Risk Factors for Mortality in Patients with Severe Acute Kidney Injury Treated with CRRT: A Single-Center Retrospective Study

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Keywords. Acute kidney injury; Continuous renal replacement therapy; In-hospital death; Risk factors; Model

Introduction. To explore the risk factors of in-hospital death in patients with severe acute kidney injury (AKI) after continuous renal replacement therapy (CRRT) and to build a prediction model.
Methods. In total, 378 patients with AKI were treated in the ICU of affiliated hospital of Fujian Medical University, Zhangzhou City, between June 2018 and August 2024. All patients received CRRT. According to prognosis, patients were divided into the survivor and mortality groups. The clinical data from both groups were compared. A nomogram prediction model was developed based on independent risk factors identified through multivariable logistic regression analysis.
Results. Overall, 195 patients (51.59%) died in the hospital. Compared with the survival group, the mortality group had significantly higher Acute Physiologic Assessment and Chronic Health Evaluation (APACHE) II and Sequential Organ Failure Assessment (SOFA) scores, mechanical ventilation rates, lactic acid levels, SCr at baseline, the last recorded SCr before death or discharge, duration of anuria before CRRT, total duration of RRT, and ICU stay, while initial and final eGFR were significantly lower (all, $P < .05$). Multivariable logistic regression analysis showed that APACHE II score, SOFA score, duration of anuria before CRRT, and total duration of RRT were independent risk factors for hospital death in AKI ($P < .05$), while initial higher eGFR was a protective factor ($P < .05$). The consistency index (C-index) of the nomogram model was 0.751 (95%CI: 0.683~0.819), and the AUC of the ROC curve was 0.738 (95%CI: 0.701~0.775), which had good discrimination. The evaluation results of the calibration curve and clinical decision curve suggested that the model was accurate and effective.
Conclusion. The APACHE II score, SOFA score, anuria duration before CRRT, and total RRT time were independently associated with in-hospital mortality of AKI patients treated with CRRT. These findings demonstrate the severity markers of AKI; nevertheless, prospective validation will remain necessary.

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INTRODUCTION

Acute kidney injury (AKI) is one of the most complex and critically relevant issues concerning those in intensive care units (ICUs), characterized by a rapid decline in renal function and a rise in serum creatinine (SCr).[1,2] AKI is frequently associated with

multi-organ failure, which contributes to its high morbidity and mortality rates.[3] Continuous renal replacement therapy (CRRT) is the most common form of supportive lifesaving therapy in ICU setting for AKI.[4] With its universal application, however, mortality during CRRT treatment remains unbearably high, with an alarming range from 30% to 60%.[5,6]

Finding factors related to mortality in AKI patients receiving CRRT is important for optimizing treatment strategies. Several studies suggested that severity scoring systems, especially APACHE II and SOFA, are likely predictors of mortality.[7,8] Nevertheless, other risk factors, such as the duration of anuria prior to CRRT initiation and the duration of time on renal replacement therapy (RRT), have not been thoroughly investigated.[9,10]

This study aims to identify the clinical profile and independent predictors of in-hospital mortality among AKI patients treated with CRRT and set up a nomogram prediction model to aid clinicians in their decision-making.

MATERIALS AND METHODS

Study Design

This retrospective study included 378 AKI patients admitted in ICU of affiliated hospital of Fujian Medical University, Zhangzhou City, between June 2018 and August 2024. Since it was a retrospective study, informed consent was not required.

Patient Selection

Patients were classified into survival and mortality groups. The study included patients aged 18 years or older, with a first ICU hospitalization lasting at least 72 hours, diagnosed with AKI according to KDIGO criteria [11], and received CRRT treatment.

The exclusion criteria applied for CKD are mostly concerned with the fact that eGFR < 60 mL/min/1.73m^2 for three months or more before admission was one of the indications. Other exclusion criteria comprised previous renal replacement therapy, presence of malignancy, or lack of complete clinical data.

Data Collection

Patient data were collected retrospectively from medical records. Demographic variables included age, sex, and body mass index. Clinical characteristics included comorbidities such as hypertension, diabetes mellitus, coronary artery disease, chronic obstructive pulmonary disease, and APACHE II and SOFA scores.

The treatment summary included the timing of CRRT initiation, total CRRT duration, presence of sepsis or septic shock, mechanical ventilation requirement, hemofiltration therapy, and administration of vasoactive medications.

Laboratory variables in this study included blood lactic acid level, first serum creatinine, creatinine upon discharge or death, initial eGFR, and final eGFR.

eGFR was calculated using the CKD-EPI equation based on serum creatinine. We acknowledge that eGFR equations are not validated in the non-steady state of acute kidney injury; they were used here to provide a standardized general estimate of renal function at baseline and follow-up. The results should be interpreted with caution.

CRRT Protocol

CRRT with CVVH was performed through femoral, internal jugular, or subclavian vein catheterization. Pre-dilution replacement fluid ratios have been maintained at 50-80%, and blood flow was kept at 150 mL/min.

Net ultrafiltration rate was adjusted individually based on hourly fluid balance and hemodynamic status, typically not exceeding 200 mL/h. The total effluent flow rate (including replacement fluid and net ultrafiltration) was prescribed at 20–30 mL/kg/h to ensure adequate clearance. Sodium citrate was used as anticoagulation in the extracorporeal circuit, and calcium was monitored every 3-6 hours.

Anuria was defined as urine output < 50 mL/day prior to initiation of CRRT. Chronic kidney disease (CKD) was defined as eGFR less than 60 mL/min/1.73m^2 for at least three consecutive months preceding ICU admission.

Statistical Analysis

All statistical analyses were conducted with SPSS 22.0. Continuous variables were compared using the independent t-test, and categorical variables using the chi-square test. Variables with $P < .05$ in univariable comparisons were entered into a multivariable logistic regression model with stepwise selection to identify independent risk factors for in-hospital mortality. Results are presented as adjusted odds ratios (ORs) with 95%

confidence intervals (CIs). A two-tailed $P < .05$ was considered statistically significant.

RESULT

Comparison of clinical data between two groups of patients

One hundred and ninety-five patients with AKI died in hospital, with a mortality rate of 51.59%. Compared with the survival group, Apache II score, SOFA score, mechanical ventilation, lactic acid level, initial SCr, terminal SCr, duration of anuria before CRRT, and total duration of RRT and ICU stay in the death group were significantly increased. In contrast, mechanical ventilation, initial and terminal eGFR were significantly decreased ($P < .05$). There was no significant difference in sex, age, body mass index (BMI), basic diseases, AKI classification, vasoactive drugs and sepsis/septic shock between the two groups ($P > .05$)(Table 1).

Multivariable logistic regression analysis of factors affecting the prognosis of patients

applying the statistically significant differences between the aforementioned two groups as independent variables and the patient's prognosis (survival = 0, death = 1) as dependent variables, multivariable logistic regression analysis was used to analyze the related factors affecting the prognosis of patients. The results showed that APACHE II score (OR: 3.264, 95% CI:2.928-3.513, $P < .05$), SOFA score (OR: 3.982, 95% CI:3.372-4.512, $P < .05$), duration of anuria before CRRT (OR: 3.549, 95% CI:3.028-4.226, $P < .05$), and total RRT duration (OR: 3.982, 95% CI:3.372-4.512, $P < .05$) were independent risk factors affecting the prognosis of patients with AKI, while initial eGFR was a protective factor (OR: 0.426, 95% CI:0.185-0.826, $P < .05$) (Figure 1).

Prediction model construction

Based on the results of the multi-factor analysis, the nomogram prediction model was constructed using R-language statistical software. The total score was the sum of the corresponding scale scores of each index, and the value corresponding to the risk prediction axis was the risk value of

Table 1. Comparison of Clinical Data of Patients with Different Prognosis

Category	Survival group (n = 183)	Death group (n = 195)	t/ (χ^2)	*P*
Male [n (%)]	99 (54.10)	108 (55.38)	0.403	.526
Age	57.62 ± 8.43	60.80 ± 10.95	1.607	.111
BMI (kg/m^2)	24.75 ± 2.36	23.94 ± 2.84	1.820	.179
APACHE II	21.73 ± 2.66	23.19 ± 4.41	3.204	.030
SOFA	11.02 ± 2.22	12.79 ± 2.82	5.548	.001
Hypertension [n (%)]	60 (32.79)	93 (47.69)	2.601	.107
Diabetes [n (%)]	42 (22.95)	51 (26.15)	0.572	.449
Coronary heart disease [n (%)]	39 (21.31)	54 (27.69)	2.647	.104
COPD [n (%)]	78 (42.62)	75 (38.46)	0.391	.532
AKI I [n (%)]	51 (27.87)	24 (12.31)	2.769	.096
AKI II [n (%)]	69 (37.70)	75 (38.46)	0.385	.535
AKI III [n (%)]	63 (34.43)	96 (49.23)	1.523	.270
Norepinephrine [n (%)]	72 (39.34)	96 (49.23)	1.102	.294
Dopamine [n (%)]	18 (9.84)	24 (12.31)	0.078	.792
Sepsis/septic shock [n (%)]	75 (40.98)	84 (43.08)	0.092	.762
Trauma [n (%)]	15 (8.20)	18 (9.23)	1.101	.304
Cardiovascular events [n (%)]	21 (11.48)	27 (13.85)	1.502	.278
Mechanical ventilation [n (%)]	114 (62.30)	144 (73.84)	4.054	.017
Lactic acid level (mmol/L)	3.82 ± 1.34	4.47 ± 1.52	3.685	.021
Initial sCr (mg/dl)	2.15 ± 0.68	2.55 ± 0.79	3.473	.015
Initial eGFR mL/ (min·1.73m^2)	36.26 ± 14.74	30.07 ± 10.38	4.462	.009
Terminal sCr (mg/dl)	1.040 (0.895,1.295)	3.280 (2.978,3.943)	8.646	< .001
Terminal eGFR mL/ (min·1.73m^2)	71.17 (59.57,90.02)	19.67 (15.95,24.07)	8.441	< .001
Duration of no urine before CRRT starts (h)	11.80 ± 4.71	19.11 ± 5.98	4.854	.005
Total RRT duration (d)	8.64 ± 3.42	15.81 ± 5.07	5.362	.001
Length of stay in ICU (d)	12.58 ± 4.78	15.30 ± 5.45	3.379	.037

$P < .05$ was considered statistically significant.

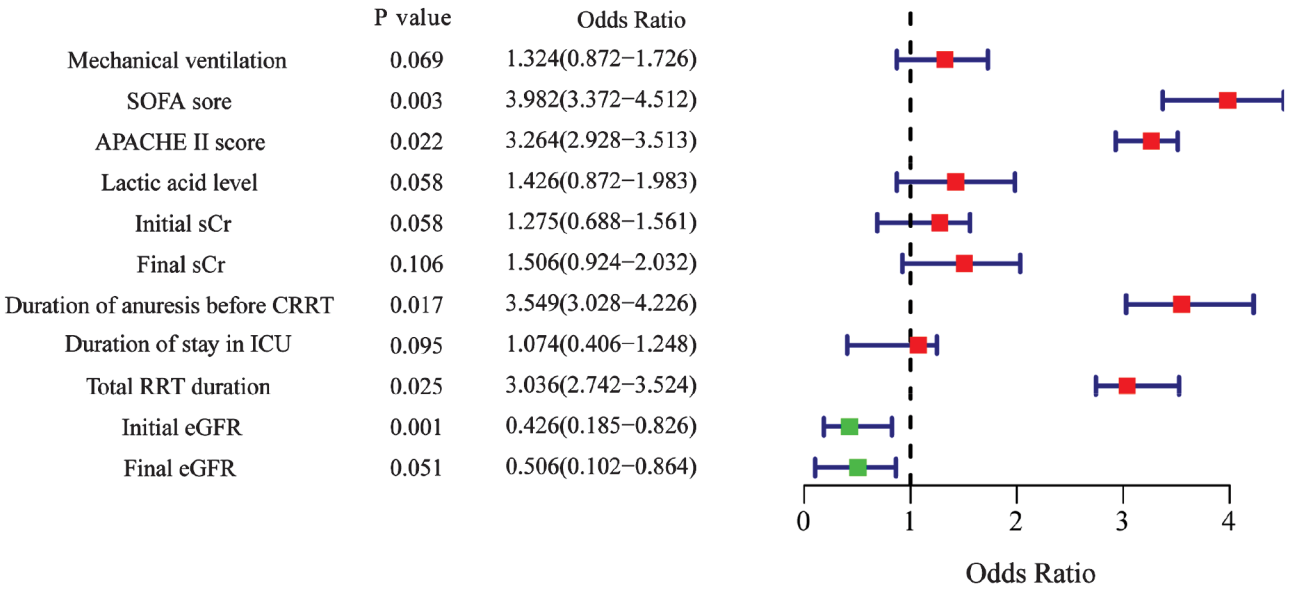

Figure 1. Forest map of multivariable logistic regression analysis affecting the postoperative prognosis of patients. The figure illustrates Odds Ratio (OR) and confidence intervals (CI) for independent predictors of mortality, emphasizing their respective influences on clinical variables. The higher the HR, the higher any variable influences the mortality risks.

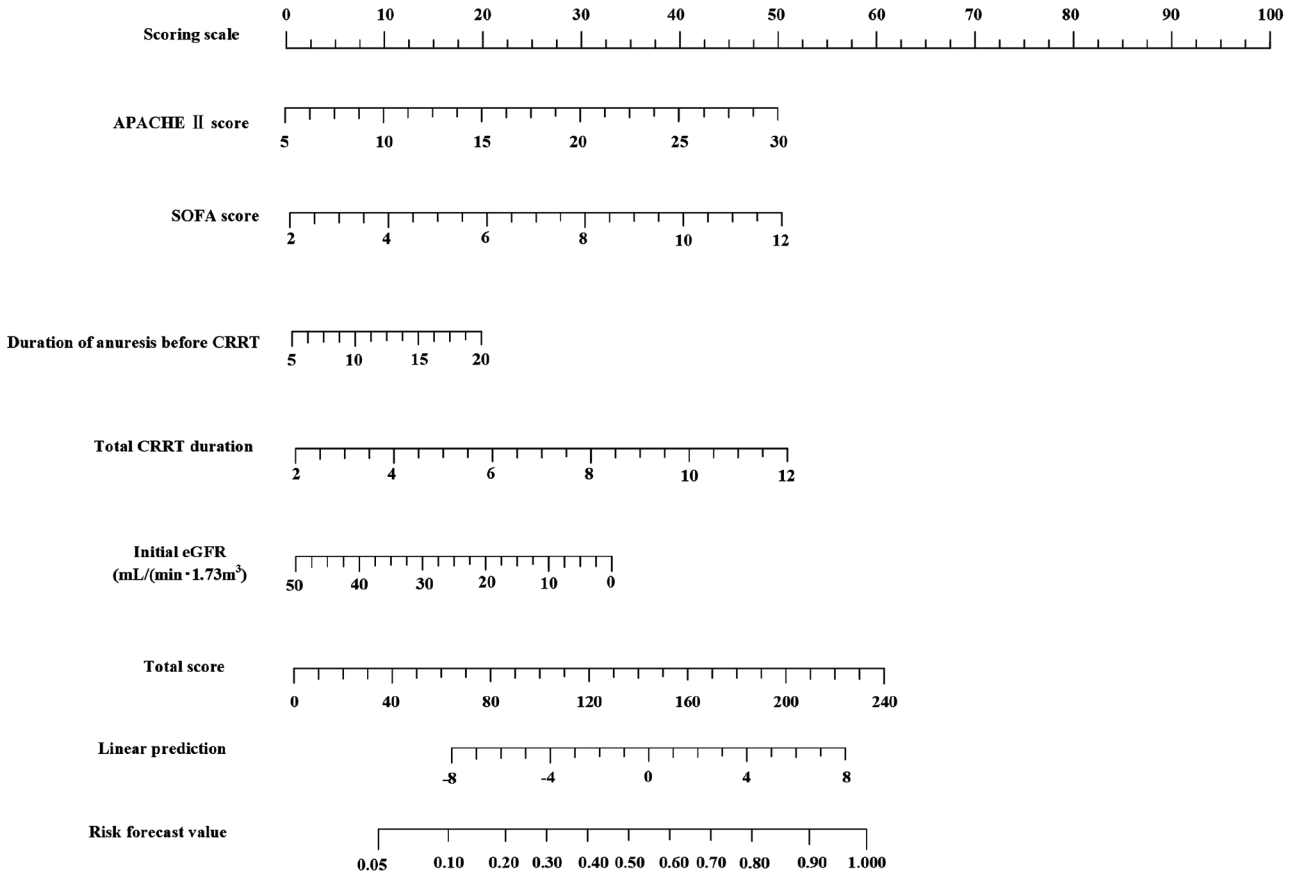

Figure 2. Nomogram risk prediction model for in-hospital death of AKI patients after CRRT treatment. The nomogram incorporates independently significant risk factors established via multivariate analysis to supply an individualized mortality risk estimation. A point value is provided for each predictor, and the total score predicts the probability of in-hospital mortality.

in-hospital death of AKI patients treated with CRRT (Figure 2).

Discrimination evaluation of the nomogram model

Harrell concordance index analysis and ROC curve were used to evaluate the model discrimination. The calculated result of the C-index is 0.751 (95%CI: 0.683~0.819), and the AUC of the ROC curve was 0.738 (95%CI: 0.701~0.775). The above results indicated that the risk prediction model discrimination was acceptable (Figure 3)

Calibration degree

The calibration curve of the nomogram prediction model showed that the model's prediction probability was highly consistent with the actual probability, and the Hosmer-Lemeshow goodness-of-fit test showed that the difference was not statistically significant. The calibration was high (Figure 4).

Validity evaluation of the nomogram model

The clinical decision curve was used to evaluate the nomogram model's effectiveness. The nomogram model constructed this time was far from the extreme curve, and the net benefit rate was high, suggesting the model was effective (Figure 5).

DISCUSSION

AKI is a clinical syndrome characterized by a sudden and persistent decline in eGFR. This is most commonly seen in intensive care settings, where it is associated with renal hypoxia, ischemia, and damage to the renal medulla.[12] Continuous renal replacement therapy (CRRT) is a key modality for the care of AKI in critically ill patients, although its effect on mortality remains a subject of debate. CRRT differs from intermittent hemodialysis because it provides continuous clearance for metabolic waste, stabilizes hemodynamics, and maintains fluid, electrolyte, and acid-base balance.[13] The tragically high mortality rate, however, ranges from 30 to 60%.[14]

The in-hospital mortality rate among AKI patients receiving CRRT in our study was 51.59%. Historical studies have assessed the risk factors for mortality in CRRT-treated AKI patients. Our results indicate that a longer duration of anuria before CRRT is accountable for mortality; meanwhile, large randomized trials

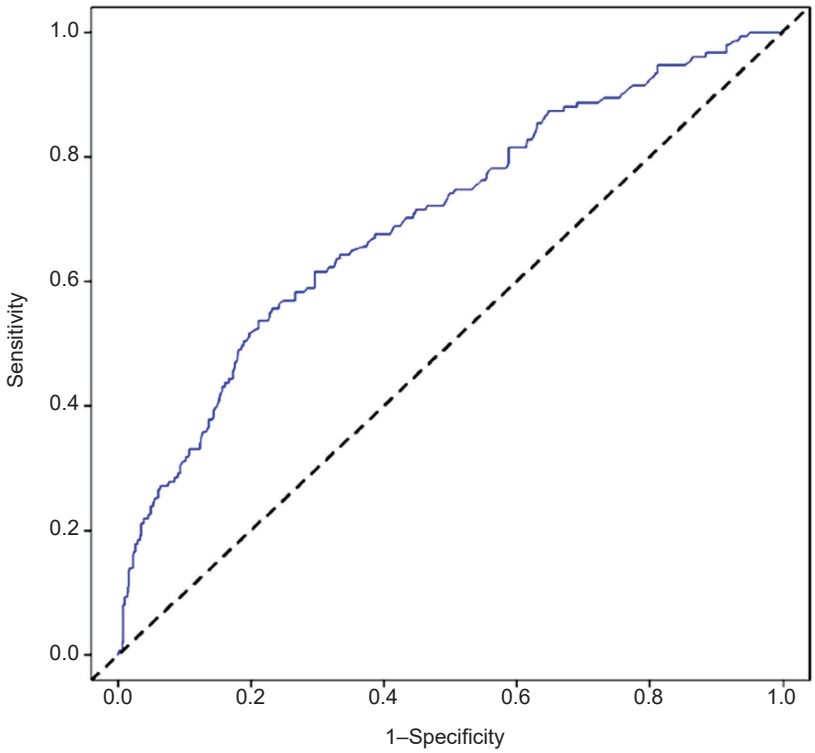

Figure 3. ROC curve of nomogram model. A ROC curve evaluates the model's discriminative ability about the area under the curve (AUC). A high AUC means better predictive accuracy.

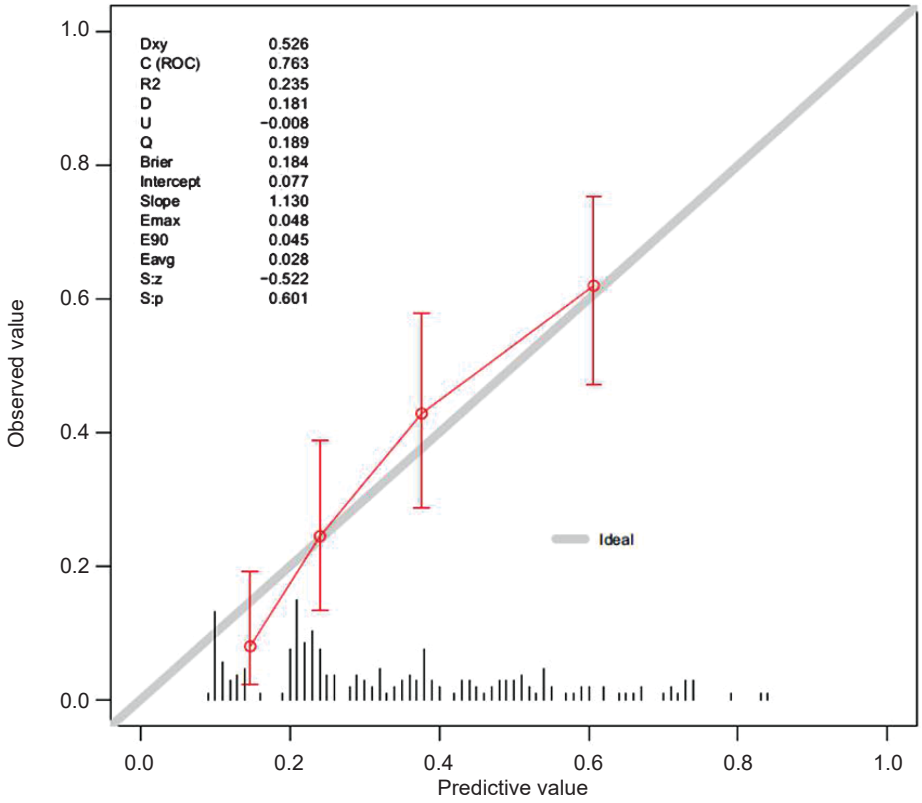

Figure 4. Calibration curve of nomogram model. The calibration curve contrasts predicted and observed mortality rates to determine how well the model performs. The closer the curve gets to the diagonal, the better the calibration.

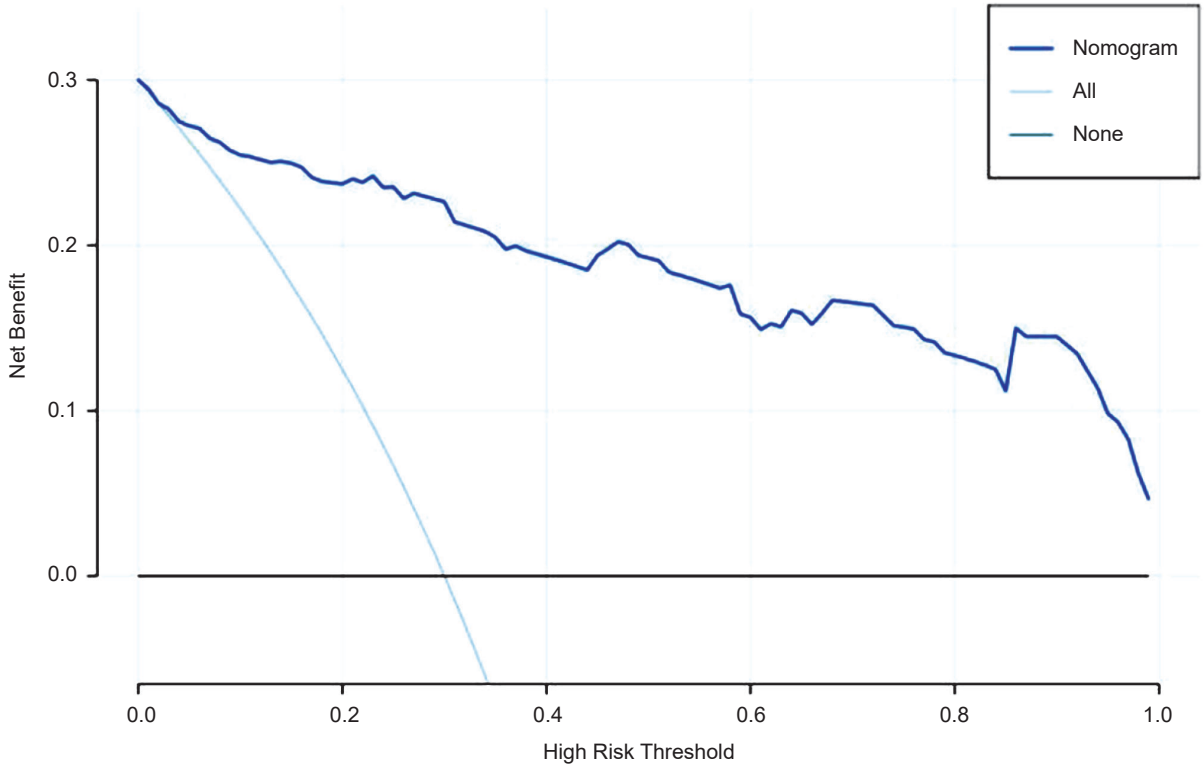

Figure 5. Clinical decision curve of nomogram model. The figure illustrates the clinical net benefit from using a prediction model in varied threshold probabilities supporting this prediction model's eventual applications in clinical decision-making. A higher curve illustrates more clinical utility from the model.

(e.g., ELAIN, AKIKI-1, IDEAL-ICU, STARRT-AKI) have delivered superior evidence on optimal timing for RRT.[15-17] Apart from an early CRRT initiation, several studies evaluated APACHE II and SOFA scores as prognostic indicators; they were significantly higher in non-survivors than survivors, indicating disease severity.[18] APACHE II and SOFA scores, determined by the multivariable logistic regression study, were confirmed to independently predict mortality, which is in accordance with previous literature.[19] Levels of lactic acid were previously identified as a prognostic marker for mortality in critically ill patients. However, the references previously cited did not provide evidence that lactate represents a risk factor for mortality in AKI patients. These have been supplanted by studies that quantitatively assess lactate levels in AKI populations.[20–22] Increased blood lactate is a direct reflection of systemic hypoperfusion and anaerobic metabolism; this correlates directly with the severity of the disease.

In this study, the need for mechanical ventilation was associated with increased mortality in univariable analysis. However, it did not emerge as an independent predictor in the multivariable model, suggesting that the requisite for mechanical ventilation likely serves as a surrogate marker of greater disease severity, such as respiratory failure, sepsis, or shock, rather than being an independent causative factor.[23] In addition, our study found that the baseline eGFR had a protective role for in-hospital survival, a finding echoed by Wu *et al.*, who stated that poor renal function upon entry to CD was a leading determinant of long-term survival for critically ill patients with AKI receiving CRRT.[24] The controversy surrounding the optimal timing for CRRT continues to stir debate in nephrology and critical care.

While our study indicates that prolonged anuria before CRRT is directly proportional to worse outcomes, other large RCTs such as AKIKI-1, IDEAL-ICU, and STARRT-AKI have illustrated that timing strategies should be brought to bear on individual patient requirements rather than embody a universal early versus late initiation template.[15–17] Thus, while early intervention may be beneficial, it should be dictated by factors specific to each patient instead of arbitrary time thresholds. A nomogram prediction model was developed based on the independent risk factors identified in this study. An area under the ROC curve slightly above 0.738 suggests that the model has only modest discrimination power. The reliability of the predictive model has been further ratified by calibration and decision curve analyses.

Several limitations of this study should be acknowledged. First, this was a single-center retrospective study with a relatively modest sample size (n = 378), which may limit the generalizability of the findings and introduce selection bias. Second, and importantly, we estimated GFR using the CKD-EPI equation based on serum creatinine. Because this equation assumes a steady-state and has not been validated in the non-steady state of acute kidney injury, the initial and final eGFR values reported here should be interpreted as rough estimates of renal function rather than precise measures of true GFR. Future studies in this setting would benefit from employing kinetic eGFR (KeGFR) or relying directly on serial creatinine determinations. Third, although the nomogram showed acceptable discrimination (AUC = 0.738), it was developed and internally validated in a single cohort without external validation; its clinical applicability needs to be confirmed in independent populations. Fourth, despite using multivariable logistic regression, residual confounding from unmeasured factors—such as detailed fluid balance, nutrition, or genetic predisposition—cannot be excluded. Fifth, the definition of anuria (< 50 mL/day) and the decision to initiate CRRT were based on clinical judgment at the time, which may have varied among attending physicians. Finally, the relatively wide confidence intervals for some predictors in the multivariable model suggest limited precision, which should be kept in mind when interpreting individual risk estimates.

CONCLUSIONS

Overall, the APACHE II score, SOFA score, hours of anuria before CRRT, and hours on RRT were found to be independent risk factors for in-hospital mortality among patients with AKI undergoing CRRT. Initial eGFR was shown to be a protective factor. These observations underscore the need for individualization in CRRT timing and greater scrutiny of patient management. These risk models and others should be duly revised, and prospective studies should be carried out to optimize treatment strategies for critically ill AKI patients.

DECLARATIONS

Ethical approval

All procedures performed in studies involving human participants were by the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Zhangzhou Affiliated Hospital Ethics Committee of Fujian medical University approved this study. Ethical approval number: 2022LWB295. Written informed consent was obtained.

Consent for publication

Not applicable.

Data Availability

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

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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None.

AUTHOR CONTRIBUTIONS

De Kang was the guarantor of the integrity of the entire study and carried out study concepts & design and manuscript editing; Yitao Wang carried out study concepts and manuscript review; PingLong Lin and Bosheng Huang contributed to clinical studies, data acquisition, and literature research; Yuanlve Che, Qingjiang Zheng and Fengjuan Ye helped to data analysis and statistical analysis, literature research, De Kang and Yitao Wang helped to manuscript editing. All authors have read and approved this article.

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