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The Association Between Catheter Type and Dialysis Treatment: A Retrospective Data Analysis at Two U.S.-Based ICUs

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IMPORTANCE: Dialysis catheter type may be associated with differences in continuous renal replacement therapy (CRRT) treatment in the critically ill, with potential implications for patient outcomes and healthcare costs.

OBJECTIVES: To evaluate the association between the catheter type and multiple dialysis treatment outcomes among the critically ill.

DESIGN: Retrospective, observational study.

SETTING: Two U.S.-based ICUs.

PARTICIPANTS: Critically ill patients receiving CRRT between April 1, 2018, and July 1, 2020. A total of 1,037 CRRT sessions were analyzed.

MAIN OUTCOMES AND MEASURES: Circuit life, alarm interruption frequency (including a subset of vascular access [VA]-related alarms), termination type (elective vs nonelective), and blood flow rates. Pre- ($n = 530$) and post-catheter change ($n = 507$) periods were assessed, and the post-change period was further divided into intervals of pre-COVID ($n = 167$) and COVID contemporaneous ($n = 340$) to account for the pandemic's impact.

RESULTS: Compared with pre-change sessions, post-change sessions had 31% longer circuit life (95% CI, 1.14–1.49; $p < 0.001$), 3% higher blood flow rate (1.01–1.05; $p < 0.01$), and lower proportion of nonelective terminations (adjusted odds ratio [OR], 0.42 [0.28–0.62]; $p < 0.001$). There were fewer interruptions for all alarms (adjusted count ratio, 0.95 [0.87–1.05]; $p = 0.31$) and VA-related alarms (0.80 [0.66–0.96]; $p = 0.014$). The sessions during COVID period were statistically similar to pre-COVID sessions for all outcomes except a lower proportion of nonelective terminations (adjusted OR, 0.39 [0.22–0.70]; $p < 0.01$).

CONCLUSIONS: A change in catheter type was associated with longer CRRT sessions with fewer interruptions and unexpected terminations in a population of critical patients.

KEY WORDS: acute kidney injury; continual renal replacement therapy; critical care; intensive care units; renal dialysis

Over 5 million people in the United States are admitted to ICUs each year (1). Multicenter studies suggest that more than half of ICU patients and approximately 5–7% of all hospitalized patients are affected by acute kidney injury (AKI), which is characterized by a significant loss in kidney function causing accumulation of nitrogen metabolism end products such as urea (2–4). Increasing severity of AKI in ICUs is associated with increased mortality, and patients with AKI were shown to have decreased renal function when discharged from the hospital (2). While there are multiple methods for treating AKI, continuous renal replacement therapy (CRRT) is the most common dialysis option in critical care settings as it more gently corrects

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KEY POINTS

Question: Is there an association between catheter type and continuous renal replacement therapy (CRRT) treatment outcomes?

Findings: This multicenter, retrospective analysis of 1,037 CRRT sessions demonstrated post-change sessions had 31% longer circuit life ([1.14–1.49]; $p < 0.001$), 3% higher blood flow rate ([1.01–1.05]; $p < 0.01$), fewer non-elective terminations (odds ratio, 0.42 [0.28–0.62]; $p < 0.001$), and fewer interruptions for vascular access-related alarms (adjusted count ratio, 0.80 [0.66–0.96]; $p = 0.014$), when compared with pre-change sessions. Pre-COVID and COVID contemporaneous sessions were statistically similar for most treatment outcomes, but number of sessions increased two-fold following the onset of the pandemic.

Meanings: A change in catheter type is associated with longer CRRT sessions with fewer interruptions.

acid-base balance, fluid overload, and azotemic control in a manner more comparable to that of an actual kidney (5).

In dialysis treatment, it is essential to minimize differences between prescribed and delivered hemodialytic doses, which can affect morbidity and mortality in the critically ill (6). Several studies have evaluated dialysis treatment using specific metrics such as circuit life (7–9), filtration rate (6), and alarm interruptions (10). Session interruptions can disrupt and delay therapeutic filtration and lead to complications, including worsening acidosis, dangerous electrolyte derangements, increased plasma urea, and creatinine concentration (7). Frequent interruptions can also induce alarm fatigue, with clinicians becoming desensitized to recurring alerts, which could permit otherwise preventable patient harm and worsen provider burnout (10). The use of proper dialysis equipment, including dialysis catheters, may considerably affect treatment outcomes. A large observational cohort study (**Supplemental Digital Content,** http://links.lww.com/CCX/B85) concluded that dialysis catheter dysfunction is associated with missed sessions due to vascular access (VA)-related problems and increased hospitalizations (11). Multiple studies have also compared acute dialysis catheters regarding their impact on dialysis treatment outcomes in the ICU (5, 12, 13) and transplant center settings (12, 14) and reported significant differences in circuit life (5, 12–14) and incidence of circuit cessation (13). However, these single-centered studies emerged from a single region (i.e., Australia) and did not evaluate additional outcomes such as workflow disruptions. Therefore, multicenter studies from various regions would be warranted to investigate the impact of catheter choice on a comprehensive set of dialysis treatment outcome measures in the critically ill.

Given the prevalence of AKI among critical care patients, device selection for optimal CRRT sessions should be informed by research. Using data from two U.S.-based ICUs, this study aims to evaluate the impact of short-term dialysis catheters on multiple dialysis treatment outcomes.

METHODS

Study Design

A retrospective, multicenter study was conducted using data from CRRT sessions in the ICUs of two hospitals (Hoag Hospital Irvine, Irvine, CA, and Hoag Hospital Newport Beach, Newport Beach, CA) from April 1, 2018, to July 1, 2020. Our analysis was determined to be exempt from local institutional review board (IRB) review in advance by Western IRB (Puyallup, WA), and no IRB review was necessary since it did not fall under the board's guidelines as human subjects research (exemption reference: 1-1446084-1; approved June 18, 2021). All procedures were followed in accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration of 1975.

Both hospitals transitioned to a single acute dialysis catheter (Power-Trialysis Short-Term Curved Extension Dialysis Catheter Tray, 15 and 20 cm Insertion Lengths, Becton Dickinson, Franklin Lakes, NJ) on May 13, 2019. Before this date, the institutions used three different catheters (Mahurkar Elite IC Catheter Kit, 12F × 13 cm, Curved, 3-Lumen

Medtronic, Fridley, MN; Covidien Mahurkar Elite 12F Dual Lumen Catheter 16 cm, curved, Kit Medtronic, Fridley, MN; High-Pressure Triple Lumen Acute Dialysis Catheter IC Tray, 20 cm, Curved Extensions, 12F, Cardinal Health, Dublin, OH). The transitionary period from April 2, 2019, to June 30, 2019, during which the devices may have been used concurrently, was excluded from the study. CRRT session data were obtained from the dialyzers in the ICUs of both hospitals (NX1000-5 and NX1000-5-A, NxStage Medical, Lawrence, MA).

Study intervals were defined as the "pre-change" period (from April 1, 2018, to April 1, 2019), and the "post-change" period (from July 1, 2019, to July 1, 2020). The post-change period was further divided into two intervals to evaluate the impact of the COVID-19 pandemic. The "pre-COVID period" from July 1, 2019, to December 31, 2019, was followed by the "COVID period" from January 1, 2020, to July 1, 2020.

There was no change to clinical practice patterns or prescribed doses at either facility at any point in the study, before or after the catheter change. Catheter insertion site was the internal jugular vein in approximately 75% of cases and the femoral vein in the remaining 25%. In both pre- and post-change periods, anticoagulation was used only when indicated, that is, where there was evidence of a clotting issue. There was no prophylactic use of anticoagulants. Protocols for targeting calcium were maintained before and after catheter change.

Data Collection and Outcomes

The outcome measures were circuit life, mean frequency of alarm interruptions (i.e., all alarms and VA-related alarms), the type of treatment termination (i.e., elective vs nonelective), and mean blood flow rate (mL/min) within a CRRT session. Circuit life was defined based on previously published literature as the sum of filter run time between initiation and termination of dialysis treatment (5, 9). The mean frequency of interruptions per CRRT session included a subset of alarm notifications intended for the operator, indicating VA-related interruptions. Electively and nonelectively terminated treatments were distinguished by specific data patterns to identify termination that was intentional by clinicians versus unexpected stoppage; other published studies have made similar distinctions (5, 9).

Patient-identifying information was not gathered with the data, and the dialyzers were not integrated or connected to any other datasets or hospital electronic health record systems. Mean values of access pressure (AP), vascular pressure (VP), effluent pressure (EP), and ultrafiltration rate in mL/hr were collected per CRRT session. Mean therapy rate in L/hr was calculated by dividing therapy fluid amount by therapy duration.

Statistical Analysis

Differences in outcome measures (e.g., circuit life, alarm interruptions) between pre-change and post-change sessions, as well as pre-COVID and COVID sessions, were compared using a chi-square test for a categorical variable and *t* tests for continuous variables. To analyze associations between catheter type and CRRT treatment outcomes, generalized linear models with log link functions, gamma and negative binomial distributions, and logistic regressions were employed. Models were adjusted for differences in mean values of AP, VP, EP, ultrafiltration rate, and therapy rate that could confound the relationship between catheter type and dialysis treatment outcomes. All statistical analyses were performed using SAS Version 9.4 (SAS Institute, Cary, NC) with a significance level set at $\alpha = 0.05$.

RESULTS

Session Characteristics

There were 1,153 CRRT sessions with valid filter timestamps performed during the study period. Excluded from the data were 79 sessions performed during the transitionary period, as well as 25 sessions with missing blood flow rates. Twelve sessions containing system alarms with a three-digit code that indicated system errors, internal communications errors, or detector malfunctions were also excluded. After the exclusions, the dataset included 1,037 CRRT sessions.

Table 1 provides summary statistics of the study measures for the total ($n = 1{,}037$), pre-change ($n = 530$), and post-change ($n = 507$) periods. The post-change period was further divided into the pre-COVID ($n = 167$) and COVID ($n = 340$) periods. Overall, mean circuit life was 8.8 ± 10.6 hours, mean frequency of all alarm interruptions per session was 7.0 ± 6.5, and mean frequency of VA-related interruptions per session was

TABLE 1.
The Effects of Catheter Change on Renal Replacement Therapy Outcome Metrics

Outcome Metrics	Total ($n = 1,037$)	Pre-Change Period ($n = 530$)	Post-Change Period: Pre-COVID Period ($n = 167$)	Post-Change Period: COVID Period ($n = 340$)	Post-Change Period: Total Post-Change ($n = 507$)	p: Total Post-Change vs Pre-Change
Circuit life (hr), mean ± SD	8.8 ± 10.6	7.8 ± 10.4	9.9 ± 12.0	9.9 ± 9.9	9.9 ± 10.6	0.001
Frequency of all alarm interruptions, mean ± SD	7.0 ± 6.5	7.4 ± 7.1	6.3 ± 6.0	6.8 ± 5.6	6.6 ± 5.7	0.045
Frequency of vascular access-related interruptions, mean ± SD	2.1 ± 3.8	2.5 ± 4.4	1.7 ± 3.5	1.7 ± 3.0	1.7 ± 3.2	< 0.001
Proportion of nonelective treatment terminations						
Yes, count (%)	901 (86.9)	484 (91.3)	151 (90.4)	266 (78.2)	417 (82.2)	< 0.001
No, count (%)	136 (13.1)	46 (8.7)	16 (9.6)	74 (21.8)	90 (17.8)	
Blood flow rate, mean ± SD	227.4 ± 33.6	223.3 ± 34.5	229.3 ± 31.0	232.9 ± 32.6	231.7 ± 32.1	< 0.001
Access pressure (mm Hg), mean ± SD	−77.4 ± 64.7	−86.4 ± 70.8	−64.7 ± 63.1	−69.5 ± 52.5	−67.9 ± 56.2	< 0.001
Vascular pressure (mm Hg), mean ± SD	111.2 ± 53.2	108.9 ± 52.2	110.8 ± 55.6	115.1 ± 53.4	113.7 ± 54.1	0.145
Effluent pressure (mm Hg), mean ± SD	133.1 ± 55.2	127.4 ± 54.0	138.1 ± 58.5	139.6 ± 54.7	139.1 ± 55.9	< 0.001
Ultrafiltrationrate (mL/hr), mean ± SD	136.3 ± 98.4	123.2 ± 87.4	156.0 ± 120.4	147.0 ± 99.9	149.9 ± 107.0	< 0.001
Therapy rate (L/hr), mean ± SD	2.4 ± 0.8	2.4 ± 0.9	2.3 ± 0.7	2.3 ± 0.7	2.3 ± 0.7	0.003

2.1 ± 3.8. The majority of all CRRT terminations were nonelective (86.9%), and the mean blood flow rate was 227.4 ± 33.6 mL/min.

Pre- Versus Post-Catheter Change Comparisons

The findings from adjusted and unadjusted statistical models are reported in **Table 2**. After controlling for the mean values of AP, VP, EP, ultrafiltration rate, and therapy rate, post-change sessions had a 31% longer circuit life (duration ratio, 1.31; 95% CI, 1.14–1.49; $p < 0.001$) and a 20% decrease in mean frequency of VA-related interruptions (count ratio, 0.80; 95% CI, 0.66–0.96; $p = 0.014$) compared with pre-change sessions. Post-change sessions were also 58% less likely to have a nonelective termination (odds ratio [OR], 0.42; 95% CI, 0.28–0.62; $p < 0.001$) compared with pre-change. Additionally, post-change sessions had a mean blood flow rate that was 3% higher (flow rate ratio, 1.03; 95% CI, 1.01–1.05; $p = 0.003$) relative to pre-change. Though not statistically significant, mean frequency of all alarm-related interruptions decreased by 5% from pre- to post-change periods (count ratio, 0.95; 95% CI, 0.87–1.05; $p = 0.31$).

Pre-COVID Versus COVID Comparisons Within the Post-Change Period

For the pre-COVID and COVID periods, results from unadjusted and adjusted statistical models are provided in **Table 3**. The sessions for pre-COVID and COVID were statistically similar for the mean values of circuit life (duration ratio, 0.96; 95% CI, 0.80–1.16), frequency of all alarm interruptions (count ratio, 1.06; 95% CI, 0.93–1.22), frequency of VA-related interruptions (count ratio, 0.97; 95% CI, 0.74–1.28), and blood flow rate (flow rate ratio, 1.01; 95% CI, 0.99–1.04). The only significant difference between the periods was a decrease in likelihood of

TABLE 2.
Modeled Associations Between Catheter Type and Continuous Renal Replacement Therapy Outcomes

Outcome Measures	Post-Change vs Pre-Change (Reference)		
	Unadjusted Ratio (95% CI)	*p*	Adjusted Ratio (95% CI)
Circuit life[a]	1.27 (1.10–1.46)	< 0.001	1.31 (1.14–1.49)
Mean frequency of all alarm interruptions per session[b]	0.89 (0.81–0.98)	0.023	0.95 (0.87–1.05)
Mean frequency of vascular access-related interruptions per session[b]	0.66 (0.54–0.81)	< 0.001	0.80 (0.66–0.96)
Proportion of nonelective treatment terminations[c]	0.44 (0.30–0.64)	< 0.001	0.42 (0.28–0.62)
Mean blood flow rate[a]	1.04 (1.02–1.06)	< 0.001	1.03 (1.01–1.05)

[a]Generalized linear model with gamma distribution and log link function was used.
[b]Generalized linear model with negative binomial distribution and log link function was used.
[c]Logistic regression was used.

TABLE 3.
Modeled Associations Between Pre-COVID (Reference) and COVID Subgroups and Continuous Renal Replacement Therapy Outcomes

Outcome Measures	Unadjusted Ratio (95% CI)	*p*	Adjusted Ratio (95% CI)	*p*
Circuit life[a]	1.00 (0.81–1.23)	0.99	0.96 (0.80–1.16)	0.688
Mean frequency of all alarm interruptions per session[b]	1.08 (0.93–1.25)	0.304	1.06 (0.93–1.22)	0.383
Mean frequency of vascular access-related interruptions per session[b]	1.00 (0.72–1.39)	0.991	0.97 (0.74–1.28)	0.835
Proportion of nonelective treatment terminations[c]	0.38 (0.21–0.68)	0.001	0.39 (0.22–0.70)	0.002
Mean blood flow rate[a]	1.02 (0.99–1.04)	0.237	1.01 (0.99–1.04)	0.276

[a]Generalized linear model with gamma distribution and log link function was used.
[b]Generalized linear model with negative binomial distribution and log link function was used.
[c]Logistic regression was used.

nonelective terminations (OR, 0.39; 95% CI, 0.22–0.70; $p = 0.002$).

DISCUSSION

Dialysis treatment is essential for the critically ill patients given the prevalence of AKI requiring CRRT (15). The choice of dialysis equipment, including the type of catheter used, should be assessed when managing patients with AKI to increase the chances of long-term recovery (16). This study thus evaluated the association between acute dialysis catheter type and a comprehensive set of dialysis treatment outcomes in two U.S.-based ICUs. To our knowledge, this is the first U.S. study that examined the impact of short-term catheters on dialysis treatment using multiple metrics, including circuit life and alarm interruptions. Our analysis revealed significant associations between the catheter choice and a set of outcome parameters, which highlights the role of hemodialysis equipment in achieving optimal CRRT sessions.

Following a change in the type of dialysis catheter that was used in two U.S. hospitals, we observed significant increases in circuit life, which was consistent with the findings of Dunn and Sriram (5) and Fealy et al (12), both of which compared two distinct dialysis catheters and found significant associations between the catheter type and circuit life. Kim et al (14), however, did not find significant differences in circuit life in a similar comparison. Fealy et al (12) also attempted to identify independent predictors of circuit life by evaluating various demographic and medical (i.e., disease severity) factors and concluded that the catheter type is not an independent predictor of circuit life despite being associated with longer dialysis sessions. Worth noting, both Fealy et al (12) and Kim et al (14) conducted their studies at the same liver transplantation center, and this specific population has a high risk of bleeding and clotting simultaneously, leading to a procoagulant state that increases the frequency of filter clotting (17). Furthermore, the sample sizes of these studies were relatively smaller (254 and 341 circuits). These selection criteria may partially explain the lack of statistical significance in their findings, as noted by the authors. Such results may or may not be directly comparable to different types of critical patients, including those within our study, which includes a larger sample size and more variation in patients' critical illnesses. Our results show that the catheter change is associated with longer sessions, which may improve the effectiveness of dialysis treatment and reduce adverse patient outcomes. The efficacy of CRRT depends on the longevity of dialysis sessions, and inadequate circuit life can lead to clinical implications, including blood loss and hemodynamic instability (9, 18).

In the post-change period, we found significant reductions in the occurrence of alarm interruptions, as well as a specific subset of suspensions caused by VA-related alarms. Clinical notifications usually occur in the form of pager beeps and alerts from a growing number of devices that all compete for providers' attention (19). Current literature is limited regarding the impact of alarms and interruptions in the dialysis setting. However, multiple systematic reviews have evaluated the effects of alarm fatigue, or sensory overload attributed to an excessive number of alarms, and demonstrated significant impacts on provider efficiency, communication errors, and patient safety, including nurse burnout in a wide range of clinical settings from primary care facilities to surgical theaters (20–22). Specifically, interruption overload can lead to errors in medication administration (23), surgical and procedural errors (24), and disruptions in treatment (25). Too many alarms can also lead to desensitization and even disabling of alerts in clinical and critical care settings (10, 26). Patient deaths have additionally been linked to alarm fatigue as providers may not respond to missed but essential device alerts (19). Our results indicate that the catheter change decreased the prevalence of alarm interruptions, which can decrease the risk of alarm fatigue and the downstream impacts not only on patients but also on providers.

Decisions on device selection should consider the full impact on clinical practice, including the potential of workflow disruptions. It is important to note that there are differences between the catheters (i.e., material, design, and size), and it is possible that the reported improvements may have been related to certain viscoelastic properties of the device used post-change, such as the antithrombotic polyurethane material and improved flow (decreased turbulence), lowering the risk of clotting. However, as we did not study these properties directly, any connection between various catheter features and improved outcomes would require further research.

In the post-change period, we compared pre-COVID and COVID sessions to assess if the pre-and post-change evaluations were influenced by potential differences in the CRRT sessions that occurred during the pandemic. These results thus shed light on the possible impacts, or lack thereof, that COVID-19 has on multiple dialysis treatment outcomes. The analysis demonstrated that the pre-COVID and COVID sessions were largely similar from the perspective of the measured treatment outcomes, which is somewhat surprising based on previously published literature that reported the effects of the novel coronavirus on clotting and thrombotic mechanisms (27–29). The use of aggressive anticoagulant treatment during the COVID period, which was commonly used by U.S. physicians (30–32), may partially explain the similarity in the CRRT sessions. However, in a Singapore-based study, the probability of filter clotting among patients with COVID-19 increased despite additional anticoagulant use (33). It is likely that the effects of the pandemic on CRRT sessions are complex and cannot be narrowed down to a single aspect, such as anticoagulation treatment. More expectedly, during the post-change interval, the number of CRRT sessions doubled in the COVID period compared with the pre-COVID period, which can be due to two inter-connected reasons: first, the pandemic led to an increase in the number of patients admitted to the ICU as the incidence of COVID-19 increased in the region. Second, patients diagnosed with the novel coronavirus were more likely to develop AKI and require CRRT (34).

The COVID-19 pandemic proves multifaceted and affects CRRT sessions through myriad factors; therefore, further research is warranted to better understand the effects, and the mechanisms, of the novel coronavirus on dialysis treatment outcomes.

Overall, our study contributes to a body of literature demonstrating the role of dialysis equipment in delivering efficient CRRT sessions, which can have direct and downstream impacts on patients and providers. The benefits of longer and uninterrupted CRRT sessions, and reductions in workflow disruptions, are well-documented in the literature. A reduction in circuit life leads to adverse patient consequences, including blood loss, decreased hemodialytic dose delivery, and inadequate solute clearance (6, 9, 18). Alarm interruptions can also negatively affect patient safety and contribute to provider burnout (10, 19, 22). Although our study provides insights on the effect of catheter change on dialysis treatment outcomes, further clinical trials are needed to fully address the complexity of CRRT sessions and the influential factors. Data from additional geographical regions, and a more extensive set of CRRT sessions, would be beneficial to capture a more representative assessment of catheters on these outcomes in the ICU setting.

In addition to the intrinsic shortcomings of the retrospective design, our study has several limitations. First, we did not have access to demographic data and could therefore not account for the potential impacts of patient characteristics on CRRT sessions. Second, medical history (i.e., disease type/severity, comorbidities) and treatment (i.e., anticoagulation use) data were also not available and could not be included in the analysis. Finally, our study was limited to ICUs in two U.S.-based hospitals within close geographical proximity; thus, the results may not be generalizable due to varying clinical practices, guidelines, and equipment in other institutions and regions.

CONCLUSIONS

The impacts of dialysis catheter design/selection and the COVID-19 pandemic on CRRT session parameters have not been adequately studied. Our findings from two U.S.-based hospitals suggest that a change in the type of acute dialysis catheter is associated with longer, uninterrupted sessions and fewer unexpected stoppages. While there was a considerable increase in the volume of CRRT sessions during the COVID period, the sessions were largely similar across measured outcomes. Awaiting clinical trials and multicenter studies from other regions, these results highlight the impact of catheter choice in a general ICU population. Further exploration is needed to identify and quantify the specific impacts of acute dialysis catheter types on clinical practice and patient outcomes.

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