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Research article

An early warning model to predict acute kidney injury in sepsis patients with prior hypertension

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ABSTRACT

Background: In the context of sepsis patients, hypertension has a significant impact on the likelihood of developing sepsis-associated acute kidney injury (S-AKI), leading to a considerable burden. Moreover, sepsis is responsible for over 50 % of cases of acute kidney injuries (AKI) and is linked to an increased likelihood of death during hospitalization. The objective of this research is to develop a dependable and strong nomogram framework, utilizing the variables accessible within the first 24 h of admission, for the anticipation of S-AKI in sepsis patients who have hypertension.

Methods: In this study that looked back, a total of 462 patients with sepsis and high blood pressure were identified from Nanfang Hospital. These patients were then split into a training set (consisting of 347 patients) and a validation set (consisting of 115 patients). A multivariate logistic regression analysis and a univariate logistic regression analysis were performed to identify the factors that independently predict S-AKI. Based on these independent predictors, the model was constructed. To evaluate the efficacy of the designed nomogram, several analyses were conducted, including calibration curves, receiver operating characteristics curves, and decision curve analysis.

Results: The findings of this research indicated that diabetes, prothrombin time activity (PTA), thrombin time (TT), cystatin C, creatinine (Cr), and procalcitonin (PCT) were autonomous prognosticators for S-AKI in sepsis individuals with hypertension. The nomogram model, built using these predictors, demonstrated satisfactory discrimination in both the training (AUC = 0.823) and validation (AUC = 0.929) groups. The S-AKI nomogram demonstrated superior predictive ability in assessing S-AKI within the hypertension grade I (AUC = 0.901) set, surpassing the hypertension grade II (AUC = 0.816) and III (AUC = 0.810) sets. The nomogram exhibited satisfactory calibration and clinical utility based on the calibration curve and decision curve analysis.

Conclusion: In patients with sepsis and high blood pressure, the nomogram that was created offers a dependable and strong evaluation for predicting S-AKI. This evaluation provides valuable insights to enhance individualized treatment, ultimately resulting in improved clinical outcomes.

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1. Introduction

Sepsis is a pervasive and lethal condition resulting from an uncontrolled immune reaction to an infection. It causes organ dysfunction leading to septic shock with hypotension and multisystem organ failure [1]. For several years, it has been the primary reason for ICU admissions and deaths globally, with a consistent rise in its occurrence [2]. Sepsis, the primary reason for AKI, is prevalent in approximately 40–50 % of instances among severely ill individuals [3]. Furthermore, sepsis-related acute kidney injury (S-AKI) is linked to an increased likelihood of death during hospitalization and a prolonged duration of hospital stay in comparison to alternative types of AKI [3,4]. Around 244.5 million adults in China suffer from hypertension, leading to a considerable disease burden [5]. Research has shown that pre-existing high blood pressure is among the most important factors that increase the risk of AKI [6,7]. Among the 19,579 patients in Beijing city, recorded in a vast regional population database, it was found that 52.2 % of individuals with S-AKI also had hypertension, which is considered a contributing factor for S-AKI [6]. While the primary causes of AKI have been proven to be reduced blood flow to the kidneys, resulting in the death of tubular epithelial cells or acute tubular necrosis, there is still ongoing discussion about the pathophysiological mechanisms responsible for S-AKI. Nevertheless, the timely identification of S-AKI and individualized treatment in sepsis patients with high blood pressure remains crucial for enhancing the clinical outlook.

At present, there is no known approach to hinder or manage S-AKI. Several new markers suggested for the diagnosis of AKI include the DNI, PENK, IL-18 in urine, KIM-1 in urine, and NGAL. The high cost and technical requirements make them challenging to implement in clinical practice [8–10]. A significant obstacle to the successful translation of these indicators in clinical settings is the disparity between clinical and preclinical studies. For instance, animal models of AKI are unable to replicate human conditions (such as age and comorbidities) and there is also a variation in the definition of AKI [11,12]. Furthermore, traditional risk factors for S-AKI, like advanced age, persistent high blood pressure, diabetes, platelet levels, and PCT levels, fail to offer adequate data for prompt detection when employed as a sole indicator, thus delaying timely intervention [7,13,14]. Hence, the creation of a nomogram utilizing regular data can lead to a remarkably precise and evidence-driven assessment of risk, offering significant clinical significance. This retrospective study presents a nomogram model that aims to predict the occurrence of S-AKI in sepsis patients with pre-existing hypertension, using variables obtained within 24 h of admission.

2. Materials and methods

2.1. Study design

From January 2015 to December 2021, a study was conducted on 462 sepsis patients who had pre-existing hypertension. The study obtained anonymized clinical data from the Information Department of Southern Medical University Southern Hospital's data processing and application platform.

2.2. Patients

The study included all sepsis patients aged 18 years and older with prior hypertension. Two doctors with moderate professional designations assessed the patients individually to determine their eligibility for participation in the study. The diagnosis of sepsis was made according to the criteria outlined in Sepsis-3.0 [1]. Moreover, a prior diagnosis of hypertension or treatment with antihypertensive medication indicated hypertension. Exclusion criteria encompassed the following: (1) Individuals below the age of 18; (2) Hospital stays lasting less than 24 h; (3) Patients with end-stage renal disease or undergoing hemodialysis; (4) Individuals with hematological disorders. According to the clinical practice guidelines of Kidney Disease Improving Global Outcomes (KDIGO), a rise in serum Cr of at least 0.3 mg/dl or 26.5 % mol/l observed within 48 h, an increase in serum Cr level of at least 1.5 times over the initial level within seven days, or a cumulative urine output equal to or less than 0.5 ml/kg/hour in the preceding 6 h, the participants were identified as S-AKI [15].

2.3. Data collection

The age, gender, temperature (T), heart rate (HR), comorbidities (hypertension, diabetes, and cardiovascular disease), respiratory rate (RR), source of infection, and sequential organ failure assessment (SOFA) score were readily accessible within 24 h of admission. Within 24 h of admission, the following laboratory results were also accessible: white blood cell count (WBC), percentage of neutrophils (NEUT%), lymphocyte count, monocyte count, platelet count (PLT), procalcitonin (PCT), prothrombin activity (PTA), D-Dimer (D-D), thrombin time (TT), fibrinogen degradation products (FDP), prothrombin time (PT), urinary glucose level, international normalized ratio (INR), cystatin C level, fibrinogen level (FIB), uric acid level (UA), and creatinine (Cr) level. The level of activated partial thromboplastin time (APTT) was not included in this study because it was affected by lupus inhibitors, elevated factor VIII levels, and contamination with heparin [16,17]. Furthermore, the study did not incorporate blood urea nitrogen (BUN) due to its susceptibility to non-renal influences, including protein consumption, catabolic condition, upper gastrointestinal bleeding, volume status, and high-dose steroid treatment [18].

2.4. Statistical analysis

A prediction model was constructed (using 75 % of the sample size) in the training group and validated (using 25 % of the sample

size) in the validation group. The median with quartile was used to express the continuous variables; appropriate comparisons were made using Mann-Whitney U-tests. Percentages were used to express the categorical variables, and either Pearson's chi-squared or Fisher's exact tests were employed. To determine the autonomous factors of S-AKI, a multivariate logistic regression analysis and a univariate logistic regression analysis were used in the training group. To utilize the nomogram, a vertical line is extended upwards towards the "Points" axis. The totals of all predictors were summed, and the ultimate value was found on the axis labeled as "Total Points". In conclusion, a vertical line was sketched towards the 'Probability of S-AKI' axis to assess the likelihood of AKI (Fig. 2).

To evaluate the nomogram's ability to discriminate between the training and validation groups, the area under the receiver operating characteristic (ROC) curve was computed. To evaluate the conformity of our observations with our anticipated results, we constructed calibration graphs. A detailed analysis of the DCA was conducted to evaluate the clinical advantage of the nomogram. In the various levels of high blood pressure, a subgroup analysis was conducted for high blood pressure level I, high blood pressure level II, and high blood pressure level III.

SPSS 26.0 and R version 4.1.2 were used for the analyses. A statistical significance was attributed when P value was less than 0.05.

3. Results

3.1. Basic characteristics

This study included 462 sepsis patients with hypertension, of whom 193 (41.8 %) had S-AKI (Fig. 1). Furthermore, the training dataset, consisting of 75 % of the total cases (n = 347), and the validation dataset, comprising 25 % of the total cases (n = 115), were selected randomly. The demographic features, vital signs, and laboratory tests presented in Table 1 demonstrate similarities in the training and validation sets. Among the sepsis patients with hypertension, the occurrence of S-AKI was 40.9 % in the training set and 44.3 % in the validation set. In the training group, 43.2 % of patients were female, with a median age of 67 years (ranging from 57 to 74). Within the validation set, the participants had a median age of 67 years (with a range of 60–75), and 35.7 % of them were female.

3.2. Univariate analysis results in the training group

Within 24 h of admission (Table 2), all the demographic features, vital signs, and laboratory tests were accessible. In comparison to the non-AKI group, univariate analyses indicated that the S-AKI group exhibited a significant increase in RR, diabetes (2.306, 1.480–3.595), cardiovascular disease, SOFA, WBC, PCT (1.022, 1.014–1.030), TT (1.030,1.010–1.050), INR, FDP, PT, UA, Cystatin C (2.577, 1.936–3.431), and Cr (1.008, 1.006–1.010). On the other hand, the S-AKI group exhibited significantly lower levels of MAP, PLT, and PTA (0.962, 0.948–0.977) compared to the non-AKI group. Furthermore, the hypertension grade and infection sources were significantly different between the S-AKI group and the non-AKI group.

3.3. Independent predictors of S-AKI and development of a nomogram in the training group

Significant variables identified in the univariate analyses, including RR, MAP, hypertension, cardiovascular disease, diabetes, SOFA, WBC, PCT, TT, PTA, NEUT, INR, PT, PLT, UA, FDP, Cystatin C, and Cr, were included in the multivariate logistic regression analyses. In Table 3, diabetes (2.034, 1.201–3.44), PTA (0.977, 0.965–0.990), PCT (1.014, 1.005–1.023), cystatin C (1.614, 1.143–2.281), TT (1.024,1.000–1.048), and Cr (1.004, 1.001–1.006) were identified as significant factors for predicting S-AKI in sepsis patients with hypertension. Furthermore, a nomograph was created using these attributes to forecast S-AKI in septic patients who have high blood pressure (Fig. 2).

3.4. Verification of the prediction model

The model demonstrated good predictive ability for S-AKI in sepsis patients with hypertension, as shown by the ROC curve analyses in Fig. 3. This was observed in both the training cohort (AUC = 0.823) and the validation cohort (AUC = 0.829). Cutoff points refer to

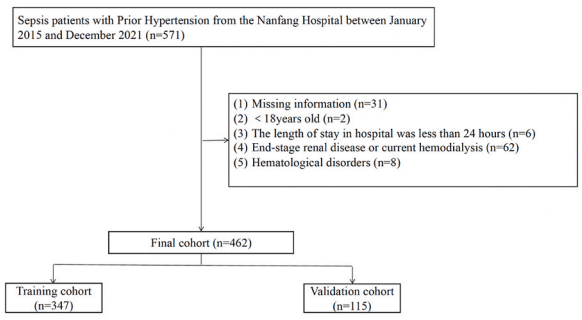

Fig. 1. The flowchart of patient selection.

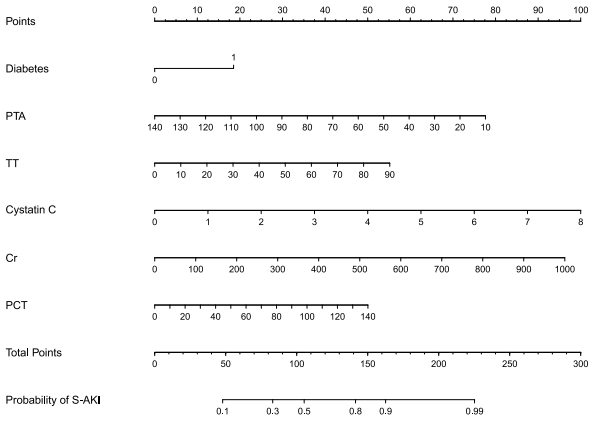

Fig. 2. A nomogram for assessing the likelihood of S-AKI in septic patients who have high blood pressure. To utilize the nomogram, our initial step involves sketching a vertical line in an upward direction towards the "Points" axis. Add up the scores for each predictor and find the ultimate value on the 'Total Points' axis. In conclusion, simply draw a vertical line to the axis labeled "Probability of S-AKI" to ascertain the likelihood of AKI. Sepsis-induced acute kidney injury (S-AKI) is characterized by elevated serum procalcitonin (PCT) levels, prolonged thrombin time (TT), decreased prothrombin time activity (PTA), and increased creatinine (Cr) levels.

the linear prediction value rather than the probability. The calibration curve of the nomogram indicated a successful calibration, as the predicted probabilities aligned with the observed results (Fig. 4). The nomogram demonstrated a superior net benefit across a broad and applicable range of threshold probabilities, as indicated by the DCA, suggesting its significant clinical usefulness (Fig. 5).

3.5. A subgroup analysis of hypertension in the total cases

In the total cases, there were 65 (14.1 %) patients with hypertension grade I, 156 (33.8 %) patients with hypertension grade II, and 241 (52.2 %) patients with hypertension grade III. The nomogram demonstrated superior predictive ability for S-AKI in hypertension grade I (AUC = 0.901) compared to hypertension grade I (AUC = 0.810) and hypertension grade II (AUC = 0.810) sets, as depicted in Fig. 6. The calibration curve of the model in all three sets of hypertensions grade I, grade II, and grade III showed that the predicted probabilities aligned with the observed results, suggesting a successful calibration (Fig. S1). According to DCA, the nomogram demonstrated a greater overall advantage in comparison to the various threshold probabilities, suggesting significant potential for clinical usefulness (Fig. S2).

4. Discussion

In this study, 41.8 % of sepsis patients with hypertension developed AKI, which is like previous findings. A study conducted in nine central hospitals in China found that out of 146,148 adult patients with sepsis, 68,835 cases of AKI (47.1 %) were identified during their hospitalization period [19]. In our study and others, infection sources were significantly different (P = 0.040) in developing S-AKI during sepsis [20]. Several multicenter observational studies indicated that S-AKI patients had a greater risk of death, higher resource utilization rates, higher medical costs, and worse outcomes than those without AKI [19,21]. Zhou et al. showed a notable disparity in the mortality rate after 28 days between patients with S-AKI and those with sepsis alone, with percentages of 43.9 % and 23.4 % respectively [22]. Even if patients recover from S-AKI at the time of discharge, there is still an impact on long-term mortality of up to 15 years [23]. However, recovery by hospital discharge from AKI also improves survival compared with patients without recovery [24]. In sepsis patients with hypertension, constructing a rapid and accurate nomogram model for S-AKI has facilitated early prediction, the development of effective preventive strategies, and treatments, thus decreasing the risk of S-AKI.

Approximately 17%–20 % of sepsis patients have diabetes mellitus [25,26]. Numerous studies have revealed that T2DM does not elevate the overall mortality rate among patients with sepsis; however, it is linked to a heightened susceptibility to S-AKI [26–28]. Furthermore, prolonged high blood sugar levels can lead to kidney injury through the activation of NF-kappa B, TGF-x, and oxidative stress [27]. Our current investigation also revealed that PCT, PTA, TT, cystatin C, and Cr independently predicted the development of S-AKI in sepsis patients with hypertension. Identifying biomarkers that indicate inflammation dysregulation is crucial in predicting S-AKI during routine clinical reactions. Numerous studies have suggested that PCT has a crucial role in the diagnosis of bacterial infection and the guidance of antibiotic treatment in patients with sepsis [29,30]. Furthermore, the study revealed that PCT demonstrated higher accuracy in predicting S-AKI compared to certain conventional inflammatory biomarkers such as white blood cells (WBC), platelets (PLT), lymphocytes, monocytes, and neutrophils (NEUT), which aligns with previous research [30,31]. Elevated levels of proinflammatory cytokines and chemokines in the blood due to infection and inflammation, increased synthesis of proinflammatory cytokines by PCT leading to cytotoxicity and apoptosis of mesangial cells, decreased glomerular filtration rate associated with increased PCT concentrations in the early stages of AKI, and attraction of monocytes resulting in cell damage at the inflammation site are the reasons for elevated PCT levels in S-AKI.

Table 1
Baseline characteristics of sepsis patients with hypertension.

Variable	Total (n = 462)	Training(n = 347)	Validation(n = 115)	*P*-value
S-AKI, n (%)				0.59
No	269(58.2)	205(59.1)	64(55.7)	
Yes	193(41.8)	142 (40.9)	51(44.3)	
Age	67(58–75)	67(57–74)	67(60–75)	0.58
Gender, n (%)				0.18
Female	191(41.3)	150(43.2)	41(35.7)	
Male	271(58.7)	197(56.8)	74(64.3)	
Vital signs				
T (∘C)	36.5(36.2–37.0)	36.5(36.2–37.0)	36.5(36.2–37.0)	0.59
RR (bpm)	20(18–23)	20(18–22)	20(18–23)	0.98
HR (bpm)	88(78–106)	87(78–105)	92(77–108)	0.76
MAP (mmHg)	89(79–106)	86(70–99)	87(77–104)	0.33
Comorbidities				
Hypertension, n (%)	0.23			
Grade I	65(14.1)	51(14.7)	14(12.2)	
Grade II	156(33.8)	123(35.4)	33(28.7)	
Grade III	241(52.2)	173(49.9)	68(59.1)	
Diabetes, n (%)	178(38.5)	133(38.3)	45(39.1)	0.97
Cardiovascular disease, n (%)	186(40.3)	143(41.2)	43(37.4)	0.54
Infection sources, n (%)				0.15
Pulmonary infection	110(23.4)	81(23.3)	29(25.2)	
Intra-abdominal infection	269(58.2)	209(60.2)	60(52.2)	
Urinary infection	55(11.9)	36(10.4)	19(16.5)	
Central nervous system infection	12(2.6)	7(2.0)	5(4.3)	
Skin and soft tissue infections	9(1.9)	7(2.0)	2(1.7)	
Cardiovascular system infections	7(1.5)	7(2.0)	0(0)	
SOFA	5(3,10)	5(3,10)	5(3,10)	0.92
Laboratory test				
WBC (x 10^9/L)	9.41(6.23–14.72)	9.17(6.08–14.06)	10.48(6.38–15.99)	0.27
Monocyte (x 10^9/L)	0.43(0.25–0.62)	0.43(0.25–0.62)	0.42(0.23–0.65)	0.82
NEUT (%)	87.05(76.58–92.10)	86.5(79.5–92.0)	88.0(78.2–93.2)	0.28
Lymphocyte (x 10^9/L)	0.77(0.47–1.16)	0.79(0.48–1.16)	0.73(0.46–1.17)	0.52
PLT (x 10^9/L)	148(91–215)	147(85–218)	150(100–205)	0.89
PCT (ng/ml)	3.08(0.54–23.02)	2.91(0.50–21.63)	3.30(0.66–30.98)	0.25
PTA (%)	74(60–87)	74(60–88)	75(57–87)	0.55
TT (S)	13.90(0.99–17.3)	1.99(0.98–17.20)	15.1(1.01–17.60)	0.09
INR	1.19(1.08–1.37)	1.18(1.07–1.36)	1.19(1.08–1.37)	0.59
FDP (mg/L)	10.09(5.02–21.90)	10.09(5.03–21.90)	9.82(4.80–22.05)	0.94
D-D (mg/L)	3.40(1.80–7.11)	3.46(1.76–7.09)	3.27(1.80–7.25)	0.84
FIB (g/L)	4.43(3.13–5.90)	4.48(3.11–5.99)	4.30(3.14–5.72)	0.57
PT (S)	14.50(13.10–16.4)	14.40(13.1–16.4)	38.0(33.9–44.3)	0.82
UA (umol/L)	318(213–436)	318(210–430)	316(220–442)	0.78
Cystatin C (mg/L)	1.41(0.99–2.04)	1.42(0.98–2.04)	1.35(0.99–2.05)	0.89
Cr (umol/L)	83(56–171)	83(56–171)	83(55–182)	0.89

The median with quartile was used to express the continuous variables. S-AKI refers to sepsis-associted acute kidney injury. T represents body temperature. SOFA stands for sequential organ failure assessment. HR indicates heart rate. RR represents respiratory rate. MAP refers to mean arterial pressure. WBC stands for white blood cell. NEUT% represents neutrophil percentage. PLT represents platelet. PCT refers to serum procalcitonin. PTA stands for prothrombin time activity. TT represents thrombin time. INR indicates international normalized ratio. FDP represents fibrinogen degradation products. D-D represents D-Dimer. FIB refers to fibrinogen. PT represents prothrombin time. UA represents uric acid. Cr represents creatinine.

Moreover, the connections between the inflammatory reaction and coagulation impairment were close and complex, leading to the development of S-AKI in cases of sepsis. For example, the inflammatory actions have the potential to harm the vascular endothelium, leading to the activation of platelets and causing dysfunction in blood clotting. Platelet granules, when released, can aggravate inflammatory responses and hyperactivate the coagulation system, thereby contributing to the formation of micro-thrombi in the microvascular of the kidney. In the clinic, APTT and PT serve as the most important parameters in assessing exogenous and endogenous coagulation, respectively. Nevertheless, numerous factors in hospitalized patients, such as a lack of vitamin K and temporary lupus inhibitors, can lead to confusion in interpreting APTT [17]. Moreover, the variability of thromboplastin reagents can lead to significant differences in PT results across different laboratories. Consequently, PTA or INR could potentially enhance the prediction of S-AKI by offering a universal PT reporting scale [32,33]. According to our research, PTA emerged as a significant predictor for S-AKI, whereas INR did not show the same association. In addition, we also indicated that TT was a functional indicator of AKI. Nevertheless, there is a lack of studies documenting the prognostic significance of TT in sepsis patients with regards to S-AKI, necessitating additional investigation.

Cr, a small molecule produced in muscle, serves as a functional indicator of AKI. However, it can be negatively influenced by various factors including age, gender, race, muscle mass, nutritional status, total parenteral nutrition, infection, protein consumption, catabolic states, and volume status [18]. Furthermore, the level of serum Cr remains unchanged until half of the renal function is lost,

Table 2
In the training cohort, an analysis was conducted on the predictive variables of S-AKI using univariate methods.

Variables	OR	95 %	*P*-value
Age (years)	1.015	0.998–1.033	0.078
Gender	0.839	0.545–1.292	0.426
Vital signs			
T (∘C)	0.981	0.731–1.317	0.900
RR (bpm)	1.065	1.020–1.112	0.004
HR (bpm)	1.008	0.998–1.018	0.105
MAP (mmHg)	0.975	0.962–0.988	< 0.001
Comorbidities			
Hypertension	–	–	0.046
Diabetes	2.306	1.480–3.595	< 0.001
Cardiovascular disease	2.040	1.317–3.161	0.001
Infection sources	–	–	0.040
SOFA	1.169	1.094–1.248	< 0.001
Laboratory test			
WBC (x 10^9/L)	1.044	1.016–1.073	0.002
Monocyte (x 10^9/L)	1.351	0.885–2.063	0.164
NEUT (%)	1.028	1.009–1.048	0.004
Lymphocyte (x 10^9/L)	0.958	0.771–0.958	0.779
PLT (x 10^9/L)	0.994	0.992–0.997	< 0.001
PCT (ng/ml)	1.022	1.014–1.030	< 0.001
PTA (%)	0.972	0.961–0.983	< 0.001
TT (S)	1.030	1.010–1.050	0.003
INR	7.263	3.093–17.054	< 0.001
FDP (mg/L)	1.009	1.000–1.017	0.038
D-D (mg/L)	1.022	0.998–1.046	0.070
FIB (g/L)	1.133	1.019–1.260	0.021
PT (S)	1.075	1.029–1.122	0.001
UA (umol/L)	1.004	1.003–1.006	< 0.001
Cystatin C (mg/L)	2.577	1.936–3.431	< 0.001
Cr (umol/L)	1.008	1.006–1.010	< 0.001

Body temperature, also known as T; Sequential organ failure assessment, also known as SOFA; Heart rate, also known as HR; Respiratory rate, also known as RR; Mean arterial pressure, also known as MAP; White blood cell, also known as WBC; Neutrophil percentage, also known as NEUT%; Platelet, also known as PLT; Serum procalcitonin, also known as PCT; Prothrombin time activity, also known as PTA; Thrombin time, also known as TT; International normalized ratio, also known as INR; Fibrinogen degradation products, also known as FDP; D-Dimer, also known as D-D; Fibrinogen, also known as FIB; Prothrombin time, also known as PT; Creatinine, also known as Cr; Confidence interval, also known as CI; Odds rate, also known as OR.

Table 3
In the training cohort, a multivariate analysis using logistic regression was conducted to identify independent predictors of S-AKI.

Variables	OR	95 % CI	*P*-value
Diabetes	2.034	1.201–3.444	0.008
PTA	0.977	0.965–0.990	< 0.001
PCT	1.014	1.005–1.023	0.002
Cystatin C	1.614	1.143–2.281	0.007
TT	1.024	1.000–1.048	0.045
Cr (umol/L)	1.004	1.001–1.006	0.008

Thrombin time is denoted as TT, serum procalcitonin is represented as PCT, prothrombin time activity is abbreviated as PTA, and creatinine is indicated by Cr.

suggesting a deficiency in sensitivity and dependability for promptly identifying AKI. However, AKI has been characterized by a rapid elevation in serum creatinine levels, a reduction in urine output, or both, suggesting that creatinine holds substantial predictive utility for AKI [34]. Additionally, research findings indicated that Cystatin-C did not surpass serum creatinine in its ability to identify neonatal AKI [35]. Recent research has revealed cystatin C as a possible indicator of S-AKI or a reliable substitute for the established benchmark “creatinine” [36,37]. Although cystatin C is a better early detection biomarker than Cr for AKI during sepsis, combining them into a composite biomarker improved the predictive value better than any biomarker alone or any other combination [38].

Using the independent predictors available within 24 h of admission, we developed and verified a straightforward nomogram model to forecast S-AKI in sepsis patients who have hypertension. The constructed nomogram exhibited superior predictive effectiveness in both the training (AUC = 0.823) and validation (AUC = 0.829) datasets. Moreover, the nomogram exhibited superior predictive capability in hypertension grade I (AUC = 0.901) compared to the other grades. Meanwhile, the nomogram that was designed showed good performance in terms of discrimination, calibration, and clinical application following verification. Here is an illustration demonstrating the application of the nomogram model for a sepsis patient who has both hypertension and diabetes.

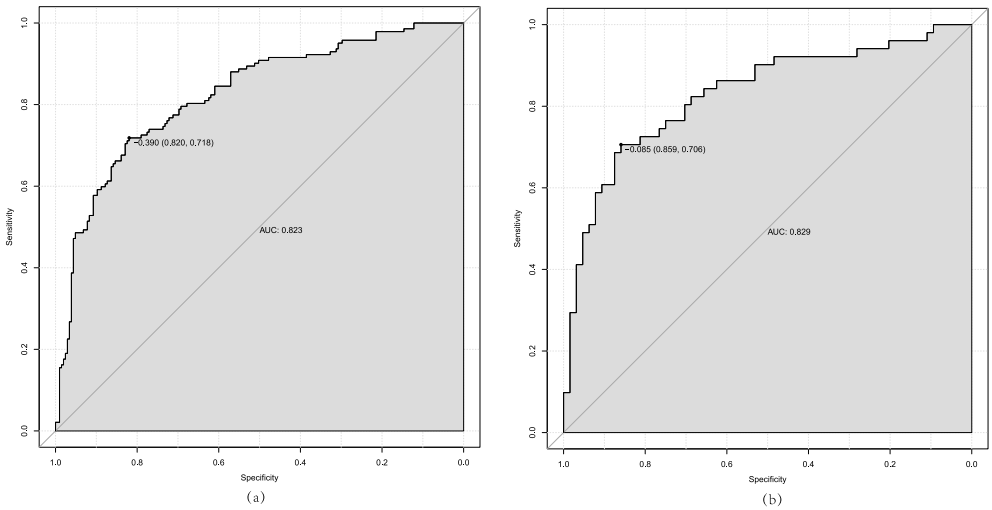

Fig. 3. The receiver operating characteristic curve for the nomogram predicting S-AKI in sepsis patients with hypertension. AUC refers to the area under the curve of receiver operating characteristics. The nomogram achieved an AUC of 0.823 in the training set (a) and 0.829 in the validation set (b) for predicting sepsis-induced acute kidney injury (S-AKI) in patients with hypertension.

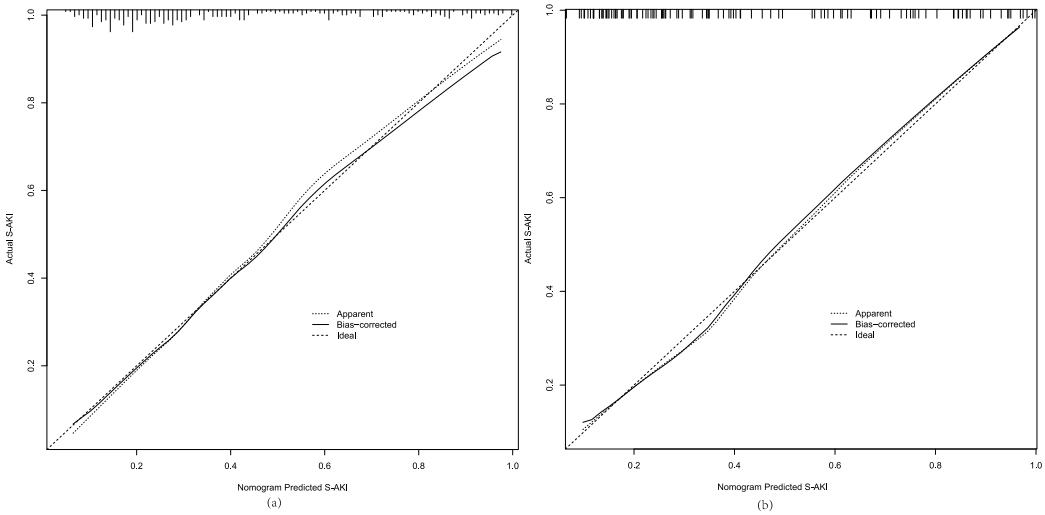

Fig. 4. Calibration curves for the predicted nomogram were obtained in both the training set (a) and validation set (b). The nomogram calculates the predicted probability on the x-axis, while the observed actual probability of S-AKI is represented on the y-axis. The clinodiagonal is the perfect prediction of an ideal model. Consequently, the initial cohort is depicted by the solid curve while the bias-corrected curve, obtained through bootstrapping with 1000 repetitions (B = 1000), demonstrates the performance of the predicted model.

Additionally, the patient has a PTA of 80 %, a TT of 50s, a cystatin C level of 3 mg/L, a Cr level of 400 μmol/l, and a PCT level of 40 ng/ml. Each parameter is denoted by a score on the "Points" axis, as illustrated in Fig. 2. To calculate the total score, add up the points for each parameter: 18 for diabetes, 35 for PTA, 30 for TT, 36 for cystatin C, 36 for Cr, and 13 for PCT, resulting in a sum of 168. Based on this score, the risk of developing S-AKI is approximately 93.6 %.

4.1. Limitations

Furthermore, this study had various constraints. Firstly, it was conducted in a solitary facility with a limited number of participants, which could have led to selection bias impacting the outcomes. The improvement of management decision-making processes over a

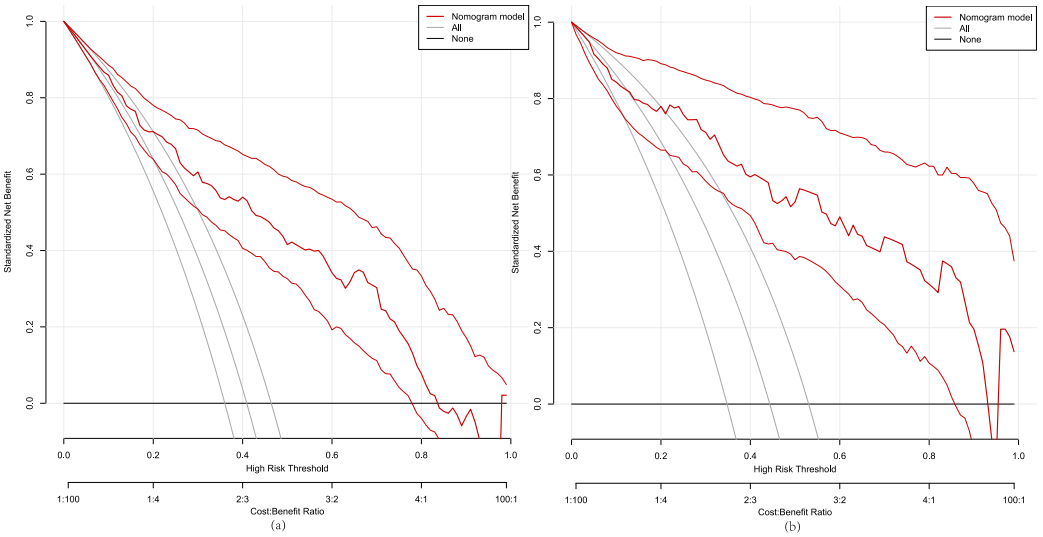

Fig. 5. DCA was performed on the nomogram in the training set (a) and the validation set (b). No patients develop S-AKI as indicated by the horizontal line, and patients develop S-AKI as indicated by the gray oblique line. The risk nomogram for S-AKI is depicted by the solid red line. Across a range of threshold probabilities, the nomogram in DCA demonstrates a higher advantage compared to both complete treatment and no treatment.

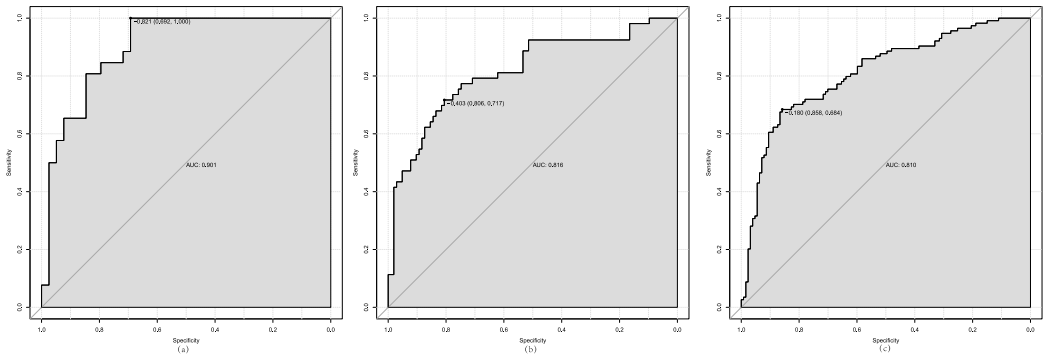

Fig. 6. The receiver operating characteristic curve for the nomogram predicting S-AKI in sepsis patients with different hypertension grades. AUC refers to the area under the curve of receiver operating characteristics. In sepsis patients with hypertension, the nomogram achieved an AUC of 0.901 in the grade I hypertension set (a), 0.818 in the grade II hypertension set (b), and 0.810 in the grade III hypertension set (c) for predicting S-AKI.

period of seven years in a retrospective study had a significant impact on the development of S-AKI. Because of deficiencies in the system and the anonymization of clinical data, we faced difficulties in acquiring certain crucial details, like the follow-up data, of sepsis patients from the Biobank. Therefore, additional multi-center prospective investigations are required to validate the results.

5. Conclusions

The findings of this research indicated that diabetes, peripheral arterial disease, toe temperature, cystatin C, creatinine, and procalcitonin, collected within 24 h of hospital admission, were autonomous indicators for sepsis-associated acute kidney injury in patients with hypertension. Moreover, the nomogram that was created using these predictors exhibited excellent performance in the discrimination, calibration, and clinical application assessments, particularly among sepsis patients classified as having hypertension grade I. The early identification of S-AKI and prompt individualized treatment of sepsis patients with high blood pressure were greatly enhanced by this particular model, leading to improved clinical outcomes.

Data availability statement

The study incorporates the original findings, which can be found in the article and Supplementary Material. For additional inquiries, please contact the corresponding authors.

Ethics statement

This study was conducted following the Declaration of Helsinki. The Medical Ethics Committee of the Southern Hospital of Southern Medical University approved this study (NFEC-2022-183). All patient data were analyzed in anonymity. Patient consent was waived by the ethics committee, as no individual data were published, nor was any intervention performed on patients.

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CRediT authorship contribution statement

Zhuo Ma: Writing – review & editing, Writing – original draft, Data curation. **Weifeng Liu:** Methodology. **Fan Deng:** Writing – review & editing. **Meichen Liu:** Methodology, Investigation. **Weijie Feng:** Validation, Supervision. **Bingsha Chen:** Validation, Supervision. **Cai Li:** Supervision, Software. **Ke Xuan Liu:** Visualization, Validation, Supervision, Software, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e24227.

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