.13
Fungus	7	7.29
Candida albicans	5	5.21
Candida glabrata	2	2.08

history, diabetes, hypertension, hypoproteinemia, tracheotomy, surgery duration, gastric tube retention, use of antibiotics, sputum drainage position, mechanical ventilation, and GCS score (P > 0.05). (See Table 2).

Univariate Analysis of Postoperative Pulmonary Infections in Patients With Severe Craniocerebral Injury in the Internal Validation Group

There were no statistically significant differences between the non-infection group and the infection group in terms of gender, BMI, cause of onset, type of severe craniocerebral injury, smoking history, alcohol consumption history, hypertension, hypoproteinemia, gastric tube retention, and use of antibiotics (P > 0.05). There were statistically significant differences in age, diabetes, tracheotomy, surgery duration, sputum drainage position, mechanical ventilation duration, and GCS score (P < 0.05). (See Table 3).

Table 2 Comparison of Clinical Data Between Internal Validation Group and External Validation Group

Index	Internal validation group (n=235)	External verification group (n=79)	t/χ^2	P
Age (years old)			2.069	0.150
<60	155 (65.96)	45 (56.96)		
≥60	80 (34.04)	34 (43.04)		
Gender[n (%)]			0.607	0.436
Male	131 (55.74)	48 (60.76)		
Female	104 (44.26)	31 (39.24)		
BMI (kg/m^2)	22.97±3.04	22.89±2.75	0.207	0.836
Cause of onset[n (%)]			0.364	0.834
Traffic accident	158 (67.23)	56 (70.89)		
High altitude fall	50 (21.28)	15 (18.99)		
Violent injury	27 (11.49)	8 (10.12)		
Types of severe traumatic brain injury[n (%)]			0.014	0.905
Subdural hematoma	71 (30.21)	25 (31.65)		
Epidural hematoma	67 (28.51)	20 (25.32)		
Brain stem injury	63 (26.81)	23 (29.11)		
Cerebral contusion and laceration	34 (14.47)	11 (13.92)		
Smoking history[n (%)]	117 (49.79)	35 (44.30)	0.712	0.399
Drinking history[n (%)]	31 (13.19)	14 (17.72)	0.988	0.320
Diabetes[n (%)]	46 (19.57)	12 (15.19)	0.755	0.385
Hypertension[n (%)]	85 (36.17)	27 (34.18)	0.102	0.749
Hypoalbuminemia[n (%)]	22 (9.36)	11 (13.92)	1.309	0.253
Tracheostomy[n (%)]	128 (54.47)	45 (56.96)	0.149	0.700
Surgical time (h)			2.509	0.113
<4	98 (41.70)	25 (31.65)		
≥4	137 (58.30)	54 (68.35)		
Indwelling gastric tube[n (%)]	123 (52.34)	44 (55.70)	0.267	0.605
Using antibiotics[n (%)]	121 (51.49)	42 (53.16)	0.066	0.797
Sputum excretion position[n (%)]			1.369	0.242
Prone position	125 (53.19)	48 (60.76)		
Supine position	110 (46.81)	31 (39.24)		
Mechanical ventilation time (d)			0.936	0.333
<7	154 (65.53)	47 (59.49)		
≥7	81 (34.47)	32 (40.51)		
GCS score (points)			0.662	0.416
≥8	146 (62.13)	45 (56.96)		
<8	89 (37.87)	34 (43.04)		

Table 3 Univariate Analysis of Postoperative Pulmonary Infections in Patients With Severe Traumatic Brain Injury in the Internal Validation Group

Index	Uninfection group (n=162)	Infection group (n=73)	t/χ^2	*P*
Age (years old)			17.717	0.000
<60	121 (74.69)	34 (46.58)		
≥60	41 (25.31)	39 (53.42)		
Gender[n (%)]			0.137	0.711
Male	89 (54.94)	42 (57.53)		
Female	73 (45.06)	31 (42.47)		
BMI (kg/m^2)	22.94±3.18	23.05±2.95	0.251	0.802
Cause of onset[n (%)]			1.264	0.532
Traffic accident	106 (65.43)	52 (71.23)		
High altitude fall	35 (21.61)	15 (20.55)		
Violent injury	21 (12.96)	6 (8.22)		
Types of severe traumatic brain injury[n (%)]			0.890	0.828
Subdural hematoma	52 (32.10)	19 (26.03)		
Epidural hematoma	45 (27.78)	22 (30.13)		
Brain stem injury	42 (25.92)	21 (28.77)		
Cerebral contusion and laceration	23 (14.20)	11 (15.07)		
Smoking history[n (%)]	82 (50.62)	35 (47.95)	0.144	0.705
Drinking history[n (%)]	19 (11.73)	12 (16.44)	0.975	0.323
Diabetes[n (%)]	20 (12.35)	26 (35.62)	17.310	0.000
Hypertension[n (%)]	55 (33.95)	30 (41.10)	1.113	0.291
Hypoalbuminemia[n (%)]	12 (7.41)	10 (13.70)	2.347	0.125
Tracheostomy[n (%)]	72 (44.44)	56 (76.71)	21.128	0.000
Surgical time (h)			19.492	0.000
<4	83 (51.23)	15 (20.55)		
≥4	79 (48.77)	58 (79.45)		
Indwelling gastric tube[n (%)]	81 (50.00)	42 (57.53)	1.145	0.285
Using antibiotics[n (%)]	85 (52.47)	36 (49.32)	0.200	0.654
Sputum excretion position[n (%)]			15.265	0.000
Prone position	100 (61.73)	25 (34.25)		
Supine position	62 (38.27)	48 (65.75)		
Mechanical ventilation time (d)			14.500	0.000
<7	119 (73.46)	35 (47.95)		
≥7	43 (26.54)	38 (52.05)		
GCS score (points)			19.908	0.000
≥8	116 (71.60)	30 (41.10)		
<8	46 (28.40)	43 (58.90)		

Logistic Regression Analysis of Factors Influencing Postoperative Pulmonary Infections in Patients With Severe Craniocerebral Injury

Multivariate analysis included variables from univariate analysis: age (assigned: ≥60 years = 1, <60 years = 0), diabetes (assigned: yes = 1, no = 0), tracheotomy (assigned: yes = 1, no = 0), surgery duration (assigned: ≥4 hours = 1, <4 hours = 0), sputum drainage position (assigned: supine = 1, prone = 0), mechanical ventilation duration (assigned: ≥7 days = 1, <7 days = 0), and GCS score (assigned: <8 points = 1, ≥8 points = 0). The occurrence of postoperative pulmonary infections (assigned: infection = 1, non-infection = 0) was used as the dependent variable. Logistic regression analysis found that age ≥60 years, diabetes, tracheotomy, surgery duration ≥4 hours, supine sputum drainage position, mechanical ventilation duration ≥7 days, and GCS score <8 points were independent risk factors for postoperative pulmonary infections in patients with severe craniocerebral injury ($P < 0.05$). (See Table 4).

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Table 4 Logistic Regression Analysis of the Influencing Factors of Postoperative Pulmonary Infection in Patients With Severe Traumatic Brain Injury

Influence factor	*β*	*SE*	*Wald*χ^2	*OR*	*95% CI*	*P*
Age	1.090	0.374	8.476	2.975	1.428~6.198	0.004
Diabetes	1.228	0.445	7.636	3.416	1.429~8.164	0.006
Tracheostomy	1.193	0.393	9.210	3.296	1.526~7.121	0.002
Surgical time	1.469	0.411	12.749	4.346	1.940~9.735	0.000
Sputum excretion position	1.195	0.377	10.070	3.304	1.579~6.912	0.002
Mechanical ventilation time	1.358	0.387	12.282	3.887	1.819~8.306	0.000
GCS score	1.461	0.379	14.836	4.311	2.050~9.068	0.000
Constant	−4.944	0.643	59.025	0.007	~	0.000

Construction of the Nomogram Prediction Model

Based on the variables from the multivariate logistic regression analysis (age, diabetes, tracheotomy, surgery duration, sputum drainage position, mechanical ventilation duration, and GCS score), a nomogram prediction model was constructed. The total score was obtained by adding the corresponding scores of each factor, and the corresponding predicted probability value indicated the risk of postoperative pulmonary infections in patients with severe craniocerebral injury. (See Figure 2).

Internal and External Validation of the Nomogram Prediction Model for Postoperative Pulmonary Infections in Patients With Severe Craniocerebral Injury

In the internal validation group, the Hosmer-Lemeshow goodness-of-fit test showed $\chi2=6.675$, P=0.464. The area under the ROC curve was 0.863 (95% CI: 0.813–0.914), and the calibration curve indicated that the predicted incidence of

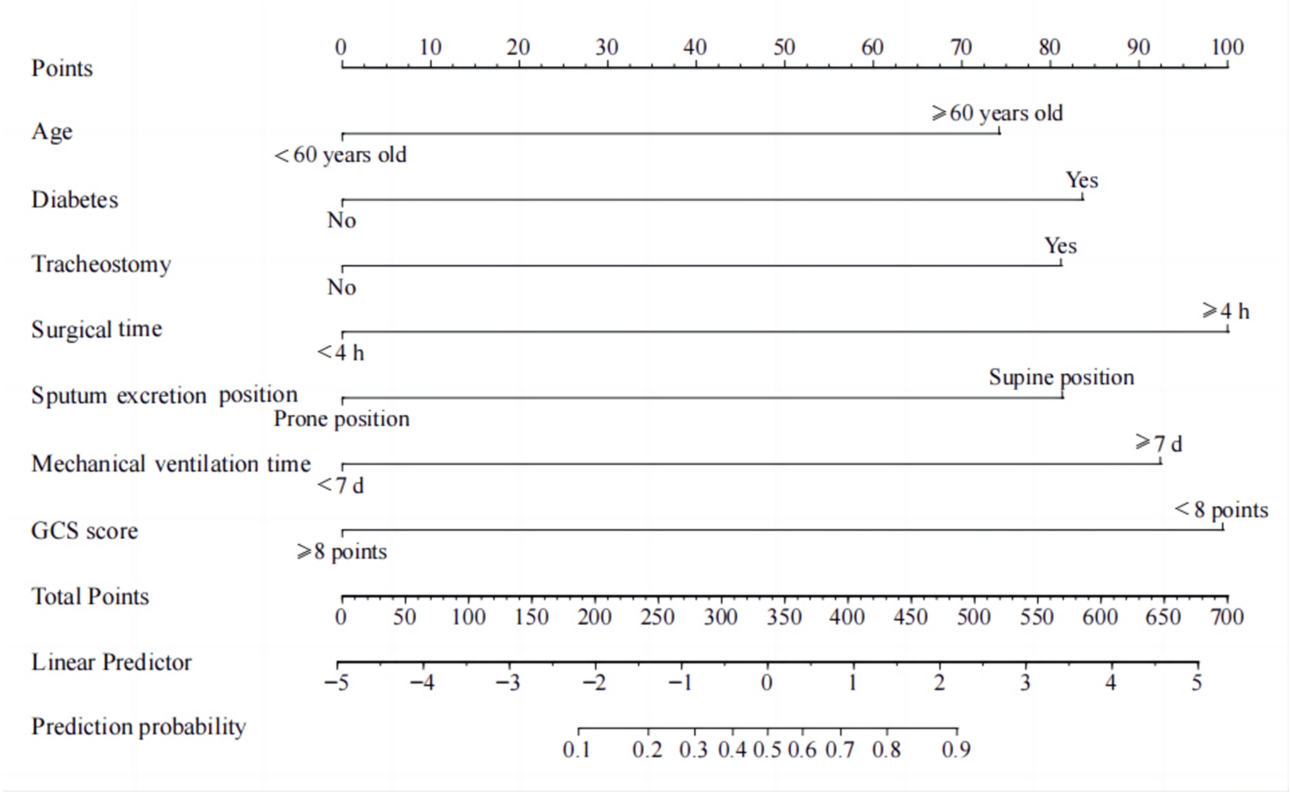

Figure 2 Column chart prediction model for postoperative pulmonary infection in patients with severe traumatic brain injury.

postoperative pulmonary infections using the nomogram prediction model was consistent with the actual incidence. In the external validation group, 25 cases (25/79, 31.65%) had postoperative pulmonary infections, the Hosmer-Lemeshow goodness-of-fit test showed $\chi 2=6.911$, P=0.546, and the area under the ROC curve was 0.846 (95% CI: 0.793–0.900). The calibration curve showed that the predicted incidence of postoperative pulmonary infections using the nomogram prediction model was consistent with the actual incidence. (See Figure 3).

Clinical Application of the Nomogram Prediction Model for Postoperative Pulmonary Infections in Patients with Severe Craniocerebral Injury

The DCA curve of the nomogram prediction model for postoperative pulmonary infections in patients with severe craniocerebral injury was constructed. The "All" line represents all patients with postoperative pulmonary infections, the

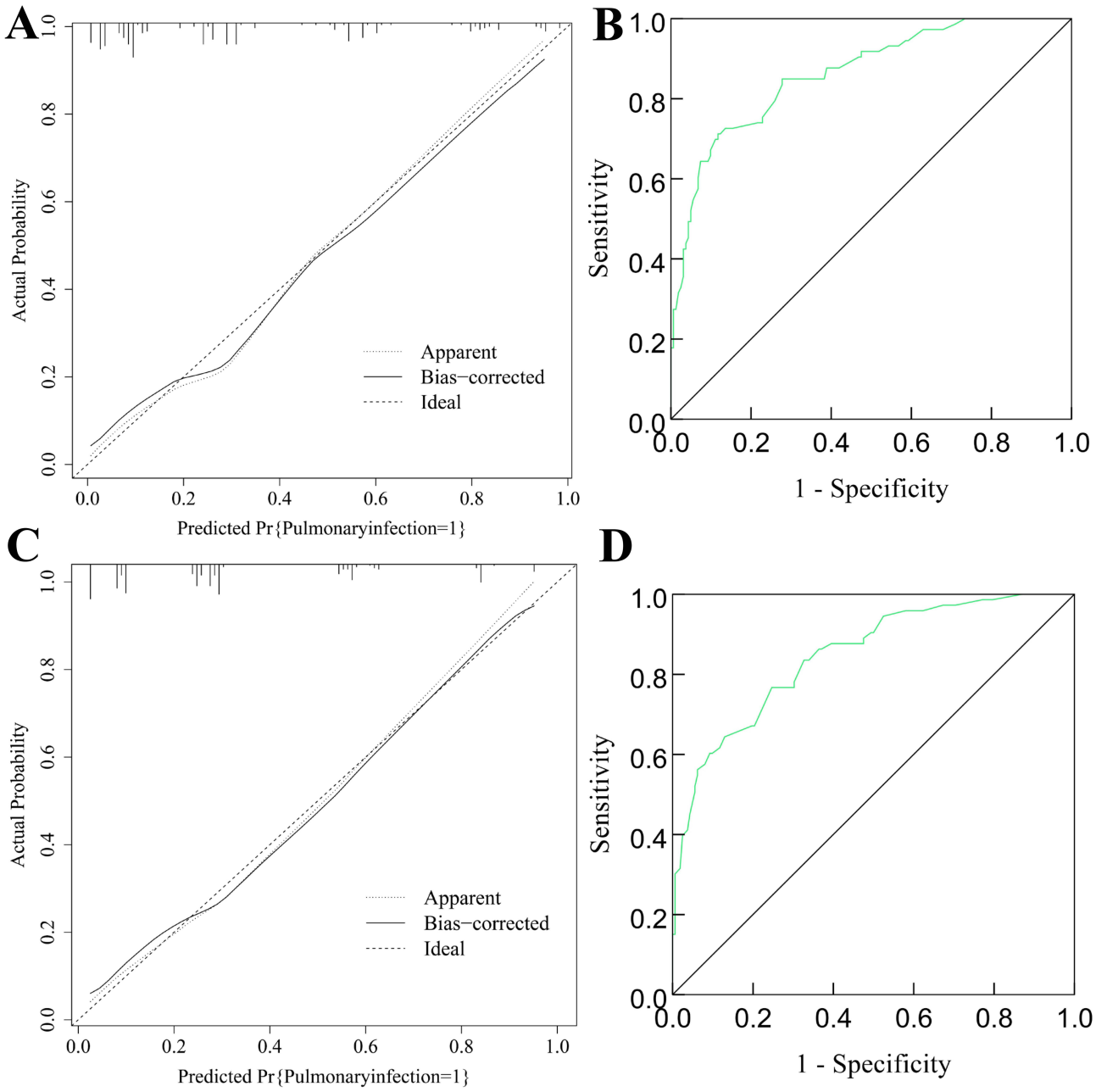

Figure 3 Calibration curves (**A**–**C**) internal and external validation) and ROC curves (**B**–**D**) internal and external validation).

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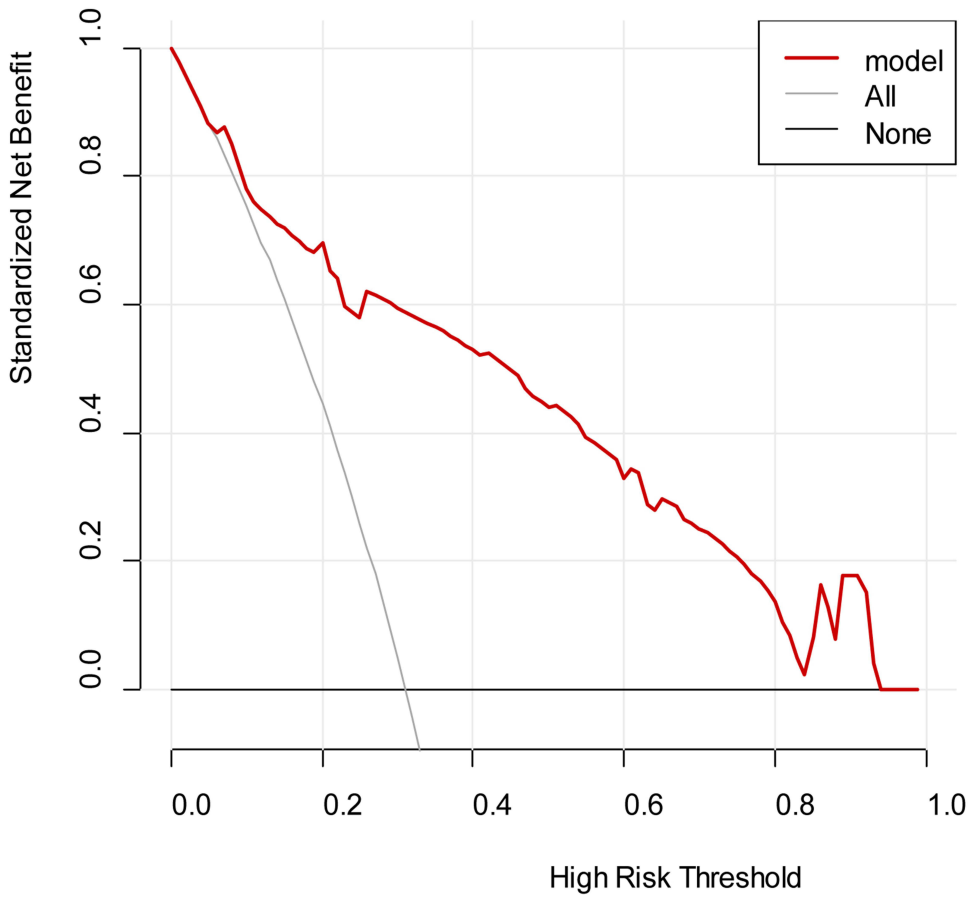

Figure 4 DCA curve of the predictive model for postoperative pulmonary infection in patients with severe traumatic brain injury using a column chart.

"None" line represents all patients without postoperative pulmonary infections, and the "Model" line represents the nomogram prediction model. The horizontal axis represents the high-risk threshold, and the vertical axis represents the standardized net benefit. When the high-risk threshold is between 0.05 and 0.95, the nomogram prediction model demonstrates a higher standardized net benefit and a higher predictive value. (See Figure 4).

Discussion

The action of systemic inflammatory mediators in patients with severe craniocerebral injury creates a systemic inflammatory environment. Extracranial organs, such as the lungs, may be affected by secondary interventions that could exacerbate inflammation, including mechanical ventilation, surgery, and tracheotomy, leading to potential pulmonary infections.[8] This study retrospectively analyzed 314 patients with severe craniocerebral injury, identifying independent risk factors associated with postoperative pulmonary infections. In the results of this study, *Acinetobacter baumannii* accounted for a relatively high proportion, which is consistent with the local epidemiological characteristics. Acinetobacter baumannii is a major pathogen responsible for respiratory infections in hospitals. The primary causes of infection in patients may include transmission from carriers and infected individuals, contamination via healthcare workers' hands, and infection through hospital medical equipment. Univariate and multivariate results showed that age, diabetes, tracheotomy, surgery duration, sputum drainage position, mechanical ventilation duration, and GCS score were independent risk factors for postoperative pulmonary infections. A nomogram with a visual representation was established for easy clinical application.

Elderly patients experience a decline in physical function and immune system function, which may be accompanied by other systemic dysfunctions. Once microbial invasion occurs, the lower respiratory tract is particularly vulnerable, leading to pulmonary infections.[9,10] Previous studies have shown that during hyperglycemia, the production of lactate by

pulmonary dendritic cells is low, the level of acetyl-CoA is high, but mitochondrial respiration remains unchanged, indicating that hyperglycemia affects glycolysis and downstream metabolic pathways in pulmonary dendritic cells.[11,12] These studies emphasize that hyperglycemia influences the immune system through pulmonary dendritic cells, which play a central role in susceptibility to pulmonary infections. Erener et al[13] also showed that diabetic patients are more prone to COVID-19 infections, possibly due to cytokine storms and pulmonary and endothelial dysfunction. Tracheotomy and prolonged surgery duration provide favorable conditions for pathogen invasion, increasing the likelihood of pathogen exposure, thereby impairing respiratory defense and clearance capabilities, and increasing the risk of pulmonary infections.[14–16] When the sputum drainage position is supine, the patient's body weight compresses the lung tissue, making sputum drainage difficult and leading to residual sputum, where pathogens can persist, inducing pulmonary infections. Aspiration of vomit may also occur, increasing the risk of infection.[17] Nie et al[18] showed that changing the patient's position to prone can improve oxygenation levels, promote sputum clearance, and enhance the treatment effect of COVID-19. Zhang et al[19] found that diabetes and mechanical ventilation duration ≥5 days are independent risk factors for pulmonary infections in patients with tracheotomy and severe craniocerebral injury, similar to our study results. This is mainly because mechanical ventilation damages the airway mucosa of surgical patients, reduces immunoglobulin secretion, leading to a decrease in mucosal protection mechanisms, lowering respiratory clearance and defense capabilities, and allowing pathogen invasion into the respiratory tract, further causing pulmonary infections.[20] Liu et al[21] found that age ≥60 years, GCS score <8 points, and prolonged surgery duration are independent risk factors for the severity of postoperative pulmonary infections in patients with craniocerebral injury and tracheotomy. Patients with low GCS scores have a higher degree of coma, and physiological functions such as swallowing and coughing may decline or even disappear, leading to a large accumulation of respiratory sputum, increasing the risk of aspiration and further causing long-term pathogen retention in the body, leading to pulmonary infections.[22]

A nomogram is a representation of a regression model that simplifies risk assessment and presents it in a user-friendly format It provides healthcare practitioners with a user-friendly interface to map the probability of an event to individual patients and enhance clinical decision-making capabilities for medical staff and patients.[23,24] The nomogram prediction model constructed in this study has wide applicability. DCA curve results showed that when the high-risk threshold is between 0.05 and 0.95, interventions based on the nomogram provide a higher prognosis. Additionally, the ROC curve, calibration curve, and Hosmer-Lemeshow test all showed ideal discrimination and calibration of the model. Clinicians can use this model for pre-assessment of patients with severe craniocerebral injury to evaluate their risk of postoperative pulmonary infections and decide on appropriate interventions. For patients with underlying diseases such as diabetes and older age, actively treating the primary disease, boosting immunity, maintaining electrolyte balance, and promoting neurological recovery can help prevent pulmonary infections. Regular position changes, sputum drainage through back tapping, and side-lying positions for comatose patients can prevent aspiration of vomit. For patients with tracheotomy, prolonged surgery duration, and extended mechanical ventilation, strict disinfection protocols, regular replacement of machine attachments, and sterile operations should be emphasized to reduce infection rates.

In conclusion, the nomogram constructed in this study includes variables such as age, diabetes, tracheotomy, surgery duration, sputum drainage position, mechanical ventilation duration, and GCS score, which can be used to accurately predict postoperative pulmonary infections in patients with severe craniocerebral injury. Targeted improvement of relevant factors in the model and individualized treatment strategies can reduce the incidence of pulmonary infections. However, the study has limitations. Firstly, the nomogram was constructed through retrospective observational research. According to the inclusion criteria, some populations were excluded, which may limit the generalizability of the model. Including other factors in the model might affect the prediction results. Secondly, although internal and external validations were conducted, the study data is still somewhat insufficient. The external validation data were derived from patients included in the non-nomogram model at our center; therefore, further external validation in other centers is required. Future research will include more cases through prospective analysis to further validate the robustness and performance of the nomogram.

Data Sharing Statement

The original contributions presented in the study are included in the article.

Ethics Approval and Consent to Participate

This study involving human participants was conducted in accordance with the ethical standards of the Medical Ethics Committee of Wenzhou Central Hospital and with the 1964 helsinki Declaration. Written informed consent to participate in this study was provided by the participants themselves, or their legal guardians/next of kin, as applicable.

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Disclosure

The authors declared no conflicts of interest in this work.

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