International Journal of Public Health and Medical Research
ISSN: 3006-7707 (Print), ISSN: 3006-3752 (Online)
Volume 6, Number 7, Year 2026
DOI: https://doi.org/10.62051/ijphmr.v6n7.04

Fluid Balance in the 24 Hours Before Continuous Renal Replacement Therapy and ICU Mortality Among Critically Ill Adult Patients: A Nursing Risk Assessment Study Using MIMIC-IV

Qiaozhen Pan, Lei Peng and Xue Ren *

The First Affiliated Hospital of Sun Yat-sen University, Emergency Ward, Guangzhou, 510000, China

*Corresponding Author: panqzh5@mail.sysu.edu.cn

ABSTRACT

Objective: To investigate the predictive value of cumulative fluid balance measured within 24 hours before initiation of continuous renal replacement therapy (CRRT) for Intensive Care Unit (ICU) mortality among critically ill adult patients. Methods: A retrospective cohort study used the MIMIC-IV 3.1 database to include adult patients who received CRRT during their first ICU admission and whose CRRT initiation occurred between ICU admission and discharge. The index time point was defined as the start of the first CRRT session. Fluid balance over the preceding 24 hours was calculated as the difference between fluid input and output and was standardized by body weight (mL/kg). Fluid balance values were winsorized at the 1st and 99th percentiles and entered into a logistic regression model in 10 mL/kg increments. The primary outcome was ICU mortality. Multivariable models assessed the association between fluid balance and ICU mortality, and model discrimination was evaluated using the C-statistic. Sensitivity analyses were performed for in-hospital mortality, specific subgroups, and after inclusion of lactate and creatinine levels. Results: Of 1,355 initially screened patients, 946 met inclusion criteria, and 444 died in the ICU (46.9% mortality rate). The body weight-standardized fluid balance during the 24 hours before CRRT was higher in non-survivors than in survivors [33.42 (16.91, 65.22) mL/kg vs. 22.71 (10.18, 45.05) mL/kg, $P < 0.001$]. ICU mortality rates increased across quartiles of fluid balance, from 34.2%, 44.1%, 53.4%, to 56.1% (trend test $P < 0.001$). Multivariable logistic regression showed that each 10 mL/kg increase in fluid balance was associated with a 5% higher risk of ICU mortality (OR = 1.05, 95% CI 1.02–1.09, $P = 0.001$); the C-statistic for the main model was 0.681. After adding lactate and creatinine, the C-statistic improved to 0.735, but the direction of the fluid balance effect reversed (OR = 0.94, 95% CI 0.91–0.98, $P = 0.006$). Conclusion: A higher body weight-standardized fluid balance within 24 hours before CRRT is associated with ICU mortality in critically ill adults and may serve as a risk signal before CRRT initiation. However, the reversal of this association when adjusting for disease severity and clinical decision-making factors suggests that its predictive value may be influenced by illness severity, treatment choices, and confounding variables. Therefore, it cannot yet support causal inference or guide fluid management independently.

KEYWORDS

Continuous renal replacement therapy; Fluid balance; Critical illness; Intensive care unit; Mortality; MIMIC-IV Prediction

Content from this work may be used under the terms of CC BY-NC 4.0 licence (https://creativecommons.org/licenses/by-nc/4.0/). Published by Warwick Evans Publishing.

1. INTRODUCTION

Continuous renal replacement therapy (CRRT) is a crucial organ support modality for critically ill patients with severe acute kidney injury, fluid overload, or metabolic derangements [1–3]. Fluid accumulation before CRRT initiation is not merely the difference between input and output but a complex reflection of multiple clinical processes, including resuscitation intensity, vasopressor use, blood product transfusions, nutritional support, declining renal function, hidden losses, and the timing of renal replacement therapy initiation [4–6]. Previous studies have shown that fluid overload is associated with adverse outcomes in patients undergoing CRRT [7, 8], yet most research has focused on net ultrafiltration rate during CRRT, cumulative percentage of fluid overload, or predefined fluid targets, with insufficient attention to the risk-identification value of fluid balance within a fixed time window before CRRT initiation [9–11].

Early identification of high-risk patients is a key component of risk management in critical care. For patients scheduled to receive CRRT, nursing teams typically need to continuously monitor fluid intake and output, changes in vasopressor use, lactate levels, renal function, and expected net ultrafiltration goals [12, 13]. If fluid balance over the 24 hours preceding CRRT can predict Intensive Care Unit (ICU) mortality, it could be used as a simple, reproducible bedside risk signal, supporting enhanced monitoring, interdisciplinary communication, and treatment plan review [14–16]. This study uses the time of first CRRT initiation as the index point to evaluate the predictive value of fluid balance, standardized by body weight, over the preceding 24 hours for ICU mortality in critically ill adult patients. It also assesses the robustness of the findings through in-hospital mortality analysis, subgroup analyses, and sensitivity analyses.

2. MATERIALS AND METHODS

2.1. General Information

This study is a retrospective cohort study based on the MIMIC-IV 3.1 database. MIMIC-IV is a publicly available, de-identified electronic health record database for intensive care patients, containing demographic data, ICU treatment records, laboratory test results, medications, fluid balances, and clinical outcomes [17]. Data extraction and management were performed in a local PostgreSQL environment, and reporting followed the STROBE statement [18].

2.2. Participants

Study participants were selected strictly according to uniform inclusion and exclusion criteria. For patients with multiple ICU admissions or multiple CRRT treatments recorded in the database, only the first ICU admission meeting eligibility criteria and the corresponding initial CRRT data were included, and duplicate cases were excluded to prevent statistical bias. Inclusion criteria: (1) Patient age $\geq$ 18 years; (2) Clear documentation of CRRT during the first ICU admission; (3) The initiation time of the first CRRT session falls within the period from ICU admission to discharge for that hospitalization; (4) At least 20 observable hours prior to CRRT initiation, with complete baseline body weight data available and full records of fluid intake and output over the 24 hours preceding CRRT, including accurate timing information required for calculating 24-hour fluid balance.

Exclusion criteria: (1) Interval between ICU admission and the start of the first CRRT < 24 hours, resulting in an observation window insufficient for analysis; (2) Missing baseline body weight data, or incomplete or disordered fluid intake/output records during the 24 hours before CRRT initiation, making accurate calculation of 24-hour fluid balance impossible; (3) Pregnant or postpartum patients; (4) Brain-dead patients or organ donors; (5) Patients who previously received CRRT at another hospital before being transferred to the ICU involved in this study; (6) Patients with end-stage renal disease undergoing chronic maintenance dialysis; (7) Cases with logical errors, severe missing data,

or extreme outliers beyond clinically reasonable ranges in core study variables; (8) For patients with multiple ICU admissions or multiple CRRT sessions, any ICU admission or CRRT record other than the first one meeting inclusion criteria.

2.3. Indexing Point and Forecast Window

The index time point was defined as the start time of the first "Dialysis-CRRT" record. All exposures and covariates were restricted to periods before the index time point, and the primary prediction window was set to 24 hours before CRRT initiation to minimize the risk of misinterpreting CRRT treatment processes or responses as predictive information.

2.4. Fluid Balance and Covariates

24-hour fluid input before CRRT was obtained from input events, and fluid output from output events. Fluid balance was calculated as total input minus total output (mL) and then divided by body weight to obtain the standardized fluid balance (mL/kg). To reduce the impact of extreme values, the standardized fluid balance was minorized at the 1st and 99th percentiles. The primary analysis used 10 mL/kg increments, with results also presented by quartiles.

Candidate covariates included age, sex, body weight, vasopressor exposure in the 24 hours before CRRT, time from ICU admission to CRRT initiation, mechanical ventilation-related records, chronic kidney failure or end-stage renal disease, source database, and diagnostic codes for AKI/sepsis. A sensitivity model further incorporated lactate and creatinine levels in the 24 hours before CRRT.

2.5. Outcome Measures

The primary outcome was ICU death, defined as death occurring during the current ICU admission. The secondary outcome was in-hospital mortality.

2.6. Statistical Methods

Continuous variables are presented as median (interquartile range), and group comparisons were performed using the Mann-Whitney U test. Categorical variables are expressed as n (%), and group comparisons were conducted using χ^2 tests or Fisher's exact probability method. The Cochran-Armitage trend test was used to assess trends in mortality across quartiles of fluid balance. Multivariable logistic regression models were constructed, reporting odds ratios (ORs), 95% confidence intervals (CIs), and P-values. The primary model predicted ICU mortality, while the secondary model predicted in-hospital mortality. Exploratory analyses were also performed within subgroups defined by chronic kidney failure/end-stage renal disease or source database, and sensitivity models incorporating lactate and creatinine were developed. Model discrimination was evaluated using the C statistic. All tests were two-sided, with statistical significance defined as $P < 0.05$.

3. RESULTS

3.1. Patient Screening and General Characteristics

A total of 1,355 adult patients who received their first CRRT during initial ICU admission were identified; after screening for a complete prediction window and availability of key variables, 946 patients were finally included. In the primary analysis, 444 patients died in the ICU, and 497 died in the hospital; among them, 275 belonged to subgroups with chronic kidney failure/end-stage renal disease or to those originating from specific databases.

As seen in Table 1, the median age was 63.00 (52.00, 74.00) years, with 579 males (61.2%). Compared with ICU survivors, ICU non-survivors were older and had higher fluid input volumes within 24 hours before CRRT, standardized fluid balance, proportion of vasopressor exposure, and lactate levels, as well as lower creatinine levels and a higher proportion of Acute Kidney Injury (AKI)/sepsis diagnoses (all $P < 0.05$). No statistically significant differences were observed between the two groups for gender, body weight, time from ICU admission to initiation of CRRT, fluid output, urine output, or albumin levels.

Table 1. Baseline characteristics of patients with different ICU outcomes

Variable	Overall (n=946)	ICU Survivors (n=502)	ICU Deaths (n=444)	P-value
Age, years	63.00 (52.00~74.00)	62.00 (50.00~71.00)	66.00 (55.00~75.00)	<0.001
Male, n (%)	579 (61.2)	313 (62.4)	266 (59.9)	0.462
Weight, kg	87.75 (73.00~104.59)	87.40 (73.00~105.15)	87.95 (72.95~104.00)	0.926
Time from ICU admission to CRRT, h	69.07 (37.71~136.94)	68.29 (36.68~123.77)	70.99 (38.27~161.66)	0.175
Fluid input in 24 hours prior to CRRT, mL	3419.20 (2111.61~5854.52)	2913.85 (1844.22~5098.48)	3836.18 (2628.05~6459.01)	<0.001
Fluid output in 24 hours prior to CRRT, mL	738.00 (267.25~1 685.00)	735.50 (250.75~1 647.00)	743.50 (274.50~1717.25)	0.419
Urine output in 24 hours prior to CRRT, mL	239.00 (70.00~669.00)	249.00 (68.25~705.25)	232.50 (74.50~610.50)	0.675
Standardized fluid balance, mL/kg	26.70 (12.77~57.26)	22.71 (10.18~45.05)	33.42 (16.91~65.22)	<0.001
Vasopressor exposure, n (%)	757 (80.0)	356 (70.9)	401 (90.3)	<0.001
Mechanical ventilation-related records, n (%)	941 (99.5)	498 (99.2)	443 (99.8)	0.378
Lactate, mmol/L	2.40 (1.50~5.10)	1.90 (1.20~3.70)	3.30 (1.90~7.40)	<0.001
Albumin, g/dL	2.70 (2.30~3.30)	2.70 (2.30~3.30)	2.60 (2.20~3.30)	0.152
Creatinine, mg/dL	4.20 (3.00~5.60)	4.70 (3.30~6.30)	3.70 (2.70~5.00)	<0.001
Chronic kidney failure/source database, n (%)	208 (22.0)	116 (23.1)	92 (20.7)	0.388
Source database flag, n (%)	173 (18.3)	80 (15.9)	93 (20.9)	0.053
AKI/sepsis diagnosis, n (%)	905 (95.7)	469 (93.4)	436 (98.2)	<0.001

Note: Continuous variables are presented as median (interquartile range); categorical variables are presented as number (%). ICU, Intensive Care Unit; CRRT, Continuous renal replacement therapy; AKI, acute kidney injury.

3.2. Fluid Balance Quartiles and Mortality

As standardized fluid balance increased from Q1 to Q4, ICU mortality rose from 34.2% to 56.1%, and in-hospital mortality increased from 41.4% to 59.5%. ICU mortality increased monotonically with higher quartiles of fluid balance (Cochran-Armitage trend test, $z = 5.182$, $P < 0.001$). The detailed information can be seen in Table 2.

Table 2. Standardized Fluid Balance Quartiles and Mortality Outcomes

Group	n	ICU death	In-hospital death	Median fluid balance (mL/kg)	ICU mortality (%)	In-hospital mortality (%)
Q1 (Lowest)	237	81	98	4.6	34.2	41.4
Q2	236	104	121	19.9	44.1	51.3
Q3	236	126	137	38.1	53.4	58.1
Q4 (Highest)	237	133	141	88.5	56.1	59.5

Note: ICU, Intensive Care Unit.

3.3. Prediction of ICU Mortality Based on 24-Hour Fluid Balance Prior to CRRT

The primary multivariable logistic model included 946 patients and 444 ICU death events (Table 3). After adjusting for age, sex, exposure to vasopressors in the 24 hours prior to CRRT, time from ICU admission to CRRT, body weight, chronic kidney failure/source database, and AKI/sepsis diagnosis, each 10 mL/kg increase in standardized fluid balance was associated with a 5% higher risk of ICU mortality (OR = 1.05, 95% CI 1.02–1.09, P = 0.001). Exposure to vasopressors, age, time from ICU admission to CRRT, and AKI/sepsis diagnosis were also associated with ICU mortality. The model C-statistic was 0.681, indicating moderate discriminatory ability.

Table 3. Multivariable Logistic Regression Model for ICU Mortality

Variables	OR	95%CI	P-value
Fluid balance (per 10 mL/kg)	1.05	1.02~1.09	0.001
Age (per year)	1.02	1.01~1.03	<0.001
Male	0.91	0.69~1.20	0.510
Vasopressor exposure in the 24 hours prior to CRRT	3.65	2.49~5.37	<0.001
Time from ICU admission to CRRT	1.04	1.01~1.07	0.016
Body weight conversion term	1.02	0.96~1.09	0.498
Chronic kidney failure/source database	1.03	0.76~1.39	0.855
AKI/sepsis diagnosis	3.90	1.73~8.80	0.001

Note: The model included 946 patients and 444 ICU death events; C statistic = 0.681. ICU, Intensive Care Unit; CRRT, Continuous renal replacement therapy; AKI, acute kidney injury.

3.4. Secondary Outcomes And Sensitivity Analysis

As shown in Table 4, each 10 mL/kg increase in standardized fluid balance was associated with a 4% higher risk of in-hospital death (OR = 1.04, 95% CI 1.01–1.07, P = 0.021).

Table 4. Multivariate Logistic Regression Model for In-hospital Mortality

Variables	OR	95%CI	P-value
Fluid balance (per 10 mL/kg)	1.04	1.01~1.07	0.021
Age (per year) Male	1.02	1.01~1.03	<0.001
Vasopressor exposure within 24 hours prior to CRRT	0.95	0.72~1.25	0.726
Time from ICU admission to CRRT initiation	3.23	2.25~4.63	<0.001
Body weight conversion term	1.03	1.00~1.06	0.044
Chronic kidney failure/source database	1.02	0.95~1.08	0.606
AKI/sepsis diagnosis	1.07	0.79~1.44	0.675
Fluid balance (per 10 mL/kg)	3.70	1.74~7.86	<0.001

Note: ICU, Intensive Care Unit; CRRT, Continuous renal replacement therapy; AKI, acute kidney injury.

In the subgroups with chronic kidney failure/end-stage renal disease or in the source database (Table 5), the association between fluid balance and ICU mortality did not reach statistical significance (OR = 1.07, 95% CI 1.00–1.15, P = 0.061).

Table 5. Exploratory model for ICU mortality in specific subgroups

Variables	OR	95%CI	P-value
Fluid balance (per 10 mL/kg)	1.07	1.00~1.15	0.061
Age (per year) Male	1.04	1.02~1.06	<0.001
Vasopressor exposure in the 24 hours prior to CRRT	1.21	0.71~2.08	0.483
Time from ICU admission to CRRT initiation	5.20	2.40~11.27	<0.001
Body weight conversion term	1.09	1.01~1.16	0.020
Fluid balance (per 10 mL/kg)	0.94	0.82~1.08	0.389

Note: Subgroup consisted of 275 cases; results are exploratory analysis. ICU, Intensive Care Unit; CRRT, Continuous renal replacement therapy.

Table 6. Sensitivity model for ICU mortality with the addition of lactate and creatinine

Variables	OR	95%CI	P-value
Fluid balance (per 10 mL/kg)	0.94	0.91~0.98	0.006
Age (per year) Male	1.01	1.00~1.02	0.034
Vasopressor exposure in the 24 hours prior to CRRT	0.93	0.67~1.28	0.643
Time from ICU admission to CRRT	2.84	1.80~4.48	<0.001
Body weight conversion term	1.06	1.02~1.10	0.001
Lactate conversion term	0.98	0.91~1.05	0.520
Creatinine	3.67	2.63~5.12	<0.001
Chronic kidney failure/source database	0.89	0.82~0.97	0.005
Fluid balance (per 10 mL/kg)	1.12	0.80~1.57	0.514

Note: The model included 835 patients and 405 ICU death events; C-statistic = 0.735. ICU, Intensive Care Unit; CRRT, Continuous renal replacement therapy.

Table 6 and Table 7 shows that after adding lactate and creatinine, the model included 835 patients and 405 ICU deaths, and the C-statistic increased from 0.681 to 0.735, indicating improved discrimination. At this point, the effect of fluid balance reversed direction (OR = 0.94, 95% CI 0.91–0.98, P = 0.006). Elevated lactate was associated with increased risk of ICU death, whereas elevated creatinine was associated with lower ICU mortality. These findings suggest that lactate and creatinine

may provide information on disease severity, CRRT indications, and clinical decision-making, and should be interpreted cautiously.

Table 7. Discrimination between the main model and sensitivity models

Model	Sample Size	Number of Events	C Statistic
Main ICU mortality model	946	444	0.681
Sensitivity model incorporating lactate and creatinine	835	405	0.735

Note: The current results do not provide the 95% CI for the C statistic, calibration, optimal threshold, sensitivity, and specificity; therefore, no additional calculations are made. ICU, Intensive Care Unit; CRRT, Continuous renal replacement therapy.

4. DISCUSSION

This study found that critically ill adult patients undergoing CRRT had a higher ICU mortality rate. Standardized fluid balance during the 24 hours before CRRT was significantly higher in the deceased group, and ICU mortality increased progressively with higher quartiles of fluid balance. In the prespecified multivariable model, each 10 mL/kg increase in fluid balance was associated with a 5% higher risk of ICU death, indicating that this easily obtainable metric from electronic medical records has predictive value. The C-statistic of the primary model was 0.681, suggesting limited discriminatory power based solely on the current set of variables. When lactate and creatinine were added, the C-statistic increased to 0.735, but the effect of fluid balance reversed, indicating that its predictive utility is highly dependent on disease severity and clinical context.

Higher fluid balance may reflect ongoing volume resuscitation, oliguria or anuria, capillary leak, cardiac and renal dysfunction, and increased disease severity [19, 20]. Fluid accumulation can lead to tissue edema, impaired pulmonary gas exchange, elevated intra-abdominal pressure, and compromised organ perfusion, all of which are associated with adverse outcomes. However, fluid balance is also shaped by treatment choices and disease course: patients with more severe shock and higher vasopressor requirements typically receive greater fluid volumes [21]. Meanwhile, worsening renal function and the timing of CRRT initiation jointly influence cumulative fluid balance [22, 23]. Therefore, the associations observed in this study cannot be interpreted as "increased fluid administration inevitably leads to death."

Particular attention should be paid to the reversal of effect direction in sensitivity models. Lactate is an important marker of circulatory perfusion deficiency and stress severity, whereas creatinine is closely related to renal function, CRRT indications, and initiation decisions. Including these variables in the model may alter the disease-severity information originally captured by fluid balance or introduce mediator adjustment, collider bias, or selection bias. Therefore, these findings further support viewing pre-CRRT fluid balance as a composite risk signal rather than an independent, directly modifiable causal target.

As in the referenced MIMIC-IV machine learning study [10], this research defines a fixed prediction window, clinical outcomes, and model evaluation metrics, while emphasizing the clinical interpretability of the prediction tool. However, the two studies differ in their data foundation: the current results are based on logistic regression and C-statistics, without training/test set partitioning, cross-validation, confidence intervals for the receiver operating characteristic curve, calibration curves, decision curve analysis, or SHAP analysis. Therefore, it would be inappropriate to present these findings as a multi-algorithm machine learning model. The current results support an "initial assessment of predictive value," but further development into a formal prediction model would require internal validation, calibration, and evaluation of clinical net benefit.

The 24-hour fluid balance before CRRT should be incorporated into the structured nursing assessment. For patients with a significant increase in positive fluid balance, the nursing team should verify the completeness of fluid intake and output records and recheck urine output, drainage volumes, and insensible losses. Besides, they should also continuously monitor vasopressor dosages, lactate levels, and respiratory and circulatory status, and jointly discuss with physicians, clinical pharmacists, and the CRRT team the timing of initiation and net ultrafiltration goals [24, 25]. Its purpose should be to trigger reassessment and communication, rather than to automatically determine prognosis or initiate restrictive fluid therapy based on a single threshold [26, 27].

5. LIMITATIONS

This study has several limitations. First, as a retrospective single-center analysis using de-identified data, residual confounding is possible, and caution is warranted when extrapolating findings to other countries, hospitals, or care processes. Second, fluid input and output were derived from electronic records, which may be affected by delayed documentation, inconsistent units, omissions, and duplicate entries; blood products, enteral nutrition, drug vehicles, irrigation fluids, and non-urinary losses might not have been fully captured. Third, key variables such as specific CRRT indications, vasopressor dosages, mechanical ventilation parameters, actual net ultrafiltration rate, and interruptions in CRRT were not included. Fourth, the primary model demonstrated only moderate discriminatory performance and lacked calibration curves, Brier scores, confidence intervals for the area under the receiver operating characteristic curve, decision curve analysis, and external validation, making it insufficient as a mature clinical prediction tool. Fifth, the complete-case sample for the sensitivity analysis was reduced to 835 patients, and missingness mechanisms could influence the results. Sixth, complex mediation, interaction, and nonlinear relationships may exist between fluid balance and disease status or treatment, which were not adequately evaluated in the current models.

6. CONCLUSION

In critically ill adult patients receiving CRRT in the MIMIC-IV database, a higher fluid balance, standardized by body weight, within 24 hours before CRRT initiation was associated with ICU mortality, with mortality increasing across quartiles of fluid balance. This metric may serve as a simple risk signal before CRRT initiation, supporting nursing review and multidisciplinary communication. However, given the primary model's limited discriminative ability and the reversal of the effect when lactate and creatinine were included, fluid balance should not currently be regarded as an independent causal factor or used as a standalone clinical decision tool. Future studies should conduct internal and external validation in multicenter cohorts, incorporate calibration and decision curve analyses, and develop more robust and interpretable risk prediction models using dynamic time-series variables.

ETHICS STATEMENT AND DATA AVAILABILITY

MIMIC-IV is a de-identified database accessible upon PhysioNet certification and signing of a data use agreement. This study uses publicly available de-identified data and does not involve direct patient contact. The database version used is MIMIC-IV 3.1.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors contributed to the study design, data analysis, interpretation of results, and manuscript writing. The corresponding author was responsible for study supervision and manuscript revision. Prior to formal submission, please verify and detail author contributions according to journal requirements.

REFERENCES

[1] See, E. J., & Bellomo, R. (2021). How I prescribe continuous renal replacement therapy. Critical Care, 25, 1. https://doi.org/10.1186/s13054-020-03448-7

[2] Liu, S.-Y., Xu, S.-Y., Yin, L., Yang, T., Jin, K., Zhang, Q.-B., et al. (2023). Management of regional citrate anticoagulation for continuous renal replacement therapy: guideline recommendations from Chinese emergency medical doctor consensus. Military Medical Research, 10, 23. https://doi.org/10.1186/s40779-023-00457-9

[3] Murugan, R., Prowle, J., & Beaubien-Souligny, W. (2024). Protocolized fluid balance neutralization during continuous renal replacement therapy. Intensive Care Medicine, 50, 2141–2143. https://doi.org/10.1007/s00134-024-07698-9

[4] Jentzer, J. C., Bihorac, A., Brusca, S. B., Del Rio-Pertuz, G., Kashani, K., Kazory, A., et al. (2020). Contemporary management of severe acute kidney injury and refractory cardiorenal syndrome: JACC council perspectives. Journal of the American College of Cardiology, 76, 1084–1101. https://doi.org/10.1016/j.jacc.2020.06.070

[5] Rewa, O. G., Ortiz-Soriano, V., Lambert, J., Kabir, S., Heung, M., House, A. A., et al. (2023). Epidemiology and outcomes of AKI treated with continuous kidney replacement therapy: The multicenter CRRTnet study. Kidney Medicine, 5, 100641. https://doi.org/10.1016/j.xkme.2023.100641

[6] Gembillo, G., Floris, M., Lo Cicero, L., Spadaro, G., Soraci, L., & Santoro, D. (2026). Slow continuous ultrafiltration and prolonged intermittent renal replacement therapy: Tailoring renal replacement therapy in intensive care unit. World Journal of Nephrology, 15, 118219. https://doi.org/10.5527/wjn.v15.i2.118219

[7] Cortina, G., Daverio, M., Demirkol, D., Chanchlani, R., & Deep, A. (2024). Continuous renal replacement therapy in neonates and children: what does the pediatrician need to know? An overview from the Critical Care Nephrology Section of the European Society of Paediatric and Neonatal Intensive Care (ESPNIC). European Journal of Pediatrics, 183, 529–541. https://doi.org/10.1007/s00431-023-05318-0

[8] Stanski, N. L., Gist, K. M., Hasson, D., Stenson, E. K., Seo, J., Ollberding, N. J., et al. (2024). Characteristics and outcomes of children and young adults with sepsis requiring continuous renal replacement therapy: A comparative analysis from the Worldwide Exploration of Renal Replacement Outcomes Collaborative in Kidney Disease (WE-ROCK). Critical Care Medicine, 52, 1686–1699. https://doi.org/10.1097/CCM.0000000000006405

[9] Naorungroj, T., Neto, A. S., Yanase, F., Eastwood, G., Wald, R., Bagshaw, S. M., et al. (2021). Time to initiation of renal replacement therapy among critically ill patients with acute kidney injury: A current systematic review and meta-analysis. Critical Care Medicine, 49, e781–e792. https://doi.org/10.1097/CCM.0000000000005018

[10] Nuermaimaiti, M., Wang, M., Lou, R., Wang, N., Si, Q., Wang, T., et al. (2025). The impact of initiation timing of continuous renal replacement therapy on outcomes in critically ill patients with acute kidney injury a retrospective study from the MIMIC-IV database. Scientific Reports, 15, 10922. https://doi.org/10.1038/s41598-024-84435-8

[11] Jin, L., Li, P., Xu, Q., Wang, F., & Zhang, L. (2025). Association of net ultrafiltration intensity and clinical outcomes among critically ill patients receiving continuous renal replacement therapy: A systematic review, meta-analysis, and trial sequential analysis. Australian Critical Care, 38, 101170. https://doi.org/10.1016/j.aucc.2024.101170

[12] Chen, Y., & Xu, S. (2024). Enhancing quality control in continuous renal replacement therapy through ICU specialist nursing care management program. Alternative Therapies in Health and Medicine, 30, 160–165.

[13] Jourdain, M., Chatti, I. G., Housni, B., Jaquet, P., Jezequel, M., Kane, O., et al. (2025). Renal replacement therapy in an intensive care unit: guidelines from the SRLF-GFRUP consensus conference. Annals of Intensive Care, 15, 100. https://doi.org/10.1186/s13613-025-01517-0

[14] Murugan, R., Bellomo, R., Palevsky, P. M., & Kellum, J. A. (2021). Ultrafiltration in critically ill patients treated with kidney replacement therapy. Nature Reviews Nephrology, 17, 262–276. https://doi.org/10.1038/s41581-020-00358-3

[15] Ruste, M., Schweizer, R., Fellahi, J.-L., & Jacquet-Lagrèze, M. (2023). Fluid removal tolerance during the de-escalation phase: is preload unresponsiveness the best guiding candidate? Critical Care, 27, 154. https://doi.org/10.1186/s13054-023-04444-3

[16] Singh, W., Nikravangolsefid, N., Palevsky, P. M., Kashani, K. B., & Murugan, R. (2026). Feasibility and acceptability of weight-based net fluid removal during continuous kidney replacement therapy: A nursing survey. Applied Nursing Research, 88, 152066. https://doi.org/10.1016/j.apnr.2026.152066

[17] Johnson, A. E. W., Bulgarelli, L., Shen, L., Gayles, A., Shammout, A., Horng, S., et al. (2023). MIMIC-IV, a freely accessible electronic health record dataset. Scientific Data, 10, 1. https://doi.org/10.1038/s41597-022-01899-x

[18] von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., Vandenbroucke, J. P., et al. (2008). The strengthening the reporting of observational studies in epidemiology (STROBE) statement: Guidelines for reporting observational studies. Journal of Clinical Epidemiology, 61, 344–349. https://doi.org/10.1016/j.jclinepi.2007.11.008

[19] Neyra, J. A., Lambert, J., Ortiz-Soriano, V., Cleland, D., Colquitt, J., Adams, P., et al. (2022). Assessment of prescribed vs. achieved fluid balance during continuous renal replacement therapy and mortality outcome. PLOS ONE, 17, e0272913. https://doi.org/10.1371/journal.pone.0272913

[20] Stenson, E. K., Alhamoud, I., Alobaidi, R., Bottari, G., Fernandez, S., Fuhrman, D. Y., et al. (2024). Factors associated with successful liberation from continuous renal replacement therapy in children and young adults: analysis of the worldwide exploration of renal replacement outcomes collaborative in Kidney Disease Registry. Intensive Care Medicine, 50, 861–872. https://doi.org/10.1007/s00134-024-07336-4

[21] Stanski, N. L., Zhang, B., Ouyang, J., Sanchez-Pinto, L. N., Faustino, E. V. S., Rogerson, C. M., et al. (2025). Derivation and validation of pediatric sepsis-associated acute kidney injury subphenotypes with prognostic relevance. Pediatric Critical Care Medicine, 26, e1084–e1095. https://doi.org/10.1097/PCC.0000000000003789

[22] Park, C. H., Koh, H. B., Lee, J. H., Jung, H.-Y., Ha, J., Kim, H. W., et al. (2024). Volume control strategy and patient survival in sepsis-associated acute kidney injury receiving continuous renal replacement therapy: a randomized controlled trial with secondary analysis. Scientific Reports, 14, 14284. https://doi.org/10.1038/s41598-024-64224-z

[23] Gunning, S., Mire, M., Gulotta, G., & Koyner, J. (2025). Impact of fluid removal rate on patients receiving continuous renal replacement therapy for acute kidney injury. Journal of Critical Care, 89, 155161. https://doi.org/10.1016/j.jcrc.2025.155161

[24] Rhee, H., Berenger, B., Mehta, R. L., & Macedo, E. (2021). Regional citrate anticoagulation for continuous kidney replacement therapy with calcium-containing solutions: A cohort study. American Journal of Kidney Diseases, 78, 550-559.e1. https://doi.org/10.1053/j.ajkd.2021.01.017

[25] Goldstein, S. L., Krallman, K. A., Roy, J.-P., Collins, M., Chima, R. S., Basu, R. K., et al. (2023). Real-time acute kidney injury risk stratification-biomarker directed fluid management improves outcomes in critically ill children and young adults. Kidney International Reports, 8, 2690–2700. https://doi.org/10.1016/j.ekir.2023.09.019

[26] do Nascimento, J. C., Sanches, M. B., & Souza, R. C. S. (2023). Validation of guidelines for the care of patients undergoing continuous renal replacement therapy. Nursing in Critical Care, 28, 379–387. https://doi.org/10.1111/nicc.12718

[27] Zhang, L., Zhu, Y., Zhou, Y., Chen, C., & Xia, Y. (2025). Nursing care for patients with cardiorenal syndrome after heart transplantation undergoing continuous renal replacement therapy: A case report and literature review. Medicine, 104, e43043. https://doi.org/10.1097/MD.0000000000043043