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ORIGINAL RESEARCH

Comparison of a Kidney Intensive Care Unit Healthcare-Led Model versus a Traditional Haemodialysis Nurse-Led Model for Continuous Renal Replacement Therapy: A Retrospective Observational Study

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Background: The optimal organisational model for delivering continuous renal replacement therapy (CRRT) to critically ill patients remains a subject of investigation.

Objective: This study compared the impact of a kidney intensive care unit (KICU) healthcare-led model with a traditional haemodialysis nurse-led model on key clinical process indicators and patient outcomes during CRRT.

Methods: In this retrospective observational study, patients requiring CRRT admitted to the KICU of a tertiary hospital between January 2022 and December 2023 were selected. Patients were divided into two groups based on the treatment leadership: the KICU group, where CRRT was led by intensive care unit supervising physicians and nurses certified in critical care blood purification techniques, and the control group, led by supervising physicians and haemodialysis nurses. Data were collected via the hospital information system and nursing records. After propensity score matching, 1180 patients were included in each group. Supplementary multivariable regression analyses were performed to provide adjusted effect estimates. Outcomes included treatment interruption rate, catheter-related infection rate, complication rate, actual delivered effluent dose, catheter insertion to treatment initiation time and patient satisfaction.

Results: The KICU group demonstrated a significantly lower overall complication rate (1.8% vs 3.7%, $p = 0.004$) and a higher rate of achieving the prescribed effluent dose (87.7% vs 81.2%, $p < 0.001$). Time to CRRT initiation was shorter in the KICU group (23.75 ± 2.43 vs 30.60 ± 6.36 minutes, $p < 0.05$). Patient satisfaction was also higher ($p < 0.05$). No significant differences were found in treatment interruption or catheter-related infections. The benefits of the KICU model on these key outcomes remained statistically significant in multivariable-adjusted analyses.

Conclusion: Continuous renal replacement therapy management by a dedicated KICU multidisciplinary team was associated with a lower complication rate, improved delivery of the prescribed dialysis dose, faster treatment initiation and higher patient satisfaction compared with a traditional model. These findings suggest that a structured, healthcare-led model can optimise the CRRT process for critically ill patients. Further multicentre studies are warranted to confirm these results.

Keywords: renal intensive care unit, healthcare-led, continuous renal replacement therapy, influence

Introduction

Acute kidney injury (AKI) represents a major life-threatening clinical problem with a rising global incidence. Among hospitalised patients, the incidence of AKI can be as high as 20%–30%, and this proportion is >50% in critically ill

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patients, with associated hospital mortality rates >30%.[1,2] Epidemiological data show that the prevalence of chronic kidney disease (CKD) in China is 10.8%, of which approximately 2% progress to end-stage kidney disease, which not only significantly increases the burden of healthcare but also is closely associated with multi-organ dysfunction, prolonged hospitalisation and high mortality rates.[3] For these critically ill patients with AKI, particularly those with haemodynamic instability, continuous renal replacement therapy (CRRT) serves as a cornerstone of supportive care. Continuous renal replacement therapy is a modality that continuously and slowly removes water and solutes through extracorporeal circulation blood purification techniques.[4] Its benefits include a lower circulatory load and a more stable metabolite removal rate than intermittent haemodialysis, making it the preferred renal replacement therapy for unstable patients. Beyond AKI, CRRT indications have expanded to include the management of severe heart failure, acute pancreatitis, sepsis and multiple organ failure,[5,6] solidifying its role as an indispensable life support system in the intensive care setting. However, the application of CRRT is not without potential complications. These can include treatment interruptions, circuit clotting events, electrolyte disorders, hypotension and catheter-related bloodstream infections, with reported rates of adverse events ranging from 5% to 15%.[7–9] These complications often arise from challenges in precise fluid management, anticoagulation control and timely responses to dynamic changes in patient condition during extended therapy.

The successful delivery of CRRT is highly dependent on meticulous execution and continuous monitoring.[10] Traditional models for implementing CRRT often rely on decentralised collaboration between haemodialysis unit nurses and physicians who may not be exclusively dedicated to the intensive care unit (ICU).[11] This fragmented approach has demonstrated significant limitations. The treatment process can become disjointed, leading to delays or errors in critical aspects, such as fluid management and anticoagulation adjustments, due to communication gaps.[12,13] Consequently, the actual delivered effluent dose often falls considerably short of the prescribed dose, potentially compromising treatment efficacy and patient prognosis.[14] Furthermore, this model is associated with a higher risk of the complications mentioned previously.[7–9] In light of these limitations, there has been a growing focus on evaluating structured models of care led by trained and specialised teams.[15,16] Recent evidence and expert consensus underscore the importance of specialised training for nurses and physicians involved in CRRT management, emphasising the need for standardised competencies for nurses managing these complex therapies.[17] Contemporary studies have begun to show that models involving closer collaboration between ICU physicians and specially trained nurses can lead to improvements in process measures and, potentially, patient outcomes, highlighting the clinical value of moving beyond traditional, siloed approaches to CRRT delivery and addressing its inherent limitations.[9,10]

The kidney ICU (KICU) model represents an innovative approach designed to address these challenges through a structured framework of multidisciplinary collaboration.[18] Its theoretical foundation is rooted in the deep integration of critical care medicine and nephrology specialities to form a cohesive and collaborative system of healthcare with advanced blood purification technology at its core. Unlike traditional ICUs or haemodialysis units, the KICU model establishes an integrated “healthcare team” to facilitate seamless cooperation between physicians and nurses throughout the entire CRRT process. This includes key linkages, such as vascular access establishment, real-time volume management and early warning of complications, thereby aiming to enhance treatment consistency and accuracy. This approach aligns with and operationalises evolving international practices, where the formation of dedicated “ICU–CRRT teams” or “acute dialysis teams” in Western countries has been advocated to improve the standardisation and quality of CRRT delivery.[8,9] These specialised teams typically comprise intensivists, nephrologists and critical care nurses with specific training in CRRT, working collaboratively at the bedside. The KICU model embodies this concept within a dedicated physical and organisational structure, aiming to provide a holistic and highly specialised care environment for the most complex critically ill patients with renal disease.

This study aims to compare the effects of the KICU nurse-led model with the traditional haemodialysis nurse-led model in the implementation of CRRT, focusing on the assessment of the rate of treatment interruption, complication rates, actual delivered effluent dose and other core indicators. It aims to clarify the role of the KICU model in the optimisation of the process of CRRT in critically ill patients to improve the clinical outcomes and to provide evidence for the paradigm innovation in the management of critical care kidney disease.

Methods

Participants

This retrospective observational study used convenience sampling to select nephrology patients admitted to the KICU of a tertiary hospital in Shanxi Province between January 2022 and December 2023 as the study participants. The patients were divided into the control group and the KICU group according to the difference in the treatment leader. The inclusion criteria were as follows: patients on CRRT; aged 18–80 years; hospitalisation time ≥1 day; able to communicate normally. The exclusion criteria were as follows: patients with vascular catheter-related infections prior to admission; patients with coexisting malignant tumours; patients with a history of CRRT treatment within 48 hours prior to the start of the study; patients with allergies to any of the materials in the KICU components; expected survival time of <24 hours; irreversible multiorgan failure; or refusal of the patient or family members to participate in this study.

The decision to initiate CRRT was made by the supervising physician based on standardised clinical indications, including severe azotaemia (blood urea nitrogen >80 mg/dL), refractory metabolic acidosis (pH <7.15), hyperkalaemia (K^+ >6.0 mmol/l) unresponsive to medical management, fluid overload unresponsive to diuretics or uremic complications (eg pericarditis, encephalopathy), in accordance with Kidney Disease: Improving Global Outcomes (KDIGO) guideline recommendations.[19]

A total of 1570 patients with renal disease between January 2022 and December 2022 were included in the control group, and 1220 patients with renal disease between January 2023 and December 2023 were included in the KICU group. The study participants gave informed consent and participated in this study voluntarily. This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the hospital (NO. 2024822).

Study Design

An illustrative workflow comparing the two models is provided in Figure 1.

Control Group

The physician in charge was responsible for formulating the haemofiltration programme, and the specialist nurse in the haemodialysis room implemented the programme according to the relevant norms or standards, which involved the following: choosing a single-connection or double-connection machine according to the patient's vital signs to ensure the patient's haemodynamic stability when they are on the machine; following the physician's instructions to set the parameters of the continuous blood purification machine and the amount of anticoagulant; recording the patient's vital signs, arterial pressure, venous pressure and trans-membrane pressure each hour; recording the amount of filtrate and 24-hour patient's in and out volume after the continuous blood purification treatment; recording the patients' vital signs, arterial pressure, venous pressure and transmembrane pressure every hour; and accurately recording the patients' continuous blood purification filtrate volume after treatment and patients' 24-hour in and out volume. The haemodialysis nurses were primarily responsible for the technical operation of the CRRT machine, circuit priming and monitoring for machine-related alarms. They worked based on shifts and were not permanently assigned to the ICU. Communication and information feedback with the supervising physician, who had other clinical responsibilities, was conducted in various ways, such as micro letter group, telephone or face-to-face communication, typically initiated by the nurse upon identifying an issue. The physician made fluid management and anticoagulation adjustments based on intermittent assessments and nurse reports. The head nurse of the haemodialysis room or the quality control nurse regularly performed quality control on the haemodiafiltration process and the achievement of various indexes and held regular meetings to analyse the problems and improve the overall quality. A formal quality control meeting involving both haemodialysis and ICU staff was held monthly.

Kidney Intensive Care Unit Group

Establishing a Research Team

The research team consisted of 11 members, comprising 4 physicians and 7 nurses, who had the following qualifications and experience: 5 had senior titles and 6 had intermediate titles; 6 held postgraduate degrees or above and 5 held undergraduate degrees; all had ≥10 years of work experience. The head nurse of the department was responsible for

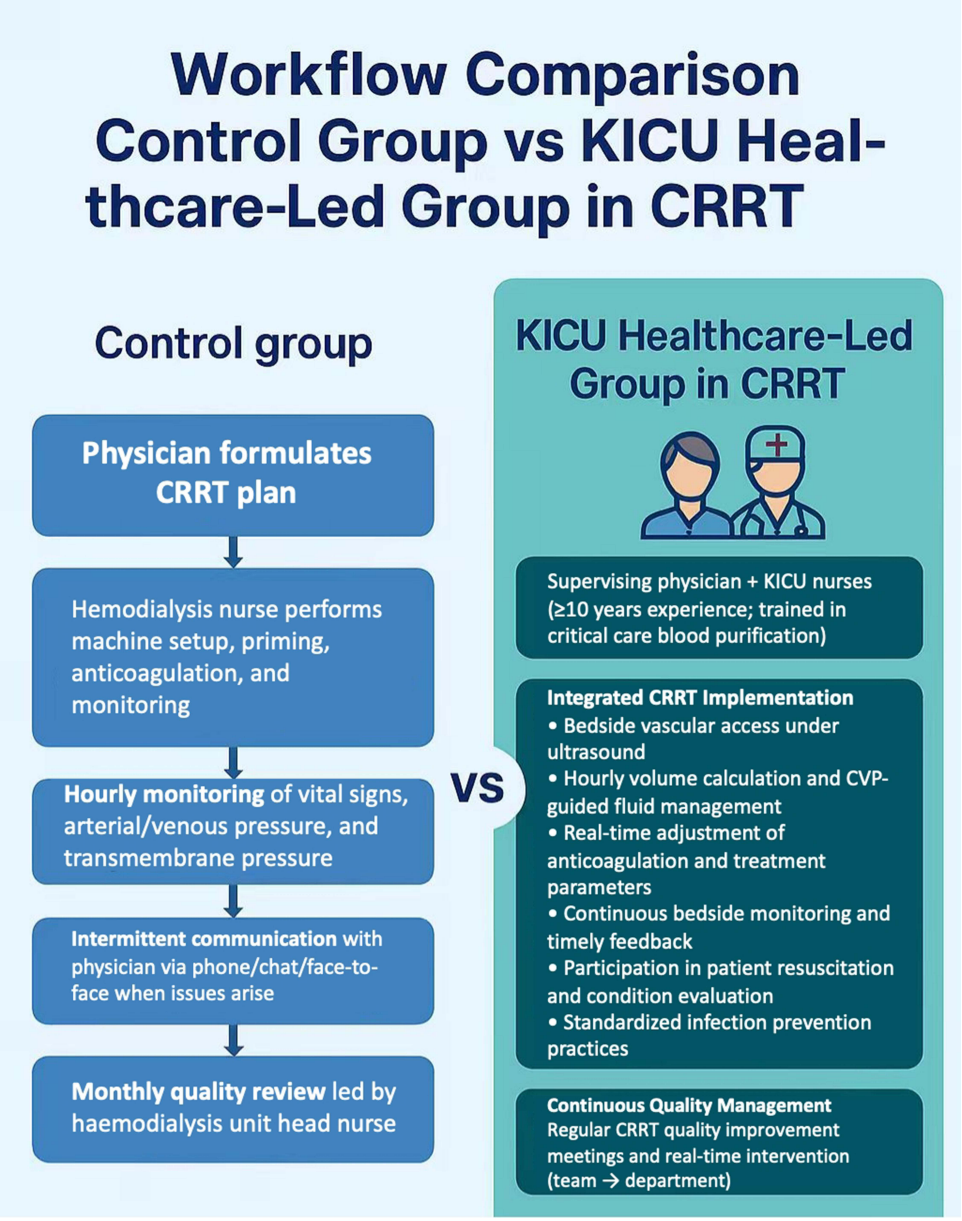

Figure 1 Infographic comparing the workflow of the control group versus the KICU group.
Abbreviation: KICU, kidney intensive care unit.

setting up the research team and organising meetings to improve the quality management of haemofiltration patients; the ward director was responsible for quality control, technical support and supervision of the implementation of the intervention programme; 3 attending physicians and 6 KICU nurses formed the CRRT healthcare integration team, responsible for the implementation of the specific programme and the collection and analysis of data.

Responsibilities of the Continuous Renal Replacement Therapy Medical and Nursing Integration Team

Attending physician: (1) establishes bedside haemofiltration vascular access for patients; (2) formulates a detailed bedside haemofiltration plan according to the patient's condition; (3) cooperates with the haemofiltration nurses to calculate and manage the patient's hourly volume; (4) adjusts the haemofiltration plan according to feedback from haemofiltration nurses; (5) participates in the haemofiltration patients' quality management improvement conference. In addition to the routine operation of haemofiltration, KICU haemofiltration nurses perform the following tasks: (1)

cooperate with physicians to perform the haemofiltration tubing operation; (2) provide timely feedback on patients' conditions during haemofiltration to ensure the strict implementation of the haemofiltration programme; (3) work with the KICU nurses in charge to perform the calculation and management of the patients' volume – calculate the amount of hourly dehydration according to the hourly inflow and outflow of fluids (including the amount of intravenous inputs and enteral nutritional fluids) and monitor the central venous pressure (CVP); (4) participate in the resuscitation of the patients and discussion of their conditions; (5) participate in the management of hospital-acquired infectious disease prevention and control; and (6) participate in the equality management improvement meeting for haemofiltration patients.

Specific Intervention Programmes

Hospital-Acquired Infection Prevention and Control. The process of dialysis catheter placement follows the principle of maximum sterile barrier and is performed under ultrasound guidance to improve the success rate of disposable puncture, as follows: after catheter placement, sterile gauze is immediately used to cover the catheter placement site,[20] and if there is any oozing of blood and seepage, it is immediately replaced; standardise and unify the key steps for changing the medication in and out of the machine: disinfect from top to bottom and from the inside to the outside without crossing over, and disinfect with cotton ball wipes three times on the outlet of the dialysis tubing and on both of the dialysis catheters. The interface of the disinfection cotton ball is wiped three times, so that there is no blood residue; disinfect the ends immediately and cover with sterile dressings or connect to the syringe to reduce the exposure time in the air.

Volume Management. Three levels of volume management are implemented for patients:[21,22] for patients with stable vital signs, relatively stable haemodynamics and about to be transitioned to dialysis, the first level of volume management strategy is implemented. For this, the total amount of fluid that should be ultrafiltered by the patient within 6–24 hours is estimated, and the ultrafiltration rate of CRRT is calculated; for patients with unstable vital signs, who cannot tolerate obvious changes in blood volume and who have just begun renal replacement therapy, the first level of volume management is utilised, and the second level is used for patients who are not on renal replacement therapy. For patients with unstable vital signs who cannot tolerate significant changes in blood volume and who have just started renal replacement therapy, the CRRT volume management record sheet (see Figure 2) is used to perform a secondary volume management strategy; to calculate the hourly therapeutic intake (including: fluids and gastrointestinal nutrient intake), CRRT intake (including sodium bicarbonate, anticoagulant and saline for flushing dialysis catheters that are not balanced by the instrument) and outgoing volume (including the patient's urine volume, stool volume, drainage flow rate, nondescript dehydration and the CRRT ultrafiltration rate) are measured, and the hourly balanced volume is calculated. The hourly balanced volume is then calculated as a reference for the CRRT ultrafiltration rate in the next hour, so that the patients reach the balance of in and out volume during the treatment period; for the acute and critical patients with

Bed No.		Name		Admission No.		Treatment mode		Treatment time		Target fluid loss		Volume Management Policy			
	Time / Category		1 h total		2 h total		3 h total		4 h total		5 h total		6 h total		7 h total
Treatment Volume	Fluid intake														
	Gastrointestinal nutrient solution intake														
CRRT Volume	Sodium bicarbonate charge														
	Anticoagulant intake														
	Saline quantity flushed														
Output Volume	Urine volume														
	Stool Volume														
	Drain Volume														
	Nondominant dehydration														
	Other														
	CRRT fluid loss														
Balance	Balance Volume	1 h		2 h		3 h		4 h		5 h		6 h		7 h	

Figure 2 CRRT capacity management record form.
Abbreviation: CRRT, continuous renal replacement therapy.

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multiple organ failure and extracorporeal membrane oxygenation (ECMO), a three-level volume management strategy is performed;[15,21] in addition to the use of the CRRT volume management record sheet, the patients' volume management is monitored through the monitoring of CVP, pulmonary capillary wedge pressure, mean arterial pressure and other haemodynamic indicators for blood flow rate and ultrafiltration volume adjustment.

Coagulation Risk Prediction and Intervention. In clinical practice, we have identified three categories of factors that predispose patients to circuit coagulation during CRRT. First, factors affecting blood flow include catheter dysfunction, defined as the inability to aspirate 3–4 mL of blood and sealing fluid within one second,[8] and patient agitation leading to repeated circuit kinking and pressure alarms. A clinically significant indicator is the occurrence of more than three pump stoppages within one hour that cannot be promptly resolved by pressing the START button. Second, patient-specific coagulation risks encompass abnormal coagulation parameters (elevated platelet count, prolonged APTT and PT, high hematocrit, or elevated ionized calcium), certain clinical conditions (comorbid tumors, severe infections, hyperlipidemia, or acute myocardial infarction), and the transfusion of blood products such as plasma or packed red blood cells during the filtration procedure. Third, treatment-related factors primarily involve the absence of anticoagulant use. Our CRRT medical-nursing team systematically assesses these factors before each treatment, including reviewing whether second-level or greater coagulation occurred during the previous session. Based on this assessment, we prescribe specific interventions such as catheter thrombolysis, limb restraint, anticoagulant dosage adjustment, and monitoring frequency. Hemofiltration nurses then implement these prescribed measures while documenting outcomes and providing feedback.

Complications Monitoring. During the haemofiltration process, nurses are required to perform "one–look, two–questions and three–monitoring". One–look: within 1 hour of boarding the machine and when getting off the machine, pay attention to check whether the patient has symptoms such as chest constriction or irritability; two–questions: in the process of boarding the machine, ask the patient in time whether there is any discomfort, such as dizziness, headache, nausea, vomiting, palpitation, abdominal pain, convulsions, chills or cold sweating; three–monitoring: according to the patient's conditions, preset the range of the patient's various vital signs, set the upper and lower limits by using the electrocardiogram monitor and closely monitor the patient's vital signs to prevent hypotension, hypokalaemia, hypocalcaemia, hypophosphataemia, hypocapnia, acid-base imbalance and infection.

Management of Supplies and Processes. For the convenience of emergency treatment, the department has a treatment cart dedicated to haemofiltration. A haemofiltration supplies box is placed in the treatment cart, with supplies such as syringes for haemofiltration, sterile dressings and heparin caps and medicines such as potassium chloride, calcium gluconate and sodium heparin; all the items in the box are managed using a list, and a complete set of haemofiltration tubing and filters is placed in the treatment cart. When emergency patients need to start bedside haemofiltration, the KICU haemofiltration nurse cooperates with the physician to insert the dialysis catheter; the nursing team leader is responsible for installing the tubing and pre-filling, and other nurses assist in the resuscitation and preparation of the supplies to shorten the treatment initiation time to the maximum extent possible.

Quality Control

Regarding hospital infection prevention and control, the research group, with the help of the teacher from the hospital infection department, re-standardised the operation of dialysis catheter placement and drug change at the upper and lower machine lines. They asked the teacher from the hospital infection department to carry out special supervision every month, and the daily supervision was completed by the sensory control physicians, nurses and head nurses of the department. Regarding volume, coagulation, adverse reactions and other aspects of the implementation of three-tiered quality control, the first level of quality control is the leader of the responsible nursing team and is responsible for the overall control of the implementation of the intervention programme. The second level of quality control is provided by the designated members of the group, who are responsible for verifying whether the measures are in place. The third level of quality control is provided by the head nurse and the director, who are responsible for organising and carrying out the quality management improvement meeting for haemofiltration patients at regular intervals to identify problems promptly and put forward the improvement measures. In summary, hospital infection prevention specialists conducted monthly audits, departmental checks were performed daily by team leaders, and research team reviews occurred weekly.

Continuous Renal Replacement Therapy Prescription and Parameters

To ensure reproducibility, the initial CRRT prescription followed a standardised protocol in both groups.[23] The default blood flow rate was set at 150–200 mL/min. The effluent dose was prescribed to achieve a target of 25–30 mL/kg/h, adjusted for patient haemodynamics. Replacement fluid was primarily administered in pre-dilution mode at a rate calibrated to achieve the desired effluent dose. For anticoagulation, either regional citrate anticoagulation (RCA) or low-molecular-weight heparin was used. The RCA protocol targeted a post-filter ionised calcium level of 0.25–0.35 mmol/l, with a 4% trisodium citrate infusion rate initially set at approximately 3.0–4.0 mmol/l of blood flow rate. When systemic heparinisation was used, a bolus of 20–30 IU/kg was followed by a maintenance dose of 5–10 IU/kg/h, titrated to maintain an APTT 1.5–2.0 times the normal value. All parameters were adjusted at the discretion of the supervising physician based on the patient's clinical status.

Evaluation Indicators

The Rate of Treatment Interruption

The rate of treatment interruption refers to discontinuation of treatment without accomplishing the treatment goal or without achieving the planned time. Indications of unplanned downtime[24] include the following: transmembrane pressure >250 mmHg, ≥50% filter fibre coagulation, improper operation and frequent alarms that cannot be disarmed, resulting in blood pump shutdown. The rate of treatment interruption was calculated as (number of treatment interruptions / total number of treatments) × 100%.

The Rate of Catheter-Related Infections

(1) Definition: A catheter-related infection is defined as an infection occurring during the indwelling period of an intravascular catheter or within 48 hours of its removal. Diagnosis requires a combination of clinical manifestations and microbiological evidence, while excluding other sources of infection.[24]

(2) Diagnostic Criteria: The diagnosis of a catheter-related infection requires meeting one of the following clinical criteria:

With Systemic Signs of Infection: Presence of bacteremia or fungemia accompanied by systemic symptoms such as fever, chills, or hypotension.

With Local Signs of Infection: Presence of local signs at the catheter exit site, such as redness, swelling, heat, pain, or purulent discharge.

Additionally, the following microbiological confirmation criteria must be met (requiring the isolation of the same pathogen from both a peripheral blood sample and a catheter-related specimen (eg, catheter tip, catheter blood, or exit site secretion), fulfilling one of the following indicators):

A quantitative culture of catheter-drawn blood yielding a colony count ≥ 10^3 CFU/mL.

A positive culture from catheter-drawn blood is detected ≥ 2 hours earlier than a positive culture from peripheral blood.

The colony count from a catheter-drawn blood culture is at least 5 times greater than that from a peripheral blood culture.[25,26]

Complication Rate

Complications refer to symptoms such as hypotension, hypokalaemia, hypocalcaemia, hypophosphataemia, acid-base imbalance, infection and other symptoms complicating the CRRT process. The formula for calculating the incidence rate of adverse complications is (number of cases of adverse complications / total number of cases treated) × 100%.

To ensure equitable assessment of laboratory-based complications, a standardised protocol dictating the frequency of laboratory monitoring (eg electrolytes, coagulation panels) was uniformly applied to all patients in both the KICU and control groups, thereby minimising the potential for detection bias.

Actual Delivered Effluent Dose Rate

The prescribed and delivered effluent dose of CRRT usually refers to the amount of solute removed from the blood per unit of time, which is usually quantified in units of mL/kg/h. According to the recommendations of the KDIGO guidelines,[19] for patients with AKI requiring CRRT, it is recommended that the CRRT dose be maintained at

20–25 mL/kg/h. The actual delivered effluent dose rate is calculated as (number of cases in which the expected delivered effluent dose has been successfully completed / total number of cases of treatment) x 100%.

Catheter Insertion and Initiation Timing

This refers to the time from the placement of the haemofiltration catheter to the start of machine operation, after obtaining informed consent from the patients and their families.

Patient Satisfaction

This refers to the overall evaluation of the quality of medical care by patients before discharge. It was evaluated using a homemade nursing satisfaction questionnaire, including the four aspects of CRRT operation technique, work attitude, health guidance and overall effect, with a score of 100; the higher the score is, the higher the patient's satisfaction.

Data Collection

Data collection and processing were completed by two nursing staff members of the participant group with postgraduate degrees. Training was conducted before collection to ensure the consistency of the evaluation indexes, and after collection, the physicians in the CRRT medical and nursing integration team determined unplanned disembarkation, line infections, the occurrence of adverse complications and achievement of the capacity target again to ensure the accuracy of the data.

Statistical Analysis

The SPSS 25.0 (IBM Corporation, Armonk, NY, USA) statistical software package was utilised to organise and analyse the data. To reduce the problem of potential bias of covariates, the variables incorporated into the propensity score matching (PSM) model were age, gender, education, marital status, monthly family income, mode of payment for medical expenses, diabetes, hypertension, CKD, treatment mode (continuous venovenous hemofiltration [CVVH]/continuous venovenous hemodiafiltration [CVVHDF]), replacement fluid replenishment mode, anticoagulant type, total duration of CRRT treatment and Acute Physiology and Chronic Health Evaluation II score upon KICU admission. The 1:1 nearest neighbour matching method was used with a calliper width of 0.02. Missing data were minimal (<2% for any variable), and a complete-case analysis was performed. To address reviewer comments and enhance the robustness of our findings, supplementary multivariable regression analyses were performed on the matched cohort. Binary outcomes were analyzed using logistic regression, and the continuous outcome (time to CRRT initiation) was analyzed using linear regression. All regression models were adjusted for the same covariates used in the propensity score matching. The count data were described by frequency and percentage, and the χ^2-test was used for intergroup comparisons; the dosage data conforming to normal distribution were expressed by $\overline{x} \pm s$, and the *t*-test was used for intergroup comparisons; the dosage data not conforming to normal distribution were described by median and quartile, and the rank-sum test was used for intergroup comparisons; the grade data were compared between groups by the rank-sum test. A *p*-value of <0.05 was considered as the difference was statistically significant.

Results

Comparison of General Information Between the Two Groups

After 1:1 PSM, the differences between the two groups of patients in terms of age, gender, education, marital status, monthly family income, mode of payment for medical expenses, whether they are diabetes, hypertension, CKD, mode of treatment, mode of replacement fluid replenishment, anticoagulant and the total length of treatment for CRRT were not statistically significant ($p > 0.05$); the standardised differences were all <10%, indicating a well-balanced cohort. See Table 1.

Comparison of Related Events and Therapeutic Dose Achievement Rate Between the Two Groups of Patients

There was no statistically significant difference between the two groups in terms of the rate of treatment interruption or catheter-related infections. However, the KICU group demonstrated a significantly lower overall incidence of complications (1.8% vs 3.7%, $p = 0.004$). A detailed breakdown revealed lower rates of specific complications in the KICU group,

Table 1 Comparison of General Information Between the Two Groups After PSM

Characteristic	CRRT Group (n=1180)	Control Group (n=1180)	P-value	Standardized Difference (%)
APACHE II score, mean ± SD	**24.5 ± 6.8**	**24.8 ± 7.1**	**0.187**	**−4.3**
Age (years)			0.415	3.1
18-44	256 (21.7)	241 (20.4)		
45-59	405 (34.3)	441 (37.4)		
60-74	356 (30.2)	332 (28.1)		
75-80	163 (13.8)	168 (14.1)		
Sex, Male	661 (56.0)	674 (57.1)	0.589	−2.2
Qualifications			0.419	3.9
Below post-secondary	921 (78.1)	894 (75.8)		
Junior college	208 (17.6)	230 (19.6)		
Undergraduate and above	51 (4.3)	56 (4.7)		
Marital status			0.712	2.1
Unmarried	57 (4.8)	60 (5.1)		
Married	963 (81.6)	973 (82.5)		
Widowed	160 (13.6)	147 (12.5)		
Monthly household income (CNY)			0.184	5.7
<5000	863 (73.1)	873 (74.0)		
5000-10,000	285 (24.2)	288 (24.4)		
>10,000	32 (2.7)	19 (1.6)		
Payment of medical expenses			0.859	2.8
Provincial medical insurance	197 (16.7)	181 (15.3)		
City medical insurance	282 (23.9)	277 (23.5)		
Intra-provincial medical insurance	502 (42.5)	532 (45.1)		
Residents insured	165 (14.0)	160 (13.5)		
Subsistence allowances	11 (0.9)	10 (0.9)		
Cross-provincial medical insurance	23 (1.9)	20 (1.7)		
Diabetes, Yes	831 (70.4)	803 (68.1)	0.212	5.0
Hypertension, Yes	926 (78.5)	896 (75.9)	0.141	6.2
Chronic kidney disease, Yes	797 (67.5)	763 (64.7)	0.139	5.9
Treatment mode, CVVH	753 (63.8)	735 (62.3)	0.443	3.1
Replacement fluid, Predilution	623 (52.8)	619 (52.5)	0.869	0.6
Anticoagulants			0.764	4.2
Low molecular weight heparin	533 (46.0)	542 (45.9)		
Argatroban	311 (26.4)	314 (26.6)		
Trisodium citrate	279 (23.6)	270 (22.9)		
Nafamostat mesilate	32 (2.7)	42 (3.6)		
No heparin	15 (1.3)	12 (1.0)		
Total CRRT duration			0.907	1.5
<24h	344 (29.2)	360 (30.5)		
24h-48h	798 (67.6)	784 (66.4)		
48h-72h	32 (2.7)	30 (2.5)		
>72h	6 (0.5)	6 (0.5)		

Abbreviations: CNY, China Yuan; CVVH, continuous veno venous hemofiltration; CRRT, continuous renal replacement therapy.

including hypotension, hypokalaemia, circuit clotting and new-onset infections. Furthermore, the rate of actual delivered effluent dose achievement was significantly higher in the KICU group than in the control group (87.7% vs 81.2%, $p < 0.001$). The difference was statistically significant ($p < 0.05$). See Table 2.

Table 2 Comparison of Related Events and Capacity Target Achievement Rates Between Two Groups [Cases (Percentage, %)]

Outcome Measure	CRRT Group (n=1180)	Control Group (n=1180)	P-value
Treatment Interruption	136 (11.6)	156 (13.2)	0.211
Catheter-related Infections	2 (0.1)	5 (0.4)	0.256
Total Complications	21 (1.8)	44 (3.7)	0.004
- Hypotension	10 (0.8)	18 (1.5)	
- Hypokalemia	4 (0.3)	9 (0.8)	
- Hypocalcemia	2 (0.2)	5 (0.4)	
- Hypophosphatemia	1 (0.1)	3 (0.3)	
- Circuit Clotting	3 (0.3)	7 (0.6)	
- New-onset Infection	1 (0.1)	2 (0.2)	
Actual Delivered Effluent Dose	1029 (87.7)	959 (81.2)	<0.001

Abbreviation: CRRT, continuous renal replacement therapy.

Comparison of the Two Groups in Terms of the Time to Catheter Insertion

Comparison of the two groups in terms of the time from decision to initiate CRRT to successful therapy commencement showed that the KICU group had a markedly shorter duration (23.75 ± 2.43 minutes) than the control group (30.60 ± 6.36 minutes), and the difference is statistically significant ($p < 0.05$). See Table 3.

Comparison of Patient Satisfaction Between the Two Groups

The comparison of patient satisfaction in the two groups under the two modes showed that the KICU group had better scores than the control group, and the difference is statistically significant ($p < 0.05$). See Table 4.

Adjusted Regression Analyses of Primary Outcomes

In accordance with reviewer recommendations, we conducted supplementary multivariable regression analyses on the propensity score-matched cohort to provide adjusted effect estimates. Logistic regression models were used for binary outcomes, and linear regression was used for the continuous outcome (time to CRRT initiation). All models were adjusted for the covariates included in the propensity score matching (age, gender, education, marital status, monthly family income, payment mode, diabetes, hypertension, CKD, treatment mode, replacement fluid mode, anticoagulant type, total CRRT duration, and APACHE II score).

The results of these adjusted analyses are presented in Table 5. They consistently corroborate the findings from the primary unadjusted comparisons. Specifically, the KICU model remained independently associated with a significantly lower odds of complications (adjusted Odds Ratio [aOR] 0.47, 95% CI 0.28–0.79, $p = 0.004$), a higher odds of achieving the prescribed effluent dose (aOR 1.71, 95% CI 1.42–2.07, $p < 0.001$), and a shorter time to treatment initiation (adjusted Mean Difference [aMD] −6.79 minutes, 95% CI −7.60 to −5.98, $p < 0.001$). No significant associations were found for treatment interruption or catheter-related infections in the adjusted models.

Table 3 Comparison of Catheterization and Catheterization Time Between 2 Groups (Scores, $\overline{\chi} \pm S$)

Group	Catheter Insertion and Initiation Examples	Catheter Insertion and Initiation Timing (min)
CRRT group	98	23.75±2.43
Control group	105	30.60±6.36
t value		−4.817
P value		<0.001

Abbreviation: CRRT, continuous renal replacement therapy.

Table 4 Comparison of Satisfaction Between 2 Groups (Scores, $\overline{\chi} \pm S$)

Group	Examples	Patient Satisfaction
CRRT group	1180	98.9±34.33
Control group	1180	96.3±21.76
t value		2.196
P value		0.028

Abbreviation: CRRT, continuous renal replacement therapy.

Table 5 Adjusted Regression Analyses of Outcomes in the Propensity Score-Matched Cohort

Outcome Measure	Adjusted Effect Estimate (95% Confidence Interval)	P-value
Binary Outcomes (Adjusted Odds Ratio, aOR)		
Treatment Interruption	0.86 (0.67–1.10)	0.230
Catheter-related Infection	0.40 (0.08–2.06)	0.273
Total Complications	0.47 (0.28–0.79)	0.004
Achievement of Prescribed Effluent Dose	1.71 (1.42–2.07)	<0.001
Continuous Outcome (Adjusted Mean Difference, aMD)		
Time to CRRT Initiation (minutes)	−6.79 (−7.60 - −5.98)	<0.001

Notes: All models were adjusted for age, gender, education, marital status, monthly family income, payment mode, diabetes, hypertension, chronic kidney disease, treatment mode, replacement fluid mode, anticoagulant type, total CRRT duration, and APACHE II score.
Abbreviations: CRRT, continuous renal replacement therapy; aOR, adjusted Odds Ratio; aMD, adjusted Mean Difference.

Discussion

Core Findings and Clinical Significance of the Study

This study provides a systematic comparison between the KICU healthcare-led model and the traditional haemodialysis nurse-led model for CRRT delivery. Our results indicate that although the rates of treatment interruption and catheter-related infections were comparable between the two groups, the KICU model was associated with a statistically significant and clinically meaningful improvement in several key outcomes. Specifically, we observed a substantial reduction in the overall complication rate, a higher achievement rate of the prescribed effluent dose, a markedly shorter time from decision to CRRT initiation and greater patient satisfaction. These findings underscore the potential of the KICU model to optimise the CRRT process through the deep integration of critical care and nephrology expertise, facilitating precise volume control, enhanced team coordination and more rapid response capabilities. This structured approach addresses several inherent limitations of traditional, fragmented care models and aligns with the growing emphasis on specialised, protocol-driven care for critically ill patients undergoing complex organ support therapies.[9,27]

Kidney Intensive Care Unit Healthcare-Led Continuous Renal Replacement Therapy Can Reduce the Complication Rate

The significantly lower complication rate observed in the KICU group represents a central finding of our study. Patients requiring CRRT are among the most vulnerable in the ICU, frequently presenting with haemodynamic instability, complex acid-base and electrolyte disorders and a high risk of bleeding or thrombosis. The KICU model's success in mitigating complications likely stems from its multifaceted approach to proactive management. The implementation of a tiered volume management strategy, guided by real-time haemodynamic monitoring when necessary, allowed for precise fluid balance control, thereby reducing the risk of hypotension or fluid overload – common triggers for haemodynamic instability and arrhythmias during CRRT.[11,17] Furthermore, the standardised protocol for coagulation risk prediction and intervention, managed by the integrated team, enabled pre-emptive adjustments to anticoagulation or dialysis catheter management, minimising clotting events within the extracorporeal circuit.[8,28] The constant presence of a dedicated team facilitated continuous monitoring and immediate intervention for early signs of electrolyte shifts (eg

hypokalaemia, hypophosphataemia) or other adverse events, preventing their progression into more severe complications. This contrasts with the reactive nature of care often seen in decentralised models, where communication delays can impede timely management.[9]

Contextualising the Kidney Intensive Care Unit Model within the Evolving Paradigm of Specialised Continuous Renal Replacement Therapy Teams

Our findings contribute to a compelling and growing body of international literature advocating for specialised, team-based approaches to manage CRRT. The benefits we observed are consistent with reports on dedicated "acute renal replacement therapy teams", "ICU–CRRT teams" and "renal rescue teams" established in other healthcare systems.[29] Similarly, multidisciplinary team training focusing on CRRT in the ICU has been associated with improved procedural efficiency and staff confidence,[30] echoing our finding of a significantly reduced dialysis catheter insertion and treatment initiation time. A recent review by Ostermann et al (2023) emphasised that the quality of CRRT is highly dependent on the expertise and coordination of the managing team, highlighting the importance of standardised protocols and continuous education – cornerstones of the KICU model.[15] The KICU structure operationalises these principles within a dedicated unit, potentially offering a more intensive and integrated version of the team-based care advocated elsewhere. The lack of a significant difference in catheter-related infections between our groups is an important finding. It may be attributed to the hospital-wide implementation of rigorous, protocolised sterile techniques for dialysis catheter insertion and maintenance, potentially mandated by institutional infection control policies that were uniformly applied across all ICUs, including the standard haemodialysis unit.[31] This suggests that although the KICU model excels in dynamic process management (complications, dose delivery, timeliness), its impact on outcomes heavily governed by standardised, discrete procedures may be less pronounced if those procedures are already effectively implemented hospital-wide.

Enhancing the Delivery of the Prescribed Continuous Renal Replacement Therapy Dose

The delivered effluent dose is a critical determinant of CRRT efficacy and has been linked to patient outcomes.[20] Our study found that the KICU group achieved a significantly higher rate of delivered dose attainment than the control group. This improvement can be directly traced to the operational advantages of the integrated KICU team. The continuous presence of trained KICU nurses at the bedside ensures more vigilant monitoring of the CRRT machine, leading to quicker responses to alarms and more timely replacement of fluid bags, thereby minimising downtime.[8,9] The close collaboration between nurses and physicians within the same unit streamlines the process for anticoagulation adjustments and troubleshooting of circuit issues, reducing the frequency and duration of treatment interruptions. In traditional models, these tasks often involve paging a remote physician and waiting for orders, creating inherent delays. The observed dose attainment rate in the KICU group exceeds some previously reported figures,[5,19] suggesting that a fully integrated, co-located team may offer advantages over other models of care coordination. This is a crucial finding, as suboptimal dose delivery remains a common challenge in CRRT practice, and our study demonstrates a viable model for its improvement.

Streamlining Continuous Renal Replacement Therapy Initiation Through Coordinated Teamwork

The dramatically shorter time to dialysis catheter insertion and CRRT initiation in the KICU group underscores the value of preparedness and seamless teamwork in critical care. For patients with life-threatening complications of renal failure, such as severe hyperkalaemia or pulmonary oedema, reducing this time-to-therapy is clinically paramount. The KICU model inherently facilitates this efficiency. The availability of a pre-assembled emergency dialysis catheter insertion cart and a CRRT machine primed and ready for use by the in-unit team leader eliminates the delays associated with summoning staff from a separate haemodialysis unit and gathering supplies from different locations. The immediate availability of KICU nurses credentialed in critical care blood purification to assist the physician at the bedside creates a self-sufficient resuscitation team. This finding aligns with studies highlighting that simulation and protocol-driven approaches for urgent procedures can significantly reduce execution time and improve outcomes in critically ill patients.[32]

Improving the Patient Experience

The higher patient satisfaction scores in the KICU group reflect the holistic benefits of the integrated care model. Continuous renal replacement therapy is a stressful and invasive experience for patients, often accompanied by anxiety, discomfort and a feeling of loss of control.[23,24] The KICU model, with its consistent team of physicians and nurses who are thoroughly familiar with the patient's condition and the intricacies of CRRT, likely fosters a greater sense of security and personalised attention. Effective and continuous communication within the team translates to more coherent and reassuring explanations for the patient. Furthermore, the superior volume management and rapid response to complications likely led to better-controlled symptoms (eg less dyspnoea, fewer episodes of hypotension), directly enhancing patient comfort and perceived quality of care. This aspect of the KICU model aligns with the broader shift in healthcare towards valuing patient-reported outcomes and experiences, particularly in high-acuity settings.

Robustness of Findings Supported by Adjusted Analyses

The primary outcomes of our study, derived from comparisons within the propensity score-matched cohort, were further validated by supplementary multivariable regression analyses. The consistency between the unadjusted results and the adjusted effect estimates strengthens the credibility of our conclusions. The fact that the beneficial associations of the KICU model with significantly reduced complications, improved dose delivery, and faster treatment initiation remained statistically significant even after controlling for all baseline covariates underscores that these improvements are robust and not attributable to residual confounding from the variables we measured. This analytical rigor reinforces the inference that the structured, integrated nature of the KICU model itself is a key driver of the observed superior outcomes.

Strengths and Limitations of the Study

The strengths of this study are the large sample size and strict quality control (three levels of data verification), which for the first time evaluated the KICU model in terms of timeliness, safety and patient experience in multiple dimensions. The integrated model of KICU is more clinically actionable than the decentralised CRRT management proposed by Connor et al. However, the study still has limitations. First, the single-centre design may limit the extrapolation of our conclusions to other settings with different patient populations or clinical practices. Second, the use of convenience sampling and the different recruitment periods for the control (2022) and KICU (2023) groups introduce the potential for selection and temporal biases, respectively; although PSM was used to balance measured covariates, the influence of unmeasured confounders cannot be entirely ruled out. Third, long-term survival and healthcare costs were not evaluated. Finally, the satisfaction scales used were not standardised, which may affect the comparability of this outcome.

Clinical Outlook

The KICU model provides a new paradigm for the management of critical renal disease, and it is recommended to (1) incorporate critical care blood purification techniques into the training system for specialised nurses, (2) develop an intelligent CRRT management platform that integrates volume monitoring and early warning functions and (3) explore the potential of artificial intelligence and machine learning to enhance real-time monitoring, predict complications such as circuit clotting and personalise fluid and dose prescriptions. Furthermore, it is crucial to explore synergistic protocols for multimodal life support between the KICU and ECMO, mechanical ventilation and other modalities. In addition, how to balance the workload of ICU nurses and the quality of CRRT still needs further research.

Conclusion

This study robustly demonstrates that the KICU model of healthcare-led CRRT was associated with improved patient outcomes compared with a traditional model, a finding consistent across both propensity score-matched and multivariable-adjusted analyses. The integrated, specialised team approach was linked to a lower incidence of complications, a higher achievement rate of the delivered effluent dose, a shorter time to treatment initiation and greater patient satisfaction. These findings suggest that optimising CRRT through multidisciplinary collaboration and process integration holds considerable promise for enhancing the care of critically ill patients with renal disease. To translate these findings

into practice, we recommend policy initiatives focused on promoting specialised training and certification for nurses in critical care blood purification and considering the development of dedicated KICU-like structures or teams in tertiary care centres to concentrate expertise and improve outcomes.

Data Sharing Statement

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

Ethics Approval and Consent to Participate

This study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of Shanxi Provincial People's Hospital, and informed consent was obtained from all participants.

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