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Development and validation of a nomogram for predicting CRBSI in hemodialysis: a retrospective cohort study

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Abstract

Objectives To develop and validate of a nomogram for predicting Catheter related bloodstream infection(CRBSI) in patients with maintenance hemodialysis.

Methods This was a retrospective cohort study.A total of 756 patients underwent hemodialysis between January 2017 to December 2021 in purification center of the Affiliated Hospital of Changsha Central Hospital, University of South China were enrolled in this research.The demographic data, hemodialysis data, laboratory indexes of the patients were analyzed. Univariate analysis and multivariate Logistic regression were used to analyze the influencing factors of CRBSI in hemodialysis patients and a nomogram model was established.Area under the receiver operating characteristic curve(AUC) and Hosmer-Lemeshow(H-L)test were used to verify the discrimination and calibration of the model.

Results Among the 756 hemodialysis patients,64 patients developed CRBSI, with an incidence rate of 8.5%(64/756). The results of multivariate analysis showed that combined with diabetes mellitus、dialysis age、catheter retention time、C-reactive protein and procalcitonin were independent risk factors for CRBSI in hemodialysis patients($P<0.05$). The receiver operating characteristic curve analysis showed that the AUC of the model was 0.88 and the H-L test results showed that the model had good goodness of fit($\chi^2=5$, $P=0.7$).The internal validation of the prediction model showed an AUC of 0.82, and the H-L results showed ($\chi^2=11$, $P=0.2$), indicating that the model has a good prediction performance and high accuracy.

Conclusion An easy-to-use nomogram for prediction of CRBSI in hemodialysis patients is well developed.This risk assessment tool can effectively identify patients at high risk of CRBSI and may be useful for optimizing catheter management.

Keywords Renal failure, Maintenance hemodialysis, Catheter related bloodstream infection, Nomogram, Prediction model

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Maintenance hemodialysis is the primary treatment for patients with Kidney Failure, and its successful implementation heavily relies on stable vascular access [1, 2]. The autologous arteriovenous fistula is typically the preferred choice for vascular access in hemodialysis patients [3]. However, central venous catheters (CVCs) have become an essential option for patients who have not yet established an endovascular fistula or are not mature enough for immediate treatment. CVCs are specifically categorized into two types: tunneled cuffed catheters (TCCs) and non-tunneled cuffed catheters (NCCs) to address the needs of different stages of treatment [3]. Studies indicate that up to 80% of patients choose CVCs for their first hemodialysis treatment, and 21% continue to rely on them for more than a year during subsequent treatments [4]. Therefore, the central venous catheter is a crucial access point for effectively treating patients undergoing hemodialysis.

However, some patients are particularly vulnerable to catheter-related infections due to their immunocompromised status and prolonged hemodialysis treatment cycles. These infections can manifest as outlet infections, tunnel infections, and catheter-related bloodstream infections (CRBSI) [5]. CRBSI is the leading cause of hospitalization and death among patients undergoing maintenance hemodialysis [6]. Notably, cardiovascular disease is the most common cause of death in these patients, followed by CRBSI [7].

Previous data indicates that the incidence of CRBSI ranges from 3.1 to 6.6 per 1,000 catheter days for patients using non-tunneled catheters (NCC) and from 0.5 to 5.5 per 1,000 catheter days for those using tunneled catheters (TCC) [8]. Typical symptoms of CRBSI include chills and fever. If not promptly recognized and managed, these infections can escalate into severe complications, such as infective endocarditis, bacteremia, or even brain abscesses. Such complications not only significantly prolong hospital stays and increase healthcare resource consumption but may also adversely affect the efficacy of hemodialysis. Ultimately, they can severely diminish the patient's quality of life and serve as critical predictors of life-threatening conditions [9–11].

Based on the above background, it is of great significance to clarify the risk factors for CRBSI in patients with hemodialysis, which can guide clinical prevention and control work as early as possible, minimize the risk of CRBSI, and ensure the treatment effect of patients. This study aims to conduct a retrospective analysis of clinical data from hemodialysis patients admitted to our hospital. Our goals are to identify the risk factors for CRBSI, develop a nomogram prediction model, and perform internal validation of the findings.

Materials and methods

Study participants

This single-center retrospective observational cohort study included 756 ESRD patients between January 2017 and December 2021 from the purification center of the Affiliated Hospital of Changsha Central Hospital, University of South China.The patients were randomly divided into two groups(training set and internal validation set). The first group (the training set) included 70% of the patients with hemodialysis ($N = 529$) to develop the nomogram to discriminate CRBSI patients. The second group (the internal validation set) included the remaining 30% participants with hemodialysis ($N = 227$) to validate the diagnostic performance of this nomogram.

The inclusion criteria were (1) older than 18 years old, (2) first or second indwelling CVC for hemodialysis include TCC and NCC, (3) patients with complete clinical information, (4) willing to participate in the study and sign the informed consent form.The exclusion criteria were (1) combined infection of other sites, (2) combined with malignant tumors, disease of the blood and immune system, (3) prolonged application of hormones or immunosuppressants.

Data collection

The clinical information, including demographic data, hemodialysis data, laboratory features of the patients were obtained from the electronic medical record. The following clinical features were abstracted from the platform: demographic characteristic(sex, age, primary disease and complication); hemodialysis-related characteristic(history of catheter infection, times of CVC intubations, catheter retention position, dialysis age, catheter retention time), laboratory indexes and catheterized blood culture strains.The timing of laboratory indexes for patients who did not develop CRBSI was collected 3 days after catheter insertion. For patients who developed CRBSI, the timing of these data was collected before the onset of CRBSI-related symptoms and confirmation of diagnosis.

Diagnostic criteria for CRBSI

Refer to the 2019 KDOQI Guidelines [12]: (1)Clinical manifestations: fever, chills, altered mental status, or unexplained hypotension (especially on the day of hemodialysis); (2)at least 1 positive blood culture result from a peripheral source (dialysis circuit or vein) and no other apparent source; (3)the same organism should be found from catheter tip culture (> 15 colony forming units per catheter segment) as well as blood culture.In this study, the diagnostic approach for CRBSI patients was as follows: patients exhibited clinical signs of infection such as fever, chills, altered mental status, or unexplained hypotension. Both catheter blood and peripheral venous blood

cultures were positive, and no other sources of infection were identified.

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of Changsha Central Hospital, University of South China (2024 Medical Review No. 061).Informed consent to participate was obtained from all of the participants in the study.

Statistical analysis

SPSS 26.0 and R software version 4.2.1 were used to conduct the statistical analyses.Categorical data (laboratory indexes) were expressed as frequencies with percentages. The differences between CRBSI and non-CRBSI groups were analyzed with the χ^2 test or Fisher's exact test, whereas the continuous variable (age) was presented as the mean with standard deviation, and differences between the two groups were compared with Student's t-test.All statistical tests were two-sided, and $p<0.05$ were considered statistically significant.Univariable and multivariable analyses were performed to identify the significant independent risk factors for CRBSI.Variables with $p<0.1$ in the univariate analysis were included in the multivariate analysis.The prediction model was developed based on the results of the multivariate analysis by binary logistic regression and further optimized by stepwise forward and backward selection.A nomogram was formulated to illustrate our prediction model by using the rms package in R software.Discrimination of the nomogram model was measured by the area under the receiver operating characteristic (ROC) curve using pROC package.Calibration was measured by the Hosmer-Lemeshow (H-L) test.

Results

Patient characteristic

From January, 2017 to December, 2021, we included a total of 756 patients who received central venous catheter insertion and underwent hemodialysis.In total, 64 cases of CRBSI were recorded in our study, with an incidence of 8.5%.The comparison of demographic characteristics and laboratory features results showed that there were statistically significant differences between hemodialysis patients with and without CRBSI in terms of combined with diabetes or coronary heart disease or hyperphosphatemia, previous catheter infection, dialysis age, duration of catheter, white blood cell count, neutrophil count, neutrophil percentage, globulin, urea, creatinine, C-reactive protein, procalcitonin, and concentrations of sodium, chloride, and phosphate ($P<0.05$).Of the 60 patients with positive catheterized blood cultures, 47 (78.3%) were gram-positive and 12 (20.0%) were gram-negative.The most common are Staphylococcus aureus with 24 strains (40.0%), and Escherichia coli with 5 strains (8.3%),respectively.Detailed information on the demographic characteristics of participants were shown Tables 1, 2 and 3.

Development of the CRBSI prediction model

Patients in the training set were used for the development of the prediction model and were divided into CEBSI and non-CRBSI groups according to central venous catheter infections.Single-factor analysis showed that there were significant differences between CRBSI and non-CRBSI individuals in whether they combined with diabetes mellitus or coronary heart disease, their history of catheter infection, dialysis age, catheter retention time, leukocyte, neutrophil, neutrophil percentage, globulin, C-reactive protein, procalcitonin, sodium, chloride, and phosphorus ($P<0.1$)(Tables 4 and 5).

The multivariate analysis combined the stepwise forward and backward selection techniques and demonstrated that combined with diabetes mellitus, dialysis age(≥1 year), catheter retention time(≥14days), C-reactive protein(CRP)and procalcitonin (PCT)were independent risk factors for CRBSI($P<0.05$)(Table 6).The nomogram integrated the five independent factors is shown in Fig. 1. This diagnostic nomogram possessed a good discriminative ability, as reflected by an AUC of 0.88(95%CI = 0.83–0.93)(Fig. 2). The result of H-L goodness-of-fit test were not significant($\chi^2=5$,$P=0.7$),which indicates good agreement between this model's prediction and the actual observation.

Validation of the clinical prediction model

In the internal validation set, this nomogram model exhibited favourable discriminative power, as reflected by an AUC of 0.82(95%CI = 0.73–0.90) and the specificity, sensitivity were 78.6%,84.2% respectively (Fig. 3). Moreover, with the result of H-L test($\chi^2=11$, $P=0.2$),this nomogram model also showed good calibration in the internal validation set.

Discussion

With the continuous development of medical technology, hemodialysis has become the main treatment modality for patients with Kidney Failure, and central venous catheterization has also become a commonly used vascular access for hemodialysis patients.However, catheter infection, as a common complication during hemodialysis, has seriously affected the treatment outcome and quality of life of patients [13].Catheter related bloodstream infections not only increase patients' pain and economic burden, but also may lead to treatment interruption and even endanger patients' lives [14, 15].A total of 756 patients received hemodialysis treatment through CVC were enrolled in the current study, and there were 64 CRBSI

Table 1 Comparison of demographic characteristics of Hemodialysis patients.($n = 756$)

Variables	Categories	Total(*n*, %)	CRBSI(*n*, %)		χ2	*P*
			No(*n* = 692)	Yes(*n*=64)		
Age	< 60	280(37.0)	260(92.9)	20(7.1)	1.004	0.316
	≥ 60	476(63.0)	432(90.8)	44(9.2)		
Sex	Male	485(64.2)	441(90.0)	44(9.1)	0.642	0.423
	Female	271(35.8)	251(92.6)	20(7.4)		
Primary disease	Diabetic nephropathy	198(26.2)	181(91.4)	17(8.6)	0.242	0.999
	Hypertension	107(14.2)	98(91.6)	9(8.4)		
Primary disease	Obstructive nephropathy	88(11.6)	80(90.9)	8(9.1)		
	Chronic glomerulonephritis	298(34.9)	274(91.9)	84(8.1)		
	Polycystic kidney	40(5.3)	36(90.0)	4(10.0)		
	other	25(3.3)	23(92.0)	2(8.0)		
Combined diabetes	No	495(65.5)	476(96.2)	19(3.8)	39.617	<0.001
	Yes	261(34.5)	216(82.8)	45(17.2)		
Combined Coronary Heart Disease	No	529(70.0)	492(93.0)	37(7.0)	4.922	0.027
	Yes	227(30.0)	200(88.1)	27(11.0)		
Combined Hypertension	No	233(30.8)	218(93.6)	15(6.4)	1.787	0.181
	Yes	523(69.2)	474(90.6)	49(9.4)		
Combined renal anemia	No	53(7.0)	50(94.3)	3(5.7)	0.579	0.447
	Yes	703(93.0)	624(91.3)	61(8.7)		
Combined hypoproteinemia	No	664(87.8)	609(91.7)	55(8.3)	0.234	0.628
	Yes	92(12.2)	83(90.2)	9(9.8)		
Combined SHPT	No	355(47.0)	322(90.7)	33(9.3)	0.595	0.440
	Yes	401(53.0)	370(92.3)	31(7.7)		
Combined hyperlipidemia	No	633(87.3)	575(90.8)	58(9.2)	2.440	0.118
	Yes	123(12.7)	117(95.1)	6(4.9)		
Combined hyperphosphatemia	No	611(80.8)	553(90.5)	58(9.5)	4.336	0.037
	Yes	145(19.2)	139(95.9)	6(4.1)		
Previous CVC infection	No	572(75.7)	658(92.3)	55(7.7)	9.141	0.002
	Yes	184(24.3)	34(79.1)	9(20.9)		
Previous CVC insert	< 2	681(90.1)	624(91.6)	57(8.4)	0.081	0.776
	≥ 2	75(9.9)	68(90.7)	7(9.3)		
Type of catheter	NCC	601(79.5)	556(92.5)	45(7.5)	3.619	0.057
	TCC	155(20.5)	136(87.7)	19(12.3)		
Dialysis age	< 1	446(59.0)	418(93.7)	28(6.3)	6.717	0.010
	≥ 1	310(41.0)	274(88.4)	36(11.6)		
Inserted site of catheter	Subclavian	1(0.1)	1(100)	0(0)	1.593	0.451
	Rt internal Jugular	545(72.1)	503(92.3)	42(7.7)		
	Femoral	210(27.8)	188(89.5)	22(10.5)		
Duration of catheter	< 14 days	500(66.1)	481(96.2)	19(3.8)	41.479	<0.001
	≥ 14 days	256(33.9)	211(82.4)	45(17.6)		

*SHPT: secondary hyperparathyroidism

patients, resulting in an incidence density of 0.91 cases per 1,000 catheter-days or 8.5 cases per 100 patients.

Further analysis of the factors associated with the occurrence of CRBSI in hemodialysis patients showed that diabetes mellitus, dialysis age, catheter retention time, procalcitonin(PCT) and C-reactive protein(CRP) were five independent risk factors for CRBSI in hemodialysis patients. Our study found that diabetes mellitus significantly increases the risk of CRBSI in patients with central venous indwelling hemodialysis catheters(OR = 8.60, 95%*CI*: 3.94 ~ 20.77).This finding is consistent with the research by Mohamed et al. [16].

Currently, more than 8% of the global population suffers from diabetes, and over 40% of these individuals will eventually develop to kidney failure [17]. The majority will progress to kidney failure, requiring either hemodialysis treatment or transplantation [17]. However, establishing arteriovenous endovascular fistulae in these patients can be challenging due to long-term hypercoagulable states that lead to peripheral vascular complications [18]. As a result, central venous catheters (CVCs)

Table 2 Comparison of laboratory features of Hemodialysis patients.($n=756$)

Variables	CRBSI [Median(P25, *P* 75)]		Z	*P*
	No	Yes		
WBC(×109/L)	6.43(5.11, 8.49)	7.32(5.81, 12.24)	-2.814	0.005
RBC(×109/L)	2.85(2.36, 3.52)	2.79(2.25, 3.35)	-1.271	0.204
PCV	0.27(0.22, 0.32)	0.25(0.21, 0.32)	-0.715	0.475
Hb(g/L)	83(69, 99.75)	80.5(66, 97)	-0.788	0.431
PLT(×109/L)	177(133, 233)	180(127.5, 232.75)	-0.376	0.707
Neutrophil count(×109/L)	4.77(3.72, 6.6)	5.38(4, 9.78)	-2.692	0.007
Neutrophil percentage(%)	76.1(70.13, 82.08)	81.8(71.43, 87.15)	-2.66	0.008
ESR(mm/h)	52.5(28, 77, 75)	45(35.25, 85.25)	-0.493	0.622
ALB(g/L)	33(29.38)	34(29, 36.38)	-0.052	0.958
GLB(g/L)	30(26, 34)	31.45(28, 35.38)	-2.119	0.034
SF(ug/L)	217.5(133.71, 320.03)	187.45(83.48, 306.38)	-1.747	0.081
Fe(umol/L)	9(5.4, 13)	8.15(4.16, 14.55)	-1.054	0.292
Urea(mmol/L)	19.65(14.19, 26.68)	16.39(13.08, 22.28)	-2.28	0.013
Cr(umol/L)	667(501.25, 863.28)	598(461.25, 760.5)	-1.966	0.049
PTH(pg/ml)	406.55(231.9, 613.38)	339.44(233.46, 553.22)	-1.114	0.265
CRP(mg/L)	14.3(5.04, 34.72)	46.8(15.03, 113.5)	-5.73	<0.001
PCT(ng/ml)	0.48(0.26, 1.48)	2.82(1.13, 14.53)	-7.391	<0.001
K(mmol/L)	4.4.(3.91, 5)	4.39(3.94, 5.08)	-0.185	0.853
Na(mmol/L)	140(137, 142)	138(135, 140.58)	-3.45	0.001
Cl(mmol/L)	103(99.63, 106)	100(97.05, 104.53)	-2.934	0.003
Ca(mmol/L)	2.06(1.89, 2.2)	2.08(1.86, 2.26)	-0.479	0.632
P(mmol/L)	1.67(1.35, 2.10)	1.35(1.18, 1.81)	-3.829	<0.001

*WBC: leukocyte; RBC: erythrocyte; PCV: hematocrit; Hb: hemoglobin; PLT: platelet; ESR: erythrocyte sedimentation Rate; ALB: albumin; GLB: globulin; SF: serum ferritin; Cr: creatinine; PTH: parathyroid hormone

Table 3 Positive results of catheter blood culture in Hemodialysis patients($n=60$)

Pathogenic bacteria	Frequency	Percentage(%)
G^+	47	78.3
MRSA	24	40.0
MRSE	16	26.7
MRCNS	2	3.3
S.capitis	2	3.3
E.faecalis	2	3.3

*G+:gram-positive bacteria; MRSA: staphylococcus aureus; MRSE: staphylococcus epidermidis; MRCNS: staphylococcus haemolyticus

have become a common vascular access method for them. Research by Martin [18] has indicated that metabolic disorders associated with high blood glucose levels decrease the number of immune cells in the body. A high glycemic environment impairs the host's cellular response by inhibiting leukocyte activity, reducing leukocyte adhesion, phagocytosis, and intracellular killing [19]. It also decreases antibody production and creates a favorable environment for pathogenic bacteria to proliferate, thus increasing the risk of infection. Additionally, high glucose levels facilitate bacterial growth and enhance bacterial virulence, further elevating the risk of CRBSI in these patients [19]. Therefore, for hemodialysis patients with diabetes, it is crucial to implement appropriate measures actively. These include effective blood glucose control, timely detection and management of complications, and strategies to improve patients' immunity in order to minimize the occurrence of infections.

Our results indicated that a dialysis duration of one year or more is an independent risk factor for CRBSI in hemodialysis patients with CVCs (OR = 2.47, 95% CI: 1.16–5.38). This finding aligns with Wang's research [20]. Dou [21] noted that hemodialysis patients commonly suffer from hypoproteinemia, immunosuppression, and malnutrition. Hypoproteinemia reduces macrophages and neutrophils' ability to kill bacteria and perform phagocytosis. It also weakens the activation of natural killer (NK) cells and decreases T-lymphocyte activity and number while suppressing their differentiation [21]. As a result, these patients are more susceptible to infections. Hemodialysis patients face nutritional deficiencies due to long-term dietary restrictions, gastrointestinal symptoms related to their condition, and fatigue induced by dialysis [22]. This inadequate protein intake compromises their overall resistance, increasing the infection risk. Additionally, the longer patients undergo dialysis, the greater their exposure to hospital environments where pathogenic bacteria thrive, heightening their risk of infections. Therefore, it is recommended that healthcare professionals enhance catheter monitoring and management to identify and treat signs of infection promptly. Patients should also be advised to focus on daily catheter maintenance, improve disinfection practices at catheter insertion sites, and strictly adhere to aseptic techniques to prevent bacterial infections.

Some researches suggested that the duration of catheter retention is correlated with the incidence of CRBSI [5, 23]. The likelihood of infection increases as the catheter is retained for a longer period. This is consistent with the results of our research that patients with CVCs in place for 14 days or more (OR = 5.19, 95%*CI*: 2.44 ~ 11.63) are more likely to develop catheter infections. Prolonged catheter retention leads to the formation of fibrin sheaths on the catheter's surface, which are primarily composed

Table 4 Comparison of demographic characteristics of patients in training set.($n = 529$)

Variables	Categories	Non-CRBSI($n = 487$, %)	CRBSI($n = 42$, %)	χ^2	*P*
Sex	Male	302(62.0)	27(64.3)	0.02	0.90
	Female	185(38.0)	15(35.7)		
Age in years	< 60	160(32.9)	13(31.0)	0.06	0.80
	≥ 60	327(67.1)	29(69.0)		
Primary disease	Diabetic nephropathy	118(24.3)	14(33.3)	2.95	0.71
	Hypertension	72(14.8)	3(7.1)		
	Obstructive nephropathy	59(12.1)	5(11.9)		
	Chronic glomerulonephritis	193(39.6)	16(38.1)		
	Polycystic kidney	25(5.1)	2(4.8)		
	other	20(4.1)	2(4.8)		
Combined diabetes	No	340(69.8)	11(26.2)	31.03	< 0.001
	Yes	147(30.2)	31(73.8)		
Combined Coronary Heart Disease	No	347(71.3)	24(57.1)	3.03	0.08
	Yes	140(28.7)	18(42.9)		
Combined Hypertension	No	155(31.8)	8(19.0)	2.39	0.12
	Yes	332(68.2)	34(81.0)		
Combined renal anemia	No	36(7.4)	2(4.8)	0.10	0.75
	Yes	451(92.6)	40(95.2)		
Combined hypoproteinemia	No	422(86.7)	38(90.5)	0.22	0.64
	Yes	65(13.3)	4(9.5)		
Combined SHPT	No	233(47.8)	20(47.6)	0	1
	Yes	254(52.2)	22(52.4)		
Combined hyperlipidemia	No	398(81.7)	38(90.5)	1.48	0.22
	Yes	89(18.3)	4(9.5)		
Combined hyperphosphatemia	No	390(80.1)	37(88.1)	1.12	0.29
	Yes	97(19.9)	5(11.9)		
Previous CVC infection	No	462(94.9)	35(83.3)	7.13	0.01
	Yes	25(5.1)	7(16.7)		
Previous CVC insert	< 2	433(88.9)	37(88.1)	0	1
	≥ 2	54(11.1)	5(11.9)		
Type of catheter	NCC	392(80.5)	29(69.0)	2.45	0.12
	TCC	95(19.5)	13(31.0)		
Dialysis age in years	< 1	296(60.8)	16(38.1)	7.31	0.01
	≥ 1	191(39.2)	26(61.9)		
Inserted site of catheter	Subclavian	0(0)	0(0)	1.64	0.20
	Rt internal Jugular	353(72.5)	26(61.9)		
	Femoral	134(27.5)	16(38.1)		
Duration of catheter	< 14 days	332(68.2)	12(28.6)	24.95	< 0.001
Duration of catheter	≥ 14 days	155(31.8)	30(71.4)		

of inflammatory factors, fibrin, and platelets. Bacteria can migrate and settle in the tissue surrounding the catheter, entering the body through these fibrin sheaths, thus increasing the risk of CRBSI [24].In addition, patients with prolonged catheter use often require more frequent catheter operations and care, such as regular dressing changes and catheter flushing. If these procedures are not standardized or conducted thoroughly, the risk of infection can increase [25]. Consequently, medical personnel should enhance hand hygiene and asepsis practices, standardize operational and nursing procedures, and educate patients about catheter self-care. This includes avoiding scratching the skin around the catheter site and maintaining good personal hygiene to prevent CRBSI.

Biomarkers are essential tools for identifying and monitoring patients who develop infections. They help determine the clinical severity of these infections and evaluate antibiotic treatments. Additionally, biomarkers serve as the gold standard for diagnosing bloodstream infections [26]. Previous studies have shown that procalcitonin (PCT), platelet, and C-reactive protein(CRP) can aid in the diagnosis of clinical bloodstream infections [27].In the present study, we found that elevated levels of PCT(OR = 1.02, 95%*CI*: 1.01 ~ 1.03) and CRP (OR = 1.01, 95%*CI*: 1.00 ~ 1.01) were independent predictors of the

Table 5 Comparison of laboratory features of patients in training set.($n=529$)

Variables	Non-CRBSI [$n=487$, Median (P25, P 75)]	CRBSI [$n=42$, Median (P25, P 75)]	Z	P
WBC(×109/L)	5.18(6.43, 8.55)	6.29(7.72, 12.50)	7065.5	< 0.001
RBC(×109/L)	2.38(2.86, 3.56)	2.25(2.68, 3.28)	11391.5	0.22
PCV	0.22(0.27, 0.33)	0.21(0.26, 0.32)	10,572	0.72
Hb(g/L)	69.5(83, 100)	66.00(80.50, 97.00)	11,024	0.40
PLT(×109/L)	135(181, 237.5)	133.75(185.50, 230.25)	10,326	0.92
Neutrophil count(×109/L)	3.81(4.80, 6.62)	4.48(5.66, 10.07)	7398	< 0.001
Neutrophil percentage(%)	70.40(76.30, 82.40)	71.85(81.55, 86.97)	8285.5	0.04
ESR(mm/h)	29(53, 78)	35.25(48.50, 87.50)	9521.5	0.46
ALB(g/L)	29 (33, 38)	28.42(34.00, 36.67)	10593.5	0.70
GLB(g/L)	26 (30, 34)	28.00(31.95, 35.88)	8427	0.06
SF(ug/L)	139.65(218.5, 325.35)	85.35(184.86, 302.67)	11,754	0.11
Fe(umol/L)	5.26(9.00, 13.20)	4.98(9.10, 15.00)	10442.5	0.82
Urea(mmol/L)	13.82(19.12, 25.52)	13.47(16.70, 22.16)	11438.5	0.20
Cr(umol/L)	498.50(647.00, 833.50)	514.5(626.0, 760.5)	10,601	0.69
PTH(pg/ml)	231.82(411.85, 622.40)	199.75(308.60, 515.3)	11770.5	0.10
CRP(mg/L)	5.40(14.9, 34.72)	20.70(47.20, 105.75)	5193	< 0.001
PCT(ng/ml)	0.24(0.47, 1.48)	1.44(3.17, 17.7)	3989.5	< 0.001
K(mmol/L)	3.90(4.38, 4.90)	3.99(4.50, 5.00)	9339	0.35
Na(mmol/L)	137(140, 142)	136(138.5, 141)	11944.5	0.07
Cl(mmol/L)	99(103, 106.25)	97.15(100.85, 104.53)	12,198	0.04
Ca(mmol/L)	1.89(2.06, 2.20)	1.83(2.04, 2.19)	10,596	0.70
P(mmol/L)	1.34(1.65, 2.08)	1.20(1.35, 1.77)	12996.5	< 0.001

Table 6 Risk factors in the prediction model for CRBSI using multivariate logistic regression

Variables	Coef	S.E.	Wald Z	P	OR	95%CI	
						2.50%	97.50%
Constant	-5.39	0.54	-10.07	0.00	0.00	0.00	0.01
Combined diabetes	2.15	0.42	5.13	< 0.001	8.60	3.94	20.77
Dialysis age in years	0.90	0.39	2.33	0.02	2.47	1.16	5.38
Duration of catheter	1.65	0.40	4.17	< 0.001	5.19	2.44	11.63
PCT(ng/ml)	0.02	0.01	2.87	< 0.001	1.02	1.01	1.03
CRP(mg/L)	0.01	0.00	2.24	0.02	1.01	1.00	1.01

development of CRBSI in hemodialysis patients with CVCs.These findings align with the research conducted by Tao [28] and Javier [29].

PCT is a protein released by cells in response to bacterial infection and is typically undetectable in healthy individuals. Its levels increase when a patient is exposed to a bacterial infection and decrease once the infection is under control. PCT is stable and largely unaffected by antibiotics and immune responses [30]. CRP is an acute-phase protein synthesized primarily in the liver. It increases dramatically in response to infection and inflammation, making it a sensitive serum biomarker for tracking the course of inflammation [31]. Our research indicates that rising levels of PCT and CRP are risk factors for the incidence of CRBSI in hemodialysis patients with CVC. We recommend that healthcare professionals closely monitor PCT and CRP levels in these patients and provide early intervention treatments to prevent the worsening of infections.

To enhance the clinical prediction of the risk of CRBSI in patients undergoing maintenance hemodialysis, our study developed a nomogram prediction model based on multivariate logistic regression results. This model visually represents the complex regression equations, and we evaluated its predictive efficacy using ROC curves. The results indicated an area under the curve (AUC) of 0.88, with sensitivity and specificity values of 0.786 and 0.842, respectively, suggesting that the model demonstrates relatively high diagnostic performance. To further validate the accuracy of this prediction model, we conducted an internal validation. In the validation group, the AUC was 0.82, with sensitivity and specificity values of 0.727 and 0.805, respectively, indicating that the model is effective in distinguishing patients at risk and has high predictive accuracy. Calibration of the model was assessed using

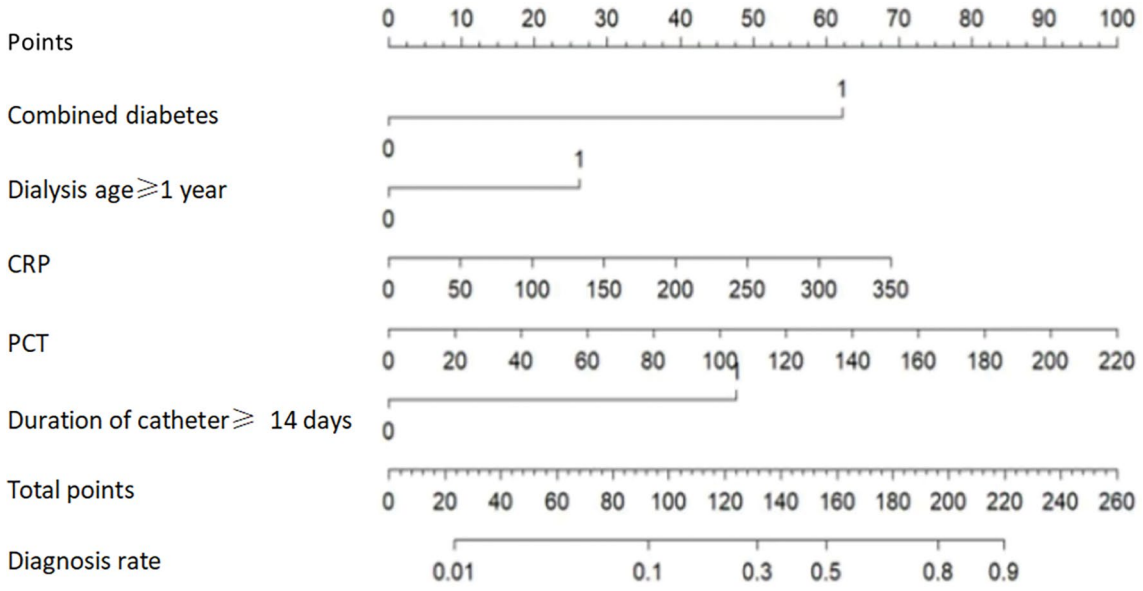

Fig. 1 Nomogram prediction model of CRBSI in hemodialysis patients

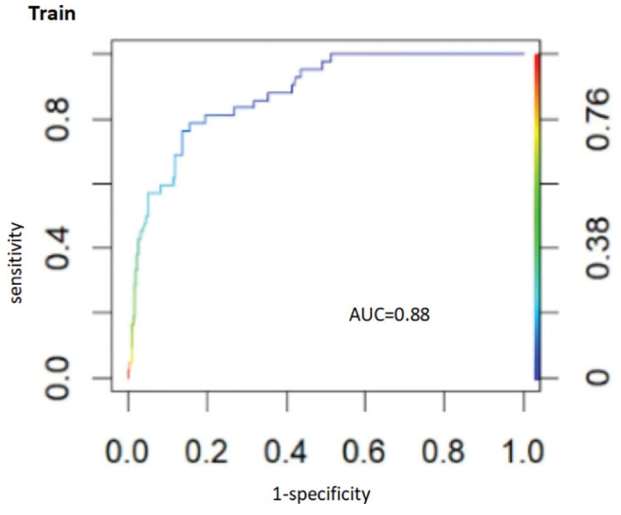

Fig. 2 Validation of the CRBSI nomogram using the receiver operating characteristic curve (ROC) in training set

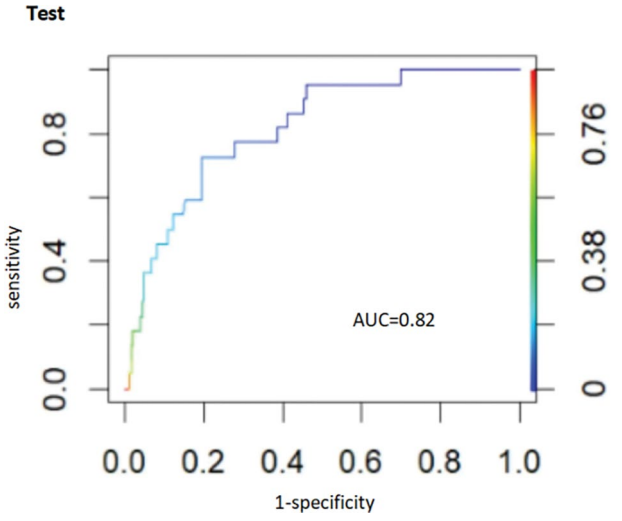

Fig. 3 Validation of the CRBSI nomogram using the receiver operating characteristic curve (ROC) in internal validation set

the Hosmer-Lemeshow test, which yielded a P-value of ≥0.05, confirming that the model is well-calibrated and can assist clinicians in predicting the risk of CRBSI.

This study does have some limitations. First, the sample size was sourced from a single hospital, which introduces specific selection bias and may affect the generalization of the findings. At the same time, there were only 64 cases of CRBSI in our study, which may not fully capture all relevant influencing factors, leading to limited predictive ability of the nomogram.To strengthen our conclusions, it would be beneficial to collect clinical data from multiple centers or regions in future research. Second, the study relied solely on clinical and laboratory data as predictors, which means other potential indicators were overlooked. For instance, medical factors such as the frequency of catheter care, ventilator use, and other invasive procedures like indwelling catheterization could increase the risk of Catheter-Related Bloodstream Infections (CRBSI) but were not thoroughly analyzed here. Future studies should consider including these factors to create a more comprehensive assessment of risk factors for CRBSI in patients undergoing Maintenance Hemodialysis. Finally, while this study developed and internally validated a risk prediction model for CRBSI in hemodialysis patients, external validation is still required to confirm the accuracy and reliability of this model.

In summary, this study developed a nomogram prediction model for CRBSI in hemodialysis patients based

on five factors: combined diabetes mellitus, dialysis age, indwelling catheter time, procalcitonin and C-reactive protein and performed internal validation, which showed that the model had good predictive performance and accuracy.Therefore, it can help healthcare professionals to identify high-risk patients with CRBSI at an early stage, optimize catheter management, and improve patients' treatment outcomes.

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Author contributions
CFW, SW, FD planned the conceptualization and design of the study. FD, YHW, CL collected the data of the article. SW, FD analyzed the data and created the text of the article. CFW, SW, FD worked together to develop the article into its final version.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the declaration of Helsinki, and the protocol was approved by the Medical Research and Clinical Technology Application Ethics Committee of Changsha Central Hospital (approval number: 2024 Medical Review No. 061).Informed consent to participate was obtained from all of the participants in the study.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

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