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Article

Prognostic Factors of *Staphylococcus aureus* Bloodstream Infection in ICU Patients and Establishment of a Prediction Model

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Abstract

Aims/Background: *Staphylococcus aureus* bacteremia (SAB) bloodstream infection (BSI) is a common complication among patients treated in the intensive care unit (ICU), predisposing them to high morbidity and mortality. The mortality rate at one and three months is 18% and 27%, respectively, and the recurrence and reinfection rate reaches 9%. This study aims to analyze prognostic factors for ICU patients with SAB BSI and establish a prediction model. **Methods**: A total of 210 SAB BSI patients admitted to the ICU from January 2020 to December 2023 were retrospectively selected. Patients were randomly divided in a 3:2 ratio into a modeling group (n = 126) and a validation group (n = 84). Within the modeling group, patients were further categorized into the good prognosis group (n = 75) and the poor prognosis group (n = 51) based on their prognosis outcomes. Univariate and binary logistic regression analyses were conducted to identify prognostic factors for SAB BSI patients. A prediction model was constructed using SPSS, receiver operating characteristic (ROC) curves were generated with R programming language, and calibration and decision curve analysis (DCA) curves were utilized to assess the model's application value. **Results**: Inappropriate initial antibiotic therapy, infection source, Acute Physiology and Chronic Health Evaluation II (APACHE II) score, and central venous catheter placement showed significant differences ($p < 0.05$). The results of binary logistic regression analysis indicated that inappropriate initial antibiotic therapy, infection source, APACHE II score, and central venous catheter placement were prognostic factors for SAB BSI patients ($p < 0.05$). The model equation was Logit(P) = –3.549 + (0.871X_1) + (0.959X_2) + (0.070X_3) + (0.832X_4). The model in the modeling group and the validation group showed a calibration curve with a slope close to 1, which indicates good consistency between the predicted risk and the actual risk. The ROC analysis results indicated that in the validation group, the model had an area under the curve of 0.7857 with a standard error of 0.0331 (95% confidence interval (CI): 0.7229–0.8518, $p < 0.001$) and a Youden's index of 0.61, resulting in a sensitivity of 80.96% and a specificity of 79.64%. The decision curve analysis (DCA) curve demonstrated that the model had a clear positive net benefit. **Conclusion**: Inappropriate initial antibiotic therapy, infection source, APACHE II score, and central venous catheter placement are prognostic factors for SAB BSI patients receiving care in the ICU. This study successfully established and validated a prediction model for SAB BSI.

Keywords: intensive care unit; *Staphylococcus aureus*; bloodstream infection; prognosis

1. Introduction

The intensive care unit (ICU) is a crucial department for managing critically ill patients in hospitals. *Staphylococcus aureus* bacteremia (SAB) bloodstream infection (BSI) is a common infectious complication in the ICU that has profound impacts on patients' prognosis [1,2]. On a global scale, SAB BSI not only has a high incidence and mortality rate, with a mortality rate reaching 18% at one month and rising to 27% at three months [3], but also has recurrence and reinfection rates of up to 9%, further complicating patient treatment and healthcare resource utilization [4]. The microbiological characteristics of SAB BSI in the ICU exhibit regional and nosocomial environment variations. A recent study [5] indicates that there has been an increase in the incidence of SAB BSI in the ICU during recent pandemics, highlighting the importance of establishing effective prediction models to guide clinical decision-making. Several studies have attempted to analyze the prognostic factors of SAB BSI in ICU patients, but they are replete with many limitations, and very few studies have established comprehensive models.

Therefore, this study conducted an in-depth analysis of clinical data and multiple factors to determine factors

influencing the prognosis of ICU patients with SAB BSI and develop an effective, driven prediction model based on these factors. It is anticipated that this model will provide strong decision-making support for clinicians, help optimize treatment protocols, improve patient survival rates, and further enhance infection prevention and control strategies in the ICU.

2. Methods

2.1 Research Object

A retrospective review was conducted on 308 SAB BSI patients admitted to the ICU of Peking University People's Hospital between January 2020 and December 2023. After screening against the inclusion and exclusion criteria, 210 patients were included in the study. Patients were randomly divided in a 3:2 ratio into a modeling group (n = 126) and a validation group (n = 84). Within the modeling group, patients were further categorized into the good prognosis group (n = 75) and the poor prognosis group (n = 51) based on their prognosis outcomes. The grouping process is illustrated in Fig. 1. The inclusion criteria are as follows: (1) patients meeting the diagnostic criteria for BSI [6], with at least one blood culture positive for *Staphylococcus aureus* and presenting with symptoms or signs such as body temperature of 38 °C or higher, temperature dropping to 36 °C or lower accompanied by chills, or hypotension. Additionally, laboratory findings should include at least one of the following abnormal indicators: increased peripheral white blood cell count, increased neutrophil count or left shift, elevated C-reactive protein (CRP) levels, or elevated procalcitonin (PCT) levels; (2) patients with no history of the same infection; (3) patients who had not received anti-infective treatment previously (no anti-infective drugs were used in the past three months); (4) patients with complete clinical data; and (5) patients aged >18 years. The exclusion criteria are as follows: (1) patients with infections caused by other pathogens; (2) patients with a history of antimicrobial drug use; (3) patients who withdrew from the study prematurely; and (4) patients with cardiac, hepatic, or renal dysfunction. This study has been approved by the Medical Ethics Committee of Peking University People's Hospital (2025PHB115-001) and was conducted in compliance with the Declaration of Helsinki. Informed consent was obtained from every subject after they or their families had been briefed about the study.

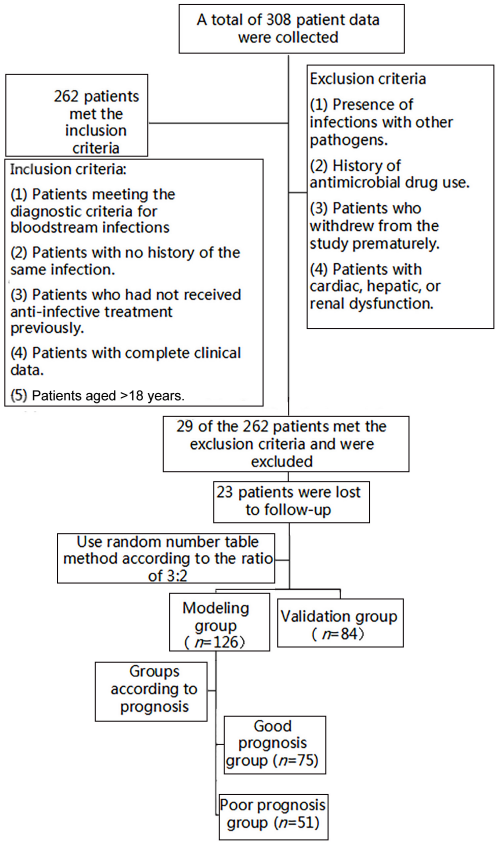

Fig. 1. Flowchart of subject recruitment and inclusion. The figure was created using Microsoft Word 2016 (version 16.0.4226.1003, Microsoft Corporation, Redmond, WA, USA).

2.2 Relevant Definitions

General information was collected through the electronic medical record system and inquiry method.

Poor prognosis is defined as in-hospital death and deterioration of the condition to the point where treatment is futile and the patient is discharged due to ineffective treatment.

Underlying conditions include diabetes, hypertension, etc.

Initial antibiotic treatment is considered inappropriate if a patient has received non-targeted (i.e., insensitive) antibiotic therapy before the release of blood culture and sensitivity test results.

Acute Physiology and Chronic Health Evaluation II (APACHE II) [7] is a widely used method for assessing disease severity and predicting mortality risk in ICU patients. The system consists of three parts: acute physiology scale, age scale, and chronic health scale, with a total score ranging from 0 to 71. Higher scores indicate a more severe condition and a higher risk of mortality. The APACHE II score provides important guidance for clinicians in treatment planning and assessing patient prognosis. Measurements were conducted under the guidance of the attending doctor.

2.3 Strain Identification and Antimicrobial Susceptibility Testing

Blood culturing was performed using the FX400 automated blood culture system (Becton Dickinson, Franklin, NJ, USA), along with Bactec Plus/F resin aerobic culture bottles and Bactec Lytic/10 anaerobic culture bottles containing hemolytic agents. For bacterial identification and drug susceptibility testing, the VITEK-2 Compact Auto-

mated Bacterial Identification System (BioMérieux, Lyon, France) was employed. The antimicrobial susceptibility results were interpreted in adherence to the guidelines outlined in the Clinical and Laboratory Standards Institute (CLSI) M100-S30 standard [8]. The standard strain used for quality control in this process was *Staphylococcus aureus* American Type Culture Collection (ATCC) 25913 (origin).

2.4 Statistical Analysis

Experimental data collected were analyzed using SPSS 27.0 (International Business Machines Corporation, Armonk, NY, USA). Shapiro-Wilk test was employed to assess normality of data. Quantitative data that conform to the normal distribution are expressed as mean ± standard deviation. An independent sample *t*-test was used to compare the data. On the other hand, categorical data are expressed as frequency. Chi-square test method was adopted for data comparison. Subsequently, factors determined as statistically significant in the univariate analysis were tested through the binary logistic regression analysis to screen for prognostic factors for SAB BSI. SPSS was used to establish a prediction model based on factors influencing the prognosis of ICU patients with SAB BSI. The receiver operating characteristic (ROC) curve was created using R language (version 4.0.2, R Foundation for Statistical Computing, Vienna, Austria), and the calibration curve and decision curve analysis (DCA) curve were constructed to determine the application value of the model. Patient information with missing data was excluded from the analysis to avoid potential deviations. A significance level of $p < 0.05$ was considered statistically significant for differences.

3. Results

3.1 General Information

Comparison of general information of patients between the modeling group and the validation group showed no statistically significant differences ($p > 0.05$, Table 1).

3.2 Univariate Analysis of Factors Influencing Prognosis of ICU Patients With SAB BSI

There were statistically significant differences ($p < 0.05$) in terms of inappropriate usage of initial antibiotic treatment, source of infection, APACHE II score, and central venous catheter placement (Table 2).

3.3 Binary Logistic Regression Analysis

Statistically significant variables identified from the univariate analysis were fed into the binary logistic regression analysis, in which inappropriate initial antibiotic treatment, source of infection, APACHE II score, and central venous catheter placement were included as independent variables, whereas prognosis was regarded as the dependent variable (poor prognosis = 1, good prognosis = 0), as shown in Table 3. The results of the binary logistic regression analysis indicate that inappropriate initial antibiotic treatment, source of infection, APACHE II score, and central venous catheter placement are influencing factors for the prognosis of SAB BSI among ICU patients ($p < 0.05$), as shown in Table 4.

3.4 Prediction Model Establishment

Based on the results of the logistic regression analysis, the variables of inappropriate initial antibiotic treatment, source of infection, APACHE II score, and central venous catheter placement (named X_1, X_2, X_3, and X_4, respectively) were included in the constructed prediction model. The expression of the joint detection factor model is $\text{Logit}(P) = -3.549 + (0.871X_1) + (0.959X_2) + (0.070X_3) + (0.832X_4)$. The slopes of calibration curves for both modeling and validation groups are close to 1, indicating good consistency between the predicted risk and actual risk of the model, as shown in Figs. 2,3.

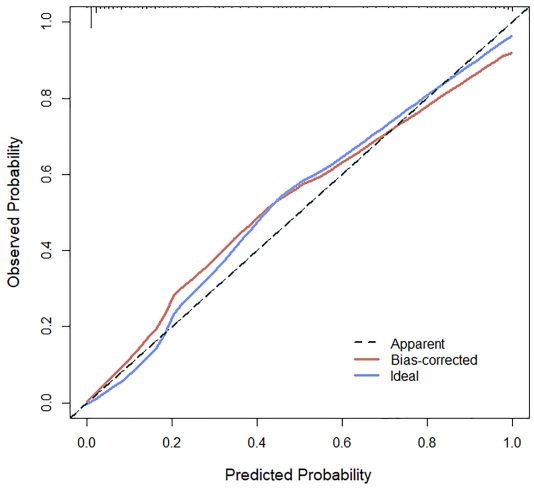

Fig. 2. Calibration curve of modeling group. The curve has a slope which is close to 1, indicating good consistency between the predicted risk and the actual risk of the model.

3.5 ROC Curve

The ROC analysis results showed that the model in the modeling group had an area under the curve (AUC) of 0.9329 with a standard error of 0.0277 (95% confidence interval (CI): 0.8779–0.9842, $p < 0.001$), a Youden index of 0.73, a sensitivity of 81.71%, and a specificity of 91.69%, as shown in Fig. 4. In the validation group, the model had an AUC of 0.7857 with a standard error of 0.0331 (95% CI: 0.7229–0.8518, $p < 0.001$), a Youden index of 0.61, a sensitivity of 80.96%, and a specificity of 79.64%, as shown in Fig. 5.

3.6 Clinical Benefit Analysis of Prediction Model

A decision curve analysis (DCA) curve was plotted to evaluate the clinical utility of the model in predicting treat-

Table 1. Comparison of general information of patients between the modeling group and the validation group.

Baseline data	Modeling group (n = 126)	Validation group (n = 84)	t/χ^2 value	p-value
Age (years)	54.79 ± 2.31	55.08 ± 2.19	0.910	0.364
BMI (kg/m^2)	22.76 ± 1.12	22.54 ± 1.28	1.316	0.189
Gender			0.080	0.778
Male	65	45		
Female	61	39		
Alcohol-drinking history			0.060	0.806
Yes	37	26		
No	89	58		
Smoking history			0.287	0.592
Yes	19	15		
No	107	69		
Underlying conditions			0.502	0.479
Yes	16	8		
No	110	76		
Inappropriate initial antibiotic treatment			0.097	0.755
Yes	37	23		
No	89	61		
Infection source			0.199	0.656
Community-acquired	35	21		
Hospital-acquired	91	63		
Central venous catheter placement			0.162	0.687
Yes	49	35		
No	77	49		
Infection route			1.523	0.958
Respiratory	43	29		
Wound	10	5		
Catheter	14	7		
Skin and soft tissue	24	18		
Urinary system	8	4		
Intra-abdominal	8	5		
Others	19	16		
Occurrence of septic shock			0.031	0.859
Yes	14	10		
No	112	74		
APACHE II score (points)	25.99 ± 7.61	24.84 ± 7.33	1.089	0.278
Respiratory failure			0.098	0.754
Yes	20	12		
No	106	72		

Abbreviation: BMI, body mass index; APACHE II, Acute Physiology and Chronic Health Evaluation II.

ment efficacy. It is evident that the model exhibits significant positive net benefit, indicating good clinical utility, as depicted in Figs. 6,7.

4. Discussion

This study aims to analyze the factors influencing the prognosis of ICU patients with SAB BSI and establish an effective prediction model based on these factors. A total of 210 SAB BSI patients admitted to our ICU from January 2020 to December 2023 were retrospectively selected. Using a random number table method, the patients were divided into the modeling and validation groups. Further stratification based on prognosis allows for a systematic exploration of various factors affecting patient outcomes, leading to the successful construction of a prediction model.

This study found that inappropriate initial antibiotic therapy is one of the significant factors influencing the prognosis of SAB BSI patients. In the modeling group, there was a notable difference between the group with poor prognosis and the group with good prognosis in terms of the

Table 2. Univariate analysis of influencing factors.

Baseline data	Good prognosis group (n = 75)	Poor prognosis group (n = 51)	t/χ^2 value	p-value
Age (years)	54.65 ± 2.21	55.18 ± 2.61	1.227	0.222
BMI (kg/m^2)	22.61 ± 1.63	22.87 ± 1.22	0.969	0.334
Gender			0.063	0.802
Male	38	27		
Female	37	24		
Alcohol-drinking history			0.167	0.683
Yes	21	16		
No	54	35		
Smoking history			0.025	0.875
Yes	11	8		
No	64	43		
Complications			0.067	0.795
Yes	10	6		
No	65	45		
Inappropriate initial antibiotic treatment			7.835	0.005
Yes	15	22		
No	60	29		
Infection source			6.244	0.012
Community-acquired	27	8		
Hospital-acquired	48	43		
Central venous catheter placement			5.271	0.022
Yes	23	26		
No	52	25		
Infection route			4.867	0.561
Respiratory	22	21		
Wound	6	4		
Catheter	8	6		
Skin and soft tissue	18	6		
Urinary system	6	2		
Intra-abdominal	5	3		
Others	10	9		
Occurrence of septic shock			0.148	0.700
Yes	9	5		
No	66	46		
APACHE II score (points)	24.33 ± 6.37	28.43 ± 8.63	3.067	0.003
Respiratory failure			0.002	0.962
Yes	12	8		
No	63	43		

Abbreviation: BMI, body mass index.

Table 3. Variable assignment.

Influencing factors	Assignment
Inappropriate initial antibiotic treatment	Absent = 0, Present = 1
Infection source	Community-acquired = 0, Hospital-acquired = 1
APACHE II score	Original value
Central venous catheter placement	Absent = 0, Present = 1

inappropriate usage of initial antibiotic treatment. This underscores the importance of timely and accurate selection of sensitive antibiotics based on susceptibility testing results [9,10]. Inappropriate initial antibiotic therapy may lead to persistent presence of the pathogen, spread of infection, and even resistance development, consequently increasing the risk of patient mortality and treatment complexity [11]. The source of infection is also a crucial factor affecting the prog-

Table 4. Binary logistic regression analysis results.

Variable	β	Standard error	Wald	p-value	Exp (β)	95% CI	
						Lower limit	Upper limit
Inappropriate initial antibiotic treatment	0.871	0.441	3.911	0.048	2.390	1.008	5.667
Infection source	0.959	0.488	3.861	0.049	2.610	1.002	6.795
APACHE II score	0.07	0.028	6.341	0.012	1.072	1.016	1.132
Central venous catheter placement	0.832	0.412	4.076	0.043	2.299	1.025	5.158
Constant	–3.549	0.906	15.357	<0.001	0.029	-	-

CI, confidence interval.

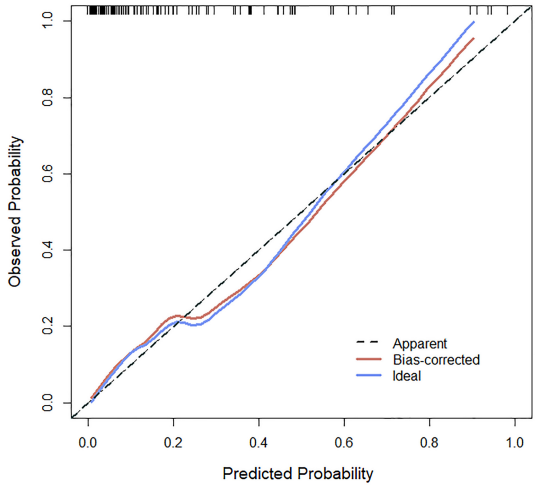

Fig. 3. Calibration curve of validation group. The curve has a slope which is close to 1, indicating good consistency between the predicted risk and the actual risk of the model.

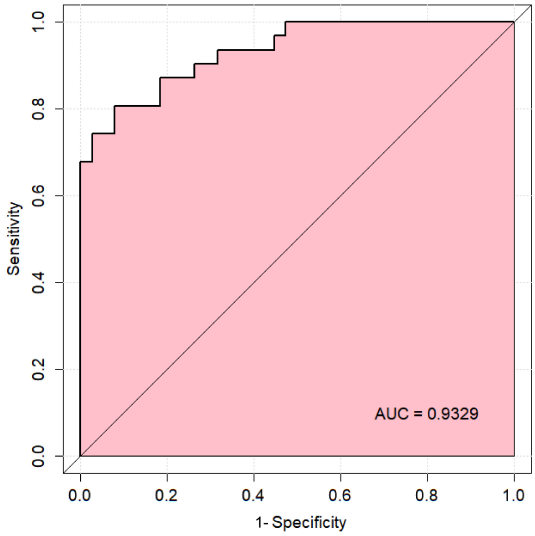

Fig. 4. ROC curve of the modeling group. The area under the ROC curve is close to 1, indicating excellent predictive performance of the model in the modeling group. Abbreviations: AUC, area under the curve; ROC, receiver operating characteristic.

nosis of ICU patients with SAB BSI. In this study, we found that the sources of infection had a significant impact on the prognosis. Specifically, patients with nosocomial or primary infections often had poorer prognoses. This could be related to factors such as the presence of more complications, compromised immune function, and susceptibility to resistant infections in patients with nosocomial infections [12]. Therefore, in the prevention and treatment of SAB BSI, efforts to identify and control the source of infection should be prioritized to reduce the occurrence of nosocomial infections. Prior research by Ju *et al.* [13] has also shown that inappropriate empirical antimicrobial therapy (odds ratio (OR): 2.25, 95% CI: 1.16–4.36) may lead to higher mortality rates, and nosocomial infections (OR: 2.80, 95% CI: 1.41–5.55) are associated with poorer clinical outcomes, which further validate the results of the present study by virtue of their finding concordance.

The APACHE II score and central venous catheter placement were also confirmed as important factors affecting the prognosis of patients with SAB BSI in this study. Research by Singh *et al.* [14] has shown that the APACHE II score and central venous catheter placement are associated with mortality in SAB BSI, adding that early use of appropriate antibiotics can improve patient outcomes. This corroborates the results of this study. Based on their analysis, the APACHE II score reflects a patient's acute physiological abnormalities, chronic health status, age, and other factors, providing a comprehensive assessment of the severity of the patient's condition and prognosis risk [15]. Central venous catheter may increase the risk of infection, mostly due to prolonged duration of catheterization, improper procedures for placement of the catheter, or inadequate maintenance [16]. Therefore, during the treatment for patients with SAB BSI, close attention should be paid to changes in the patient's APACHE II score, which are an indicator for a prompt adjustment of treatment plans and prognosis evaluation. Additionally, in the ICU setting, it is essential to strictly adhere to the indications and operation procedures for central venous catheter placement, and enhance post-catheterization care and monitoring to reduce the occurrence of infections.

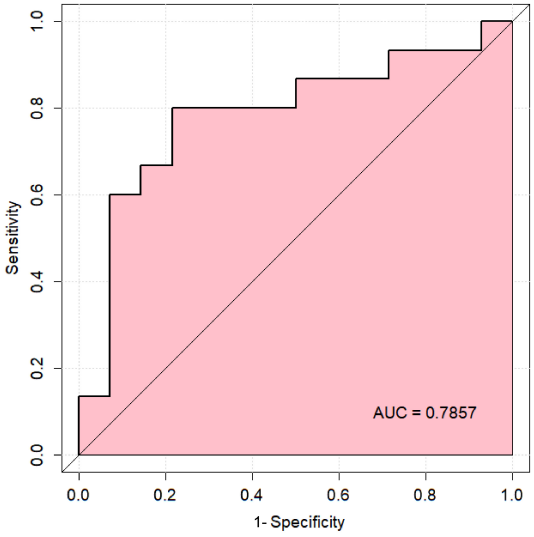

Fig. 5. ROC curve of the validation group. The area under the curve ranges from 0.7 to 0.9, indicating that the model has good predictive value in the validation group. Abbreviations: AUC, area under the curve; ROC, receiver operating characteristic.

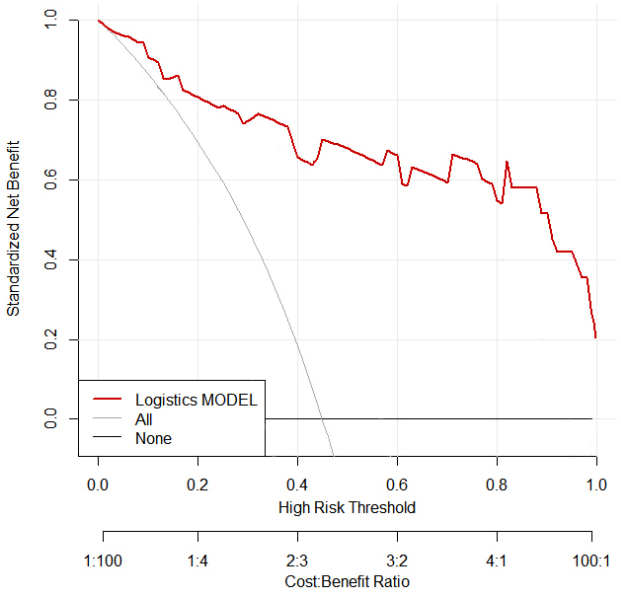

Fig. 6. DCA curve of modeling group. DCA, decision curve analysis.

Based on the analysis of the aforementioned influencing factors, this study utilized binary logistic regression analysis to construct a prediction model. The model expression is Logit(P) = –3.549 + (0.871X_1) + (0.959X_2) + (0.070X_3) + (0.832X_4), where X_1 represents the appropriateness of initial antibiotic therapy, X_2 represents the source of infection, X_3 represents the APACHE II score, and X_4 represents the central venous catheter placement status. The model demonstrated good predictive performance in both the modeling and validation groups. The calibration

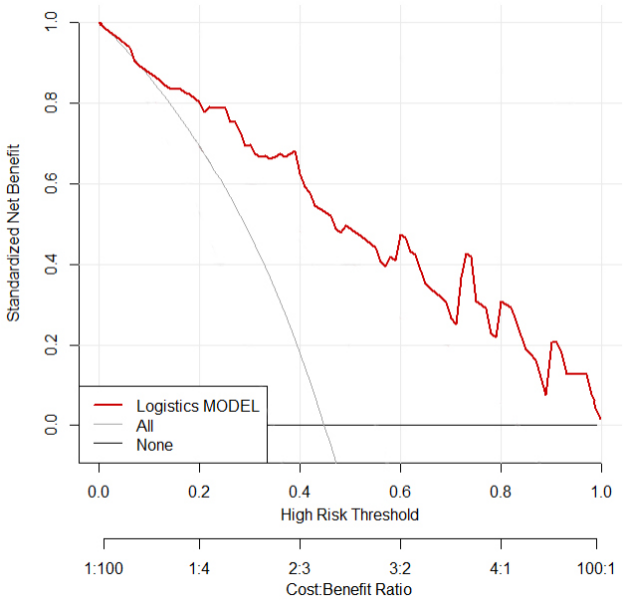

Fig. 7. DCA curve of validation group.

curve indicated high consistency between the predicted risk and actual risk of the model. In the modeling group, the AUC for the ROC curve reached 0.9329, with a sensitivity of 81.71% and a specificity of 91.69%. In the validation group, the AUC was 0.7857, with a sensitivity of 80.96% and a specificity of 79.64%. Despite being lower than the modeling group, the accuracy and diagnostic capabilities of the validation group are at high levels. Furthermore, the decision curve analysis also showed that the model could bring significant clinical benefits to patients. This study successfully constructed a prediction model for the prognosis of ICU patients with SAB BSI, and its high accuracy and reliability were confirmed through validation, demonstrating significant significance and value in both clinical practices and research fields. Previous studies have mainly focused on clinical characteristics and factor analysis, with few comprehensive models established [17,18]. Therefore, in this study, the model was developed based on multiple factors, providing doctors with an objective and precise predictive tool to enable more rigorous treatment planning and prognosis assessments. It also helps optimize the allocation of medical resources, ensuring that patients with poorer prognoses receive more attention and support, thereby enhancing overall treatment effectiveness and patient satisfaction. Moreover, the successful construction of this model has opened up new perspectives for research in the field of SAB BSI and provided new ideas and methodological references for research methods, effectively driving research progress and development in this field. The clinical significance of this prediction model is to strengthen personalized treatment decision-making for ICU patients with SAB BSI. By integrating multiple factors such as initial antibiotic treatment, source of infection, APACHE II score, and cen-

tral venous catheter placement, the model can accurately assess patient prognostic risks and provide clinical guidance for treatment plan adjustment. In the present study, variables were selected based on their clinical relevance and significant impact on prognosis; for instance, an appropriate initial antibiotic treatment can effectively prevent the infection from exacerbation, and the APACHE II score reflects the severity of the disease. By incorporating these variables, the model can more comprehensively capture patient status and help optimize treatment decisions.

Although certain results were achieved, several limitations of this study should be acknowledged. Firstly, the retrospective nature of this study indicates the possibility of incomplete or biased data being collected during research. Secondly, the sample size is relatively limited, which may restrict the broad applicability of the model. In the future, we plan to conduct prospective, multicenter studies to further validate and refine this prediction model. Additionally, we will continue to explore other potential factors that may influence the prognosis of patients with SAB BSI. We also aim to utilize more advanced machine learning methods in the process of model construction to enhance the predictive performance and clinical application value of the model.

5. Conclusion

In conclusion, this study successfully constructed a prediction model for the prognosis of ICU patients with SAB BSI and validated its accuracy and reliability. The model can provide clinicians with objective and accurate predictive results, aiding in optimizing clinical decision-making and resource allocation, and promoting research development.

Key Points

- The study aimed to analyze prognostic factors for patients with *Staphylococcus aureus* bacteremia (SAB) bloodstream infection (BSI) in the intensive care unit (ICU) and establish a prediction model, given the high morbidity, mortality, and recurrence rates associated with this condition.
- A predictive model for the prognosis of SAB BSI patients in the ICU was established.
- The study found that inappropriate initial antibiotic therapy, infection source, APACHE II score, and central venous catheter placement were significant prognostic factors for ICU patients with SAB BSI.
- Constructed using these factors, the prediction model was confirmed as a reliable and practical tool for SAB BSI prognostication through the analyses of ROC curves, calibration and decision curves.

Availability of Data and Materials

The data used to support the findings of this study are available from the corresponding author upon request.

Author Contributions

DL, MdC and BH designed the research study. PS, QG, CY and YZ performed the research. QS analyzed the data. DL wrote the first draft. All authors contributed to revising the manuscript critically for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the Declaration of Helsinki. The study was approved by the Medical Ethics Committee of Peking University People's Hospital (2025PHB115-001). Informed consent was obtained from every subject after they or their families had been briefed about the study.

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Conflict of Interest

The authors declare no conflict of interest.

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