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Impact of Standardized Anticoagulation Management Optimization on the Operational Quality and Clinical Outcomes of Continuous Renal Replacement Therapy

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Abstract: *Objective*: To evaluate the impact of optimizing a standardized anticoagulation management protocol on the operational quality of continuous renal replacement therapy (CRRT) and related clinical outcomes. *Methods*: This was a single-center retrospective quality improvement study. Adult patients who underwent CRRT for ≥24 hours in the Intensive Care Unit of Linfen People's Hospital between 2023 and 2025 were included. According to the implementation stages of the optimized anticoagulation management protocol, patients were divided into three annual groups. The distribution of anticoagulation strategies, filter lifespan per session, incidence of unplanned circuit interruption, bleeding complications, and ICU length of stay were compared among the three groups. *Results*: A total of 289 patients were included. With the implementation of the standardized anticoagulation management protocol, the proportion of regional citrate anticoagulation increased from 45.5% in 2023 to 83.5% in 2025. Filter lifespan was significantly prolonged (45.3 ± 12.1 h vs 72.4 ± 11.6 h, $P < 0.001$), while the incidence of unplanned circuit interruption and bleeding complications decreased over time (both $P < 0.05$). ICU length of stay also showed a downward trend ($P = 0.009$). *Conclusion*: The establishment and implementation of a CRRT-centered standardized anticoagulation management protocol were associated with prolonged filter lifespan, reduced complication rates, and improved operational quality of CRRT. This management approach may enhance the safety of blood purification therapy in critically ill patients in the ICU.

Keywords: Continuous renal replacement therapy; Anticoagulation management; Process optimization; Critical care medicine; Blood purification

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1. Introduction

Continuous renal replacement therapy (CRRT) is an essential organ support modality for critically ill patients with acute kidney injury and multiple organ dysfunction [1–2]. Compared with intermittent hemodialysis or other short-duration blood purification modalities, CRRT offers advantages such as hemodynamic stability and continuous removal of metabolic waste products and inflammatory mediators, making it widely used in the intensive care unit (ICU). However, the successful implementation of CRRT largely depends on appropriate and stable anticoagulation management. Inappropriate anticoagulation strategies or non-standardized management processes may lead to frequent filter clotting, unplanned circuit interruptions, and an increased risk of bleeding, thereby directly compromising treatment continuity and safety [3].

In recent years, regional citrate anticoagulation has been increasingly adopted in CRRT, and anticoagulation management has gradually shifted from experience-based practice toward standardized and protocol-driven approaches [4–5]. Against this background, we systematically reviewed and analyzed clinical data before and after the optimization of the anticoagulation management protocol in our institution. The aim of this study was to evaluate the impact of standardized anticoagulation management on CRRT operational quality and patient outcomes, and to provide practical evidence for CRRT management in regional ICUs.

2. Materials and methods

2.1. Study design

This study was designed as a single-center retrospective quality improvement study. Against the background of the gradual implementation and optimization of the CRRT anticoagulation management protocol at Linfen People's Hospital, a stage-based comparative analysis was conducted among patients who underwent CRRT during different periods to evaluate the impact of anticoagulation management optimization on CRRT operational quality and related clinical outcomes. The study period spanned from January 2023 to December 2025. According to the implementation progress of the optimized anticoagulation management protocol, patients were categorized into three annual groups (2023, 2024, and 2025), reflecting the evolving stages of protocol optimization and allowing assessment of trends in CRRT operational quality over time.

2.2. Study population

Clinical data were retrospectively collected from patients who underwent CRRT in the Intensive Care Unit of Linfen People's Hospital between January 2023 and December 2025. During the study period, other blood purification modalities, including hemoperfusion and plasma exchange, were also performed in our institution. However, given the substantial differences in indications and anticoagulation management strategies among treatment modalities, only patients receiving CRRT were included in the present analysis to ensure population homogeneity.

The inclusion criteria were as follows: (1) age ≥18 years; (2) receipt of CRRT for acute kidney injury or other critical illness-related indications; and (3) CRRT duration ≥24 hours per session. The exclusion criteria were: (1) incomplete clinical data; and (2) switching to another primary blood purification modality during treatment.

During the study period, the CRRT anticoagulation management protocol was gradually established and continuously optimized. To evaluate the impact of protocol optimization on treatment performance, patients were categorized into three annual groups (2023, 2024, and 2025) according to the stages of protocol implementation, reflecting the progressive improvement of anticoagulation management and its influence on CRRT operational quality and related clinical outcomes.

2.3. Optimization of the CRRT anticoagulation management protocol

During the initial stage of the study period (2023), anticoagulation strategies for CRRT were primarily selected based on clinicians' individual experience. Starting in 2024, our institution gradually developed and implemented a standardized CRRT anticoagulation management protocol, which entered a relatively mature phase in 2025. The main components of the protocol optimization included:

(1) Establishing a unified CRRT anticoagulation management guideline, clearly defining indications and contraindications for anticoagulation;

(2) Developing structured pathways for anticoagulation strategy selection under different clinical scenarios, with regional citrate anticoagulation (RCA) recommended as the first-line strategy;

(3) Standardizing anticoagulant dose adjustment and monitoring procedures, including regular monitoring of activated partial thromboplastin time (APTT), electrolyte levels, acid–base status, and serum calcium concentrations;

(4) Conducting targeted training programs for medical and nursing staff to improve consistency in the implementation of anticoagulation strategies;

(5) Establishing a continuous evaluation and feedback system for CRRT operational quality and related complications, with regular analysis of filter lifespan and complication rates.

2.4. Outcome measures

The primary outcome measures included: (1) Distribution of anticoagulation strategies; (2) Filter lifespan per CRRT session (hours); (3) Incidence of unplanned circuit interruption; (4) Incidence of bleeding-related complications; (5) ICU length of stay (days).

Filter lifespan was defined as the duration from the initiation of a filter to its replacement due to clotting or other causes. Unplanned circuit interruption was defined as treatment discontinuation resulting from filter clotting or unexpected technical problems. Bleeding complications included gastrointestinal bleeding, bleeding at the catheter insertion site, or bleeding events requiring blood transfusion.

2.5. Statistical analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were tested for normality and are presented as mean ± standard deviation (SD). Comparisons among multiple groups were performed using one-way analysis of variance (ANOVA) for normally distributed data, and the Kruskal–Wallis test was applied for non-normally distributed variables. Categorical variables are presented as numbers (percentage) and were compared using the chi-square test or the chi-square test for trend, as appropriate. All statistical tests were two-sided, and a P value < 0.05 was considered statistically significant.

3. Results

3.1. Background of CRRT implementation

Over the past three years, the annual number of CRRT procedures and related extracorporeal organ support therapies in our institution has shown a steady increase (**Figure 1**), indicating a growing clinical demand for CRRT-based therapies among critically ill patients.

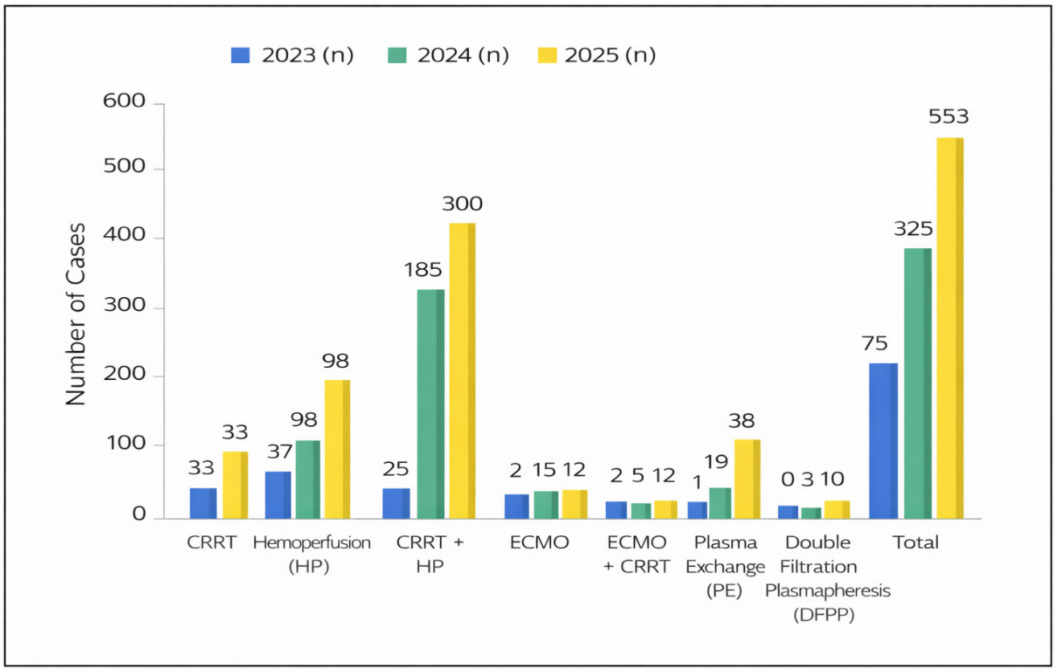

Figure 1. Annual trends in blood purification and extracorporeal support therapies from 2023 to 2025. Note: Annual trends in the utilization of blood purification and extracorporeal support therapies from 2023 to 2025. The number of cases increased steadily over the study period across most treatment modalities, particularly CRRT-based combined therapies

3.2. Baseline characteristics

No statistically significant differences were observed among the three groups in terms of sex, age, pre-treatment coagulation function, or distribution of primary diagnoses (all $P > 0.05$), indicating baseline comparability across groups (**Table 1**).

Table 1. Baseline characteristics and primary diagnoses of patients undergoing CRRT between 2023 and 2025

Variables	2023(*n*=33)	2024(*n*=98)	2025(*n*=158)	Statistic	*P* value
Baseline characteristics					
Male sex, *n* (%)	20 (60.6)	58 (59.2)	94 (59.5)	x^2= 0.032	0.984
Age (years), mean ± SD	65.2 ± 8.5	64.7 ± 9.1	63.9 ± 8.3	F = 0.432	0.650
Baseline APTT (s), mean ± SD	38.5 ± 6.2	39.1 ± 5.8	37.9 ± 6.5	F = 1.126	0.326
Primary diagnoses, *n* (%)					
Septic shock	18 (54.5)	55 (56.1)	92 (58.2)	x^2= 0.841	0.990
Acute kidney injury	12 (36.4)	35 (35.7)	54 (34.2)		
Others	3 (9.1)	8 (8.2)	12 (7.6)		

Note: Data are presented as mean ± standard deviation (SD) or number (percentage), as appropriate. Comparisons among groups were performed using one-way analysis of variance (ANOVA) or x^2 test. APTT, activated partial thromboplastin time; CRRT, continuous renal replacement therapy

3.3. Changes in anticoagulation strategy distribution

With the progressive optimization of the anticoagulation management protocol, the distribution of anticoagulation strategies differed significantly across 2023 to 2025 (x^2 = 25.89, P < 0.001) (**Table 2**). The proportion of regional citrate anticoagulation increased steadily from 45.5% in 2023 to 83.5% in 2025, whereas the use of unfractionated heparin declined over the same period.

Table 2. Distribution of anticoagulation strategies during CRRT from 2023 to 2025

Anticoagulation Strategy	2023(n = 33)	2024(n = 98)	2025(n = 158)
Local citrate anticoagulation, n (%)	15 (45.5)	65 (66.3)	132 (83.5)
Unfractionated heparin anticoagulation, n (%)	12 (36.4)	25 (25.5)	20 (12.7)
Low-molecular-weight heparin anticoagulation, n (%)	4 (12.1)	6 (6.1)	5 (3.2)
No anticoagulation, n (%)	2 (6.1)	2 (2.0)	1 (0.6)

Note: Data are presented as a number (percentage). Differences in the distribution of anticoagulation strategies among the three groups were analyzed using the chi-square test (x^2 = 25.89, P < 0.001). CRRT, continuous renal replacement therapy; UFH, unfractionated heparin; LMWH, low-molecular-weight heparin

3.4. CRRT operational quality and clinical outcomes

Between 2023 and 2025, indicators related to CRRT operational quality demonstrated continuous improvement (**Table 3**). Filter lifespan was significantly prolonged (F = 58.73, P < 0.001). The incidence of unplanned circuit interruption and bleeding complications decreased over time, with statistically significant differences observed (both P < 0.05). ICU length of stay also showed a downward trend (P = 0.009). No significant difference was found in the rescue success rate among the three groups (P = 0.127).

Table 3. Comparison of CRRT operational quality and clinical outcomes from 2023 to 2025

Outcome Measures	2023(n = 33)	2024(n = 98)	2025(n = 158)	Statistic	P value
Filter lifespan (h), mean ± SD	45.3 ± 12.1	60.8 ± 10.5	72.4 ± 11.6	F = 58.73	<0.001
Unplanned circuit interruption, n (%)	3 (9.1)	5 (5.1)	2 (1.3)	x^2 = 6.18	0.045
Bleeding complications, n (%)	2 (6.1)	3 (3.1)	1 (0.6)	x^2 = 6.07	0.048
ICU length of stay (days), mean ± SD	14.5 ± 5.2	12.8 ± 4.6	11.2 ± 4.1	F = 4.82	0.009
Rescue success rate, n (%)	28 (84.8)	88 (89.8)	148 (93.7)	x^2 = 4.12	0.127
Vasopressor support required, n (%)	18 (54.5)	42 (42.9)	52 (32.9)	x^2 = 8.65	0.013

Note: Continuous variables are presented as mean ± standard deviation (SD) and were compared using one-way analysis of variance (ANOVA). Categorical variables are presented as numbers (percentage) and were compared using the chi-square test. CRRT, continuous renal replacement therapy; ICU, intensive care unit

4. Discussion

The present study demonstrated that the implementation of a CRRT-centered standardized anticoagulation management protocol was associated with significant improvements in filter performance and reductions in complication rates. With the progressive optimization of the anticoagulation management process, the proportion of regional citrate anticoagulation (RCA) increased markedly, accompanied by a significant prolongation of filter lifespan. These findings suggest that optimization of the anticoagulation strategy structure may be an important factor contributing to improved CRRT operational quality. By achieving localized anticoagulation within the extracorporeal circuit and minimizing systemic anticoagulant exposure, RCA reduces the risk of systemic bleeding while helping maintain circuit patency, thereby prolonging filter lifespan [6]. The findings are generally consistent with previous studies reporting that RCA can extend filter lifespan and reduce bleeding risk, further supporting its broader application in CRRT practice [7].

In addition, the standardization of anticoagulation management helps unify clinical decision-making pathways and reduce variability in anticoagulation strategy selection and dose adjustment among healthcare providers [3, 8]. Through continuous training and the establishment of a quality feedback system, improvements in the timeliness and accuracy of anticoagulant dose adjustment and laboratory monitoring were achieved, which may have contributed to the observed reductions in unplanned circuit interruption and bleeding complications [9]. Notably, the absolute number of unplanned interruptions and bleeding events was relatively small. Although statistically significant differences were observed, these findings should be interpreted cautiously and require validation in larger populations.

Furthermore, a decreasing trend in ICU length of stay was observed over the study period, suggesting that optimization of anticoagulation management may indirectly enhance overall treatment efficiency by improving the continuity and stability of CRRT [10]. However, no significant difference was found in rescue success rates among the three groups, indicating that the impact of anticoagulation process optimization on short-term overall prognosis may be limited or influenced by multiple factors, including underlying disease severity [11].

Based on real-world data from a single center, this study demonstrates a feasible approach to improving CRRT quality through management optimization in a regional ICU setting, with potential practical implications for routine clinical practice.

Several limitations should be acknowledged. This was a single-center retrospective study with a relatively small sample size, and residual confounding cannot be excluded. The stage-based comparison across years was not derived from a randomized design and may have been influenced by temporal trends or overall improvements in critical care practice. In addition, the small number of certain outcome events limits statistical robustness. Long-term outcomes were not evaluated, and adjustments for disease severity, such as SOFA score analysis, were not performed. Future multicenter prospective studies incorporating severity adjustment are warranted to validate these findings.

5. Conclusion

The establishment and implementation of a CRRT-centered standardized anticoagulation management protocol may improve CRRT operational quality, prolong filter lifespan, and reduce the incidence of certain complications. This management approach may provide practical value in optimizing blood purification therapy for critically ill patients in the ICU.

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Disclosure statement

The authors declare no conflict of interest.

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