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Implementation of an Advanced Training Program to Increase Nurses' Knowledge of Continuous Renal Replacement Therapy Management

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Implementation of an Advanced Training Program to Increase Nurses' Knowledge of
Continuous Renal Replacement Therapy Management

Shane M. Brost

Doctor of Nursing Practice Project submitted
to the School of Nursing
at West Virginia University

in partial fulfillment of the requirements for the degree of
Doctor of Nursing Practice in
Nurse Anesthetist Program

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Abstract

Implementation of an Advanced Training Program to Increase Nurses' Knowledge of

Continuous Renal Replacement Therapy Management

Shane M. Brost

Background: Continuous renal replacement therapy (CRRT) is a complex, life-preserving treatment for unstable patients who require hemodialysis in the intensive care unit (ICU). Nurses responsible for managing the CRRT machine in this large academic medical center's cardiovascular ICU (CVICU) complete a one-hour basic training course focused on setting up the machine, responding to basic alarms, and changing out the CRRT circuit when necessary. Staff nurses, advanced practice providers (APPs), and nursing administrators agree that training is insufficient. Research evidence supports rigorous staff training as essential to improving the quality of CRRT delivery. **Purpose:** This Doctor of Nursing Practice (DNP) project purposed to implement an advanced CRRT training program for nurses and APPs in the hospital's CVICU to (a) increase participants' CRRT knowledge and to improve management and troubleshooting skills; (b) improve CRRT delivery in the CVICU; (c) evaluate participants' perception of training program effectiveness. **Intervention:** An advanced CRRT training program was implemented. Participants attended a four-hour CRRT training course provided by the clinical educator for the CRRT machine manufacturer. **Methods:** To assess the impact of the intervention on CRRT knowledge, participants completed a CRRT knowledge test before and after the training course. To assess the impact of the intervention on CRRT delivery, post-intervention data from the CRRT machines was compared to pre-intervention data for the following CRRT-specific outcomes of interest: downtime, dosing target accuracy, filter life, number of unnecessary filter changes, filters used per treatment day, and filter expense. To assess the impact of the intervention on perceived competency, participants were asked to complete pre- and post-intervention surveys. Statistical analyses were performed to compare pre-intervention to post-intervention data. **Results:** The advanced CRRT training course was attended by 25 participants. Participants had a statistically significant increase in knowledge as evidenced by the difference between pre- (59.37%, SD=8.46%) and post-intervention (82.54%, SD=6.63%) CRRT knowledge test scores ($p < .001$). Although there was some improvement in downtime, dosing target accuracy, and filter life, it was not statistically significant. Participants reported an increase in perceived CRRT competency and satisfaction as evidenced by their responses to the post-intervention survey and feedback suggesting it should be offered at least yearly if not more frequently. **Conclusions:** Implementation of an advanced training program is an essential first step toward increasing nurses' knowledge and improving CRRT management and troubleshooting skills.

Table of Contents

<u>Introduction</u>	1
<u>Problem Description</u>	2
<u>Problem Statement</u>	4
<u>Available Knowledge</u>	5
<u>Rationale</u>	7
<u>Specific Aims</u>	9
<u>Methods</u>	9
<u>Context</u>	9
<u>Intervention</u>	9
<u>Benchmarks</u>	10
<u>Detailed Description of the Intervention</u>	12
<u>Congruence with the Organization’s Strategic Plan</u>	13
<u>Personnel, Technology, and Budget</u>	14
<u>Evaluation Plan</u>	15
<u>Measures</u>	17
<u>Analysis</u>	21
<u>Ethical Considerations</u>	21
<u>Results</u>	22
<u>Project Timeline and Evolution</u>	22
<u>Process Measures and Outcomes</u>	23
<u>Contextual Elements Affecting the Intervention</u>	28
<u>Missing Data</u>	29

Discussion	29
Summary	29
Interpretation	30
Limitations	32
Conclusions	34
References	36
Appendix A: Literature Search Log	39
Appendix B: Evidence Table	41
Appendix C: Larrabee’s Adaptation of the Iowa Model	44
Appendix D: Letter of Site Approval	45
Appendix E: NRC Letter of Support	46
Appendix F: CRRT Knowledge Test	47
Appendix G: Pre-intervention Survey: Perceived CRRT Competency Questionnaire	51
Appendix H: Post-intervention Survey: Advanced CRRT Training Course’s Perceived Impact on Competency Questionnaire	52
Appendix I: Vendor’s CRRT Course Evaluation	53

Implementation of an Advanced Training Program to Increase Nurses' Knowledge of Continuous Renal Replacement Therapy Management

For intensive care unit (ICU) patients, acute kidney injury (AKI) is a common complication and an independent risk factor for death. Mortality rates for patients with AKI requiring renal replacement therapy (RRT) can range from 40% to 55% (Griffin et al., 2019). Acute kidney injury can be described as new-onset reduced kidney function that can lead to fluid, electrolyte, and acid-base imbalances. To support patients with AKI, RRT can perform important kidney functions including removal of solutes, metabolic waste, and excess fluid (Przybyl et al., 2017). Commonly referred to as hemodialysis, RRT can be provided either intermittently or continuously. Continuous RRT (CRRT) is the preferred modality for hemodynamically unstable ICU patients who may not tolerate the abrupt fluid shifts associated with intermittent hemodialysis (Przybyl et al., 2017).

The care of ICU patients on CRRT is coordinated by an interprofessional team. Intensive care physicians determine the need for CRRT and prescribe a dose or flow rate to purify the blood. Advanced Practice Providers (APPs) insert dialysis catheters, adjust CRRT fluid removal rates, and manage the overall care of the patient. Registered Nurses (RNs) are responsible for managing the CRRT machine to ensure patients receive the prescribed dose and that therapy is delivered efficiently. Ancillary professionals, such as pharmacists and dieticians, contribute their expertise to the care of these complex patients.

Although the therapy is termed “continuous” renal replacement therapy, CRRT is interrupted quite often for dialysate and replacement fluid bag changes, filter failure, patient procedures, and other unplanned alarm conditions that increase treatment downtime and prevent patients from receiving the recommended dose. Although some CRRT interruptions are

unavoidable, therapy can be optimized when nurses plan interventions to minimize downtime and troubleshoot alarm conditions appropriately. Subtherapeutic dosing is associated with increased length of ICU stay, increased time to renal recovery, and increased cost (Griffin et al., 2019).

Staff training is essential to effectively deliver CRRT (Cerda et al., 2016). According to Przybyl et al. (2015), RNs must be rigorously trained to understand, manage, and troubleshoot the CRRT machine. Failure to critically problem-solve complications and appropriately troubleshoot equipment issues can lead to subtherapeutic dosing, increased downtime, unnecessary filter changes, decreased filter life, increased filters used per treatment day, and increased filter expense. Przybyl et al (2015) argued that “The complexity of CRRT therapy and the potential for loss of life due to a failure to critically problem-solve complications compels the need for standardization in continuing education for nursing performing CRRT” (p. 136).

Problem Description

Cardiovascular ICU nurses practicing in a large academic center in the Appalachian Mountain Region of the United States are trained to set up the CRRT machine, discontinue treatment, and respond to basic alarms. After completing a one-hour beginner training course, new RNs permitted to care for CRRT patients. Continuing education is typically acquired through informal mentor to mentee and peer-to-peer interactions. There are currently no formal continuing education courses or means to assess RNs’ CRRT competency.

According to the CRRT machine manufacturer’s clinical educator, RNs in this hospital are the only ones in her assigned region who have not received formal CRRT training provided by the CRRT device vendor (C. Johnson, personal communication, June 17, 2020). Historically, nurses in this hospital’s ICUs worked under inconsistent departmental policies with varied

expectations and responsibilities for CRRT management. The logistics of coordinating training sessions for large numbers of RNs resulted in the hospital assuming responsibility for training (J. Gotses, personal communication September 8, 2020). Personal observation and conversations with a staff RN (J. Paskert, personal communication, October 9, 2020), an APP (J. Day, personal communication, June 11, 2020), the dialysis manager (J. Gotses, personal communication, June 2, 2020), and the nursing supervisor (L. Cyphers, personal communication, June 12, 2020) support the need for an advanced training program to improve CRRT management and troubleshooting skills of the ICU nursing staff.

When unsure of how to troubleshoot machine issues, it is common practice for RNs at this facility to return the patient's blood and replace the filter. The rationale for this decision is that if the alarm condition is prolonged, the filter is likely to clot, and they will miss the opportunity to return the patient's blood. Returning the patient's blood is vital when treatment is appropriately discontinued. However, when treatment is interrupted for unnecessary filter changes, patients are at risk of receiving subtherapeutic dosing and the facility incurs increased costs in wasted filters. This observation can be corroborated and quantified by examining the treatment data stored within the CRRT machines.

The CRRT device vendor can produce a CRRT Management Report for its client hospitals. The report, derived from treatment data stored within each CRRT machine, can be used to evaluate a hospital's CRRT program by comparing CRRT-specific outcomes to benchmarks defined by the vendor. These benchmarks were created using internal data from 2000 CRRT treatments. (R. Usovsky, personal communication, July 23, 2020). Historically, this hospital has not utilized these data reports to evaluate their CRRT program.

To gain some insight into the performance of this hospital's CRRT program, a CRRT Management Report was produced for the period of July 2019 through June 2020 using data from the machines housed in the CVICU. During this time, the average CRRT downtime was 15%, higher than the benchmark of 10%. Unnecessary filter changes accounted for 20% of all filter changes. Other good filters were discarded either because treatment was discontinued (27%) or was stopped and restarted more than three hours later (23%). Only 30% of filters were appropriately discarded because they were clotted (11%), degraded (14%), or had reached the manufacturer's maximum recommended filter life of 72 hours (approximately 3%). The average filter life of 20 hours was below the target of 30 hours and even further below the maximum recommended filter life of 72 hours. The number of filters used per treatment day was 1.2, but there is no benchmark for this parameter (Baxter Healthcare Corporation [BHC], 2020).

The data from these machines suggest that there is much room for improvement in CRRT delivery. One could argue that up to 70% of CRRT filters were being discarded unnecessarily. From July 2019 through June 2020 there were 871 CRRT filters utilized on the selected machines housed in the CVICU. At a cost of \$232.95 per filter, 70% wasted filters could mean a potential cost savings of up to \$142,029.29 per year for those CRRT machines alone. Beyond cost, critically ill CRRT patients in the CVICU stand to benefit greatly from an increase in the quality of their care.

Problem Statement

Without advanced training, nurses responsible for managing CRRT equipment in the CVICU may not be adequately prepared to ensure that patients receive the highest quality of care. Failure to deliver highly effective and efficient CRRT may lead to adverse patient

outcomes (like increased time to renal recovery and increased length of ICU stay) and increased cost.

Available Knowledge

Using the population, intervention, comparison, outcome (PICO) process (Larrabee, 2009), the following research question was developed to guide the literature search: “For CVICU RNs, how does participation in an advanced CRRT training course compared to participating in the introductory course alone impact RNs’ CRRT competency and treatment quality?”

PubMed, Academic Search Complete, CINAHL with Full Text, Education Research Complete, Health Source: Nursing/Academic Edition, and MEDLINE databases were searched for combinations of the terms "continuous renal replacement therapy", "CRRT", "nurse or nurses or nursing", "training", and "quality improvement". Articles were excluded if they were written in a language other than English, were pediatric-focused, or were greater than 10 years old. After reviewing the remaining 209 abstracts and removing duplicates, 29 were accepted for further review (See [Appendix A](#)). Articles highlighting or evaluating the importance of CRRT training were included. Those specific to anticoagulation were excluded. Review of references yielded one additional study (Palevsky et al.,). A full text review of the remaining 30 articles left six that were relevant to the PICO question and met inclusion criteria.

Although CRRT is common in intensive care units, applicable clinical practice guidelines (CPG) are not. The Kidney Disease: Improving Global Outcomes (KDIGO) group’s recommendation for CRRT dose is the only CPG within the scope of this project. To begin the process of developing future guidelines, expert consensus panels have proposed quality indicators (QIs) (Cerda et al., 2016; Rewa et al., 2018), and one review (Shen et al., 2018) proposed quality measures. Two studies describe the implementation of a CRRT training

program for ICU RNs (Przybyl et al., 2015; Przybyl et al., 2017). See evidence table in [Appendix B](#).

In 2013, Kidney Disease Outcomes Quality Initiative (KDOQI) Work Group convened to comment on the applicability of the KDIGO guidelines in the United States. They endorsed KDIGO's 1A rating for targeting a CRRT dose of 20 to 25 mL/kg/hr (Palevsky et al., 2013). Furthermore, because the actual dose that patients receive often falls short of the prescribed dose, they recommend implementing quality improvement strategies to ensure that patients receive the desired dose.

Cerda et al. (2016) reported the findings from the Acute Dialysis Quality Initiative (ADQI) Consensus Group and gave a Grade A recommendation for considering staff training when prescribing CRRT. They suggest that excellent staff training to provide a deep knowledge of CRRT management is considered essential for success. Staff training is necessary to effectively deliver CRRT while decreasing downtime and reducing patient complications.

Rewa et al. (2018) formed a consensus panel to develop a prioritized list of key QIs for CRRT care. The following proposed QIs all received high agreement among panelists: downtime, filter life, and delivered dose. The panelists agree that staff training should be a QI but concede that it is poorly defined and can be highly variable across institutions.

Shen et al. (2018) reviewed the literature and used the Donabedian model to propose quality measures. They advocate that the ratio of delivered dose to prescribed dose, filter life, downtime, and professional education be adopted as quality measures. Professional education, though, needs further validation due to heterogeneity in clinical practice.

To provide guidance for training RNs to deliver effective CRRT, Przybyl et al. outlined their approach to training RNs in two separate studies. In 2015, they studied the impact of adding

high-fidelity CRRT simulation to their existing training program. Participants reported increased satisfaction, understanding of CRRT principles, and critical thinking skills (Przybyl et al., 2015). Through this education program, they postulate that there will be reduced complications, unwarranted filter changes, unnecessary machine repairs, and filter expense.

In 2017, Przybyl et al. (2017) presented a comprehensive guide for setting up and maintaining a CRRT training program including beginner, intermediate, and advanced courses. Super users who have demonstrated proficiency in CRRT are required to complete additional training and help teach beginner courses. An education specialist from the CRRT vendor is used for the intermediate course. Competency is assessed through high-fidelity simulation annually. In addition to online and in-person didactic courses and hands-on training, high-fidelity simulation has been shown to improve the number of unplanned interruptions (Przybyl, 2017).

The goal of CRRT is for patients to receive high-quality, effective treatment aimed at recovering kidney function. Evidence shows that, in order to deliver effective treatment, RNs must be highly trained in the management and understanding of CRRT (Cerda et al., 2016; Rewa et al., 2018; Shen et al., 2018; Przybyl et al., 2015; Przybyl et al., 2017). Current guidelines recommend a CRRT dose of 20 to 25 mL/kg/hr (Palevsky et al., 2013). Authors in several studies cite the importance of evaluating the CRRT dose that patients actually receive (Rewa et al., 2018; Shen et al., 2018). Downtime is a proposed quality indicator that directly affects whether patients receive an adequate CRRT dose (Rewa et al., 2018; Shen et al., 2018). Quality improvement can be further increased through increasing filter life and decreasing the number of unnecessary filter changes. These outcomes can help improve the sustainability of a CRRT training program through cost savings (Przybyl et al., 2015).

Rationale

The Quality Caring Model and Larrabee's adaptation of the Iowa Model were used as theoretical frameworks to undergird this quality improvement project. While the Quality Caring Model supports practice changes aimed at improving the quality of patient care, Larrabee's adaptation of the Iowa Model provides a guide for implementing such a change within a health system.

Joanne Duffy's Quality Caring Model emphasizes the use of relationships between patients and caregivers to guide interventions that leave the patient feeling cared for. Interprofessional collaborative relationships are enhanced when the focus is on patients and their families; these relationships are essential for quality care (Duffy, 2018). This project will rely on patient-focused interprofessional team collaboration to improve the quality of care for patients receiving CRRT.

June Larrabee's adaptation of the Iowa Model is an excellent guide for the quality improvement process (See [Appendix C](#)). Larrabee's model uses a six-step approach to guide an evidence-based practice change in a direct patient care setting. The steps are as follows: assess the need for change in practice, locate the best evidence to support practice change, critically analyze the evidence, design the practice change, implement and evaluate the change in practice, and integrate and maintain the practice change. This stepwise model details the EBP process, encourages evaluation at each step, and allows for returning to a previous step if necessary (Melnik & Fineout-Overholt, 2019).

As previously described, there was an opportunity to improve the quality of CRRT delivery in the CVICU. The research supported implementing a CRRT training program for those caring for CRRT patients. With increased provider knowledge, it was assumed that the quality of CRRT delivery and care for these critically ill patients would have likewise increased.

Specific Aims

This Doctor of Nursing Practice (DNP) project aimed to implement an advanced CRRT training program for nurses and advanced practice providers (APPs) in the hospital's CVICU.

Specific aims for this project were to:

1. increase participants' CRRT knowledge and to improve management and troubleshooting skills as evidenced by an improved score on a CRRT knowledge test.
2. improve CRRT delivery as evidenced by decreased downtime, improved dosing target accuracy, increased average filter life, fewer unnecessary filter changes, fewer filters used per treatment day, and reduced filter expense.
3. evaluate participants' perception of training program effectiveness as evidenced by participants' self-reported increase in competency and satisfaction on the post-intervention survey.

Methods

Context

The clinical site was the CVICU of a large academic medical center the Appalachian Mountain Region of the United States. In this 26-bed CVICU, approximately 110 RNs and 12 APPs care for a variety of high acuity cardiovascular intensive care, cardiothoracic surgery, and extracorporeal membrane oxygenation (ECMO) patients. Between July 2019 and June 2020, an average of 22.6 patients per month received CRRT in the CVICU (BHC, 2020). Although many RNs frequently care for CRRT patients, none have received formal training beyond a beginner training course focused on circuit setup, basic management, and discontinuation of CRRT.

Intervention

An advanced CRRT training program was implemented to improve the quality of the CVICU CRRT program. Specifically, the training program aimed to increase participants' knowledge of CRRT principles, patient management, and circuit troubleshooting. If successful, it was theorized that increased knowledge would translate into higher quality CRRT delivery as evidenced by improved CRRT-specific outcomes on the CRRT Management Report. Equipped with the knowledge and skills attained during the training course, participants would report a feeling of increased competency when caring for CRRT patients.

Current research supports such an intervention and suggests that RNs must be highly trained in the management and understanding of CRRT to ensure patients receive high-quality, effective treatment aimed at recovering kidney function (Cerda et al., 2016; Rewa et al., 2018; Shen et al., 2018; Przybyl et al., 2015; Przybyl et al., 2017).

Benchmarks

Despite agreement that RNs must be highly trained to care for CRRT patients, a nationally standardized CRRT training program doesn't exist and there is no certification exam to validate the level of expertise necessary to deliver high quality CRRT. Rewa et al. (2018) and Shen et al. (2018) both argue that staff training should be a quality indicator for CRRT care but cite the variability of training programs and the heterogeneity in clinical practice among institutions as limitations. Most facilities use internal dialysis nurses, nurse educators, CRRT device vendors, or a combination of these to teach RNs CRRT management in four- to 12-hour courses (Przybyl et al., 2017).

There are, however, some benchmarks for CRRT-specific outcomes found in CPGs or developed by industry experts. The KDIGO guidelines suggest a CRRT dose of 20–25 mL/kg/hr (Palevsky et al., 2013). BHC used internal data from 2000 CRRT treatments from around the

country to set target ranges for therapy. Their client hospitals can compare the effectiveness of their CRRT program against those targets (R. Usovsky, personal communication, July 23, 2020). The target for downtime is < 10% and filter life is > 30 hours per filter. There are no benchmarks, however, for the number of unnecessary filter changes, the number of filters used per treatment day.

In the absence of a nationally standardized training program, Przybyl et al. (2017) developed a comprehensive CRRT training program. Their training program consists of three courses for learners of increasing levels of competency starting with their “New to CRRT” class. This eight-hour course used a combination of online learning modules and in-person didactic and hands-on training provided by a clinical education specialist and RNs designated as CRRT super users. At least six months after completing the initial course, RNs may attend their four-hour “Intermediate CRRT Course”. In their intermediate course, a CRRT device was available for demonstration of troubleshooting, and the device vendor taught device-related content. A clinical education specialist from the facility provided evidence-based practice content and was available to answer any facility-specific questions about CRRT or management of patients on CRRT. Their “Advanced CRRT Course” was designed for expert RNs seeking advanced CRRT training and super user designation.

The advanced CRRT training course implemented in this quality improvement project is analogous to the “Intermediate CRRT Course” described in Przybyl et al. (2017) with some exceptions. For this project, the advanced CRRT training course was offered to CVICU RNs who have completed a one-hour beginner training course offered by the facility’s dialysis nurse educators. These qualified RNs already received formal training on device setup, maintenance, discontinuation, and basic troubleshooting for alarm conditions. The advanced CRRT training

course was also four hours long, but the course content was provided exclusively by the CRRT machine manufacturer's clinical educator rather than a combined approach involving the facility's clinical educators. The CRRT machine manufacturer's clinical educator met with the facility's dialysis department manager (and this project's content expert), the CVICU manager, and the project leader to understand the needs of CVICU RNs and adapt the course materials to meet participants' needs.

Detailed Description of the Intervention

The four-hour advanced CRRT training course was comprised of a two-hour didactic section and a two-hour interactive machine-specific education and troubleshooting section. The didactic section covered the principles and biophysics of CRRT. The clinical educator used preexisting educational materials created by the CRRT manufacturer to present the didactic material in PowerPoint format. Participants received in-depth information about how CRRT works including patient criteria for CRRT candidacy, treatment modalities, the movement of fluids and solutes, the role of solutions, and dosing recommendations. After a 10-minute break, the clinical educator began the machine-specific education and troubleshooting section. Using an actual CRRT machine, the clinical educator explained all aspects of the user interface including treatment modalities, prescription and flow settings, patient parameters, pressure readings, and CRRT filter and circuit components. Next, the educator created a patient scenario and simulated alarm conditions to challenge participants to consider CRRT principles learned in the didactic section, interpret machine data, understand the mechanics of the CRRT circuit, diagnose the problem, and critically think through potential solutions.

Due to the COVID-19 pandemic, the facility did not permit in-person education during the intervention implementation period. The clinical educator had already established the

capacity to conduct courses remotely via videoconferencing software and had previously done so for other client facilities. There was a CRRT machine connected to a simulated patient, and there were multiple cameras that allowed the participant to view the CRRT machine, its screen, and the educator. All training courses were conducted remotely.

The project implementation period began after receiving institutional review board (IRB) approval. Once course dates were confirmed with the clinical educator, the project leader created a flyer advertising the training course and enlisted the help of CVICU clinical preceptors to distribute it to potential participants. Those who signed up were sent an email explaining the DNP project, the advanced CRRT training course, participant expectations, and were provided a link to the pre-intervention survey and videoconference. On the day of the course, the project leader opened with a review of the DNP project, explained the agenda, and introduced the clinical educator. Participants were then given detailed instructions for completing the pre-intervention CRRT knowledge test and a link to the test on Qualtrics (2022). After completing the knowledge test, the clinical educator started the CRRT training course. All participants were encouraged to keep their video feed on. At the completion of the course, participants were given instructions for completing the post-intervention CRRT knowledge test and a link to the test on Qualtrics (2022). After at least three months since completion of the advanced CRRT training course, participants were contacted via email and asked to complete the post-intervention survey.

Congruence with the Organization's Strategic Plan

The hospital mission statement is “to improve the health of West Virginians and all we serve through excellence in patient care, research, and education” (WVU Medicine, n.d.). The Heart and Vascular Institute, which houses the CVICU, has the following mission statement: “to provide the best possible heart, lung, and vascular care for our patients” (WVU Heart & Vascular

Institute, n.d.). This project is congruent with both mission statements; it aims to educate providers to deliver higher quality CRRT to improve the health of patients who have suffered AKI. A letter of site support from the CVICU manager and the hospital's Nursing Research Council can be found in [Appendix D](#) and [Appendix E](#) respectively.

Personnel, Technology, and Budget

The DNP Project Team was formed in June 2020. It includes the team leader, the faculty of record (FOR), and the manager of the dialysis unit. The CVICU manager, the CVICU clinical preceptors, and the clinical educator from the CRRT machine manufacturer were key stakeholders and were highly involved in project implementation.

As part of its contract with the client facility, the CRRT machine vendor provides free staff education and support services. They employ a clinical educator who is assigned to a region and is responsible for fulfilling education requirements for client hospitals within. The course content has been developed by the vendor and can be adapted to meet the specific needs of the client. The clinical educator had already established the capability of conducting training sessions remotely. The advanced CRRT training course was taught in a virtual classroom setting using free videoconferencing software capable of being accessed through a computer or smartphone.

The surveys and knowledge tests were made available to participants using free Qualtrics (2022) web-based software. The surveys were created by the project leader and the knowledge test was developed by the vendor and made available by the clinical educator. Links to these items were emailed to participants.

CRRT-specific data was obtained from the data cards in the CRRT machines designated for the CVICU. The dialysis department manager pulled the data cards and gave them to the

clinical educator who extracted the data from the cards and sent it to the team at the CRRT vendor who produces the CRRT Management Report for its client hospitals. Once complete, the report was then emailed to the clinical coordinator who forwarded it to the project team leader.

Budget. The staff training course was provided free of charge through the existing hospital contract with the CRRT manufacturer, but participants will need to be paid for their attendance. The CVICU manager was provided the roster of participants for each training session. At the end of the implementation period, a total of \$675.28 was paid out in workshop time to the RNs; the APPs attended using workshop time built into their contract. There was additional time burden for the project team and stakeholders.

Evaluation Plan

To assess the impact of the intervention, a pretest and posttest was used to evaluate a change in knowledge as a result of participating in the training course. Participants took the same CRRT knowledge test before and after the training course (See [Appendix F](#)). Tests were administered using Qualtrics (2022) online survey software for web-based courses and were not scored until all participants completed the training courses. For each participant, the pretest and posttest scores were calculated to find the percent of questions answered correctly. To preserve anonymity while allowing for comparison of scores, the knowledge test was preceded by a question asking participants to provide a random code word. The project team leader input participants' code word and corresponding test scores into a spreadsheet. Evidence of a change in knowledge was evaluated by comparing pretest and posttest scores.

It was theorized that increased knowledge would translate to higher quality CRRT delivery as evidenced by improved CRRT-specific outcomes on the CRRT Management Report. In February 2021, a baseline CRRT Management Report was created using data from five CRRT

machines designated to be used exclusively in the CVICU. Approximately five months after completion of the last training course, a new CRRT Management Report was created using data from the same five CRRT machines. The post-intervention data was compared to baseline to evaluate if there had been a change in the following CRRT-specific outcomes of interest: downtime, dosing target accuracy, filter life, number of unnecessary filter changes, filters used per treatment day, and filter expense.

Participants were asked to complete a pre- and post-intervention survey. The Pre-intervention Perceived CRRT Competency Questionnaire was used to assess baseline perception of CRRT skills and training (See [Appendix G](#)). Approximately three months after completing the training course, participants were asked to complete the Advanced CRRT Training Course's Perceived Impact on Competency Questionnaire to assess their perceived impact of the training course on their CRRT competency (See [Appendix H](#)). Both surveys were created using Qualtrics (2022) online survey software and links were distributed to participants via email. Results were transferred into a spreadsheet saved on a password-protected computer.

Several steps were taken to minimize confounding variables thereby increasing the likelihood that the observed outcomes were due to the intervention. The CRRT knowledge test obtained from the vendor's clinical educator was modified to include the answer "I don't know" for every question. Participants were encouraged to answer "I don't know" rather than guessing when confronted with a question to which they didn't know the answer. This was intended to ensure that when a participant answered correctly, it was because they knew the answer rather than just guessing the correct one. Participants were repeatedly reassured that the test scores were anonymous and that there were no negative consequences for answering "I don't know" or answering incorrectly. They were instructed to not to use any resources to look up answers and

that their scores were only being used to evaluate the training course, not the participants. They were told, however, that they were expected to be engaged and to give the clinical educator their undivided attention.

Several steps were taken to improve the accuracy of the CRRT-specific data and to limit confounding variables. In this facility, all CRRT machines are kept in the CVICU, and RNs from other ICUs frequently take machines from the CVICU storage room when their patient is started on CRRT. To obtain clean baseline data, the dialysis department manager and the CVICU supervisor selected five machines to be used exclusively on CVICU patients starting July 3, 2020. The machines were labeled “CVICU Research”. Signs were posted in the storage room and emails were sent to the staff of all ICUs explaining that the labeled machines were only to be used on CVICU patients. Also, CRRT dosing is in mL/kg/hr, so the patient’s daily weight must be entered into the CRRT machine each day for the machine to accurately measure the dose the patient is receiving. This was a change in practice for CVICU RNs. The CVICU manager and clinical preceptors implemented this practice change and educated staff about this new expectation. By September 2020, all staff were educated and inputting daily weights was adopted into practice.

Measures

To evaluate the impact of participating in the advanced CRRT training course, the following participant outcomes were measured: participant learning and self-reported impact on competency and satisfaction. The measured CRRT-specific outcomes were CRRT downtime, dosing target accuracy, filter life, number of unnecessary filter changes, filters used per treatment day, and filter expense.

Participant learning was operationalized as the difference in CRRT knowledge test scores before and after the intervention. The CRRT knowledge test was used to evaluate baseline and post-intervention CRRT knowledge. The vendor's clinical educators permit client facilities to use the CRRT knowledge test to assess their employees. Information regarding validity and reliability of the test was unavailable.

The CRRT-specific outcomes were chosen because they represent quantifiable data that could be influenced by the intervention. An improvement in post-intervention outcomes from baseline could suggest an increase in the quality of CRRT delivery as a result of participating in the advanced CRRT training program. These outcomes are conveniently included in the CRRT Management Report that is produced free of charge by the CRRT machine manufacturer for its client hospitals.

The CRRT-specific outcomes of interest are CRRT downtime, dosing target accuracy, filter life, number of unnecessary filter changes, filters used per treatment day, and filter expense. The operational definition of downtime is the total number of hours that CRRT is interrupted. It is reported as a percent of the total treatment time. The downtime benchmark set by the CRRT machine vendor is less than 10%. The CRRT dosing benchmark of 20 – 25 mL/kg/hr was established by the KDIGO CPG for CRRT dose (Palevsky et al., 2013). The report shows the average dose that patients received. Dosing target accuracy was operationalized by comparing the average dose that patients received to the benchmark. Filter life is operationalized as the number of hours a CRRT filter is in use before it is discarded. The filter life benchmark set by the CRRT machine vendor is greater than 30 hours. Filters need to be discarded if they reach the manufacturer's recommended lifespan of 72 hours, become clotted, become degraded, or if treatment needs to be interrupted for more than three hours (e.g., for surgery). The CRRT

machine records these event data, and they are included in the CRRT Management Report. If the filter is changed for any other reason, it is considered an unnecessary filter change and is classified as “other” on the report. Unnecessary filter change is operationalized as the average number of filters appearing under “other” on the CRRT Management Report and was compared to the pre-intervention baseline. The number of filters used per treatment day is operationalized by dividing the total number of filters used by the quotient of the total hours of treatment time divided by 24 hours. The number of filters used per treatment day was compared to the pre-intervention baseline value. Filter expense was operationalized in two ways. First, the average filter expense per month was calculated by multiplying the cost per filter by the average number of filters used per month. Second, the average filter expense per treatment day was calculated by multiplying the average number of filters used per treatment day by the cost per filter. Standardizing filter expense in this way versus just calculating total expense allowed for variability in the number of treatment days in the pre-intervention and post-intervention samples. Post-intervention filter expense was compared to baseline.

The CRRT dose was supported by the KDIGO CPG (Palevsky et al., 2013). The benchmarks for downtime and filter life were set by the CRRT machine manufacturer. Beyond that, there were no validity and reliability data for the tools used to evaluate the outcomes.

A post-intervention survey was used to evaluate participant’s perceived impact of the training course on competency and to assess satisfaction. Participants were asked to indicate to what degree they agreed with three statements. Self-reported impact on competency was operationalized by the participants’ rating using the following Likert scale: Strongly Disagree = 1, Disagree = 2, Neither Agree or Disagree = 3, Agree = 4, and Strongly Agree = 5. The questions were created by the project team leader and the tool has not been tested for reliability

or validity. The survey was followed by an open-ended question that encouraged participants to provide any further feedback on the training course.

The advanced CRRT training course was continuously evaluated and adjusted based on feedback from the DNP project team and participants. The clinical educator was required to ask participants to complete a course evaluation after each training course (See [Appendix I](#)). The course evaluation survey was anonymous, included Likert scale questions to evaluate both the course and the educator, and included an open-ended question asking how the training course could be enhanced. These evaluations were added to the end of the post-intervention CRRT knowledge test using Qualtrics (2022). After each training course, the project team leader collected these evaluations and discussed feedback with the clinical educator, and subsequent training courses were adapted as necessary.

Several steps were taken to improve the accuracy and completeness of the data, many of which have been described previously. The CRRT knowledge test included a special code word to allow pre- and post-intervention knowledge tests to be compared and to identify any participant that may have only completed one of the tests. Using Qualtrics (2022) online survey software contributed to the success and accuracy of data collection. It allowed for easy survey and CRRT knowledge test responses and accurately scored and saved data. It provided some statistical analysis and could be efficiently translated into spreadsheet and IBM SPSS (IBM, 2019) formats for further analysis. As for the CRRT-specific data, five machines were selected and labeled to be used only in CVICU. Only data from those machines were collected for baseline and post-intervention evaluation. A practice change was made to have the patient's weight updated in the CRRT machine daily. This improved the accuracy of data on the CRRT

Management Report, and lead to the successful and efficient quantification of CRRT-specific outcome variables.

Analysis

A statistical expert was consulted for data analysis and interpretation. IBM's SPSS software (2019) was used for quantitative statistical analyses. The quantitative data from the pre- and post-intervention surveys were analyzed using sum of scores and descriptive statistics. Qualitative responses to the open-ended question in the post-intervention survey were noted but were too few for meaningful analysis. The quantitative data for the pre- and post-intervention CRRT knowledge test were analyzed using a paired t-test. Additionally, an analysis of variance (ANOVA) was performed to investigate whether a participant's professional role or years of experience affected performance on the CRRT knowledge test. All quantitative data comparing post-intervention CRRT-specific outcome data to baseline was analyzed using a paired t-test.

Ethical Considerations

This DNP quality improvement project was non-human subject research and received IRB approval prior to implementation. The project proposal was approved by the clinical site's Nursing Research Council. No patients were involved in the project beyond collecting non-identifiable CRRT-specific data from the CRRT machines used in their treatment. All participants were advised that completion of the surveys and knowledge test was voluntary. Participation in the advanced CRRT training course and being paid for their time was not contingent on their completion of surveys or knowledge tests. The Qualtrics (2022) surveys were set to be anonymous, and no identifiable data was collected from the participants. A code word was utilized to allow comparison between pre- and post-intervention CRRT knowledge test scores. All data and training course rosters were stored on a password-protected computer.

Because the training course was attended via videoconference, records of course attendance were saved and shared with the CVICU manager to ensure participants were compensated for their time. No CRRT-specific data can be associated with a specific patient, and no patient's protected health information was collected. The project team leader has no conflicts of interest to disclose relevant to the project.

Results

Results

The following sections detail events of the intervention period, process measures and outcomes, detailed results, and contextual elements that influenced the intervention.

Project Timeline and Evolution

The intervention period began in January 2021 after receiving IRB and Nursing Research Council approval. As previously described, multiple steps were taken to ensure that the baseline CRRT-specific data would be as accurate as possible. In February 2021, a new set of baseline CRRT-specific data was obtained for the months since the five CRRT machines were made to be used exclusively in the CVICU.

From May 2021 through October 2021, four advanced CRRT training courses were completed. Advertisements announcing the training courses were created and distributed via email, posters, newsletters, and word of mouth in the weeks prior to the training courses. Participants enrolled in the course by contacting the project team leader. In the days prior to the training course, participants were emailed details of the training course, the DNP project, and were provided a link to the videoconference.

In April 2022, five months after the last training course was completed, data cards were retrieved from the five designated CRRT machines and a post-intervention CRRT Management

Report was created for the first four months of the post-intervention period. All CRRT knowledge tests were scored and the data from the knowledge tests, surveys, and CRRT-specific data were input into a spreadsheet and converted into SPSS (2019) format. These data were then analyzed in May and June 2022 to evaluate the impact of the advanced CRRT training course on outcomes relevant to the project's specific aims.

Process Measures and Outcomes

Of the approximately 110 RNs and 12 APPs employed in the CVICU during the intervention period, 36 signed up for the advanced CRRT training course, and 25 completed the training course. The pre-intervention survey was completed by all 25 participants. The pre-intervention and post-intervention CRRT knowledge tests were each completed by 20 participants, and 18 participants completed both tests. The post-intervention survey was completed by 15 participants.

Participants' demographic data regarding professional role and years of experience is presented in Table 1.

Table 1

Participant Demographics

	Number of Participants	% of Total Participants
Current role		
CVICU RN	23	92
APP	2	8
Years of Experience		
< 6 months	1	4
6 months to 1 year	6	24

	Number of Participants	% of Total Participants
1-2 years	4	16
2-4 years	9	36
< 4 years	5	20

The pre-intervention survey included three questions to assess participants perceived level of training and competency (See [Appendix G](#)). The results are displayed in Table 2. In response to the question about their feeling about adequacy of previous training on CRRT management and troubleshooting on the scale of 1-5 (where 1=strongly disagree, 5=strongly agree) mean score was 3.53 (SD=1.04). In response to the question about patient management on a scale of 1-5 (where 1= poor, 5=excellent) a mean score of 3.24 (SD=0.83) was recorded. In response to the question about perceived CRRT troubleshooting skills on a scale of 1-5 (where 1= poor, 5=excellent), a mean score of 3.04 (SD=0.93) was recorded.

Table 2

Pre-Intervention Survey Results

Questions	Mean Score	SD
I feel that the training I have received regarding CRRT management and troubleshooting has sufficiently prepared me to care for patients receiving CRRT.	3.52	1.04
How would you rate your current understanding of how CRRT works and patient management?	3.24	0.83
How would you rate your CRRT troubleshooting skills?	3.04	0.93

To evaluate the effect of participating in the advanced CRRT training course on participants' knowledge, scores on the pre- and post-intervention CRRT knowledge test were analyzed. The pre- and post-intervention CRRT knowledge tests were completed by 18 participants and the results are displayed in Table 3. The mean score is the number of participants' correct answers out of 35 questions. On average post-intervention knowledge scores were 8.11 points higher than pre-intervention scores (95% CI [6.14 – 10.07]). There was a significant average difference between pre- and post-intervention CRRT knowledge test scores ($t_{17}=8.703$, $p<.001$).

As previously explained, "I don't know" was added as a potential answer to each question of the CRRT knowledge test. Participants answered "I don't know" 41 times on the pre-intervention test and one time on the post-intervention test.

An ANOVA was performed to investigate whether a participant's professional role or years of experience affected performance on the CRRT knowledge test. The results of ANOVA showed that there is no significant difference in the change of knowledge mean scores due to the role [$F(1)=1.15$, $p=.298$], or years of experience [$F(3)=0.501$, $p=.687$].

Table 3

Pre- and Post-intervention CRRT Knowledge Test Results

Mean Score (SD) Pre-Intervention	Mean Score (SD) Post-Intervention	Change in the score (Pre-Post) Mean (SD)	t-test	df	p-value
20.78 (2.96)	28.89 (2.32)	-8.11 (3.95)	-8.703	17	<.001

Note. Bold text indicates a statistical significance with a p-value<0.05.

The post-intervention survey included three questions to assess their perceived impact of the training course on their CRRT competency (See [Appendix H](#)). The mean scores on a scale of 1-5 (where 1=strongly disagree, 5=strongly agree) are displayed in Table 4. The participants felt

that the intervention improved their overall understanding of CRRT (mean score: 4.73, SD: 0.45). The participants also found that the troubleshooting skills learned in the advanced training course have been valuable to their practice (mean score: 4.60, SD: 0.507). They also reported post-intervention improvement in their understanding of CRRT and the management of patients receiving CRRT (mean score: 4.73, SD: 0.458).

The post-intervention survey was followed by an open-ended question that encouraged participants to provide any further feedback on the training course. The four responses can be found in [Appendix H](#). The respondents found the training course to be “an extremely helpful class” that was “well taught” and “incredibly beneficial”. Some suggested that the training course “should be offered once or twice a year” and would have preferred it to be “in person for hands-on practice.

Table 4

Post-intervention Survey Results

Questions	Mean Score	SD
I feel that participating in the advanced CRRT training course improved my overall understanding of CRRT	4.73	0.458
I have found the troubleshooting skills learned in the advanced CRRT training course to be valuable to my practice.	4.60	0.507
My overall understanding of CRRT and management of CRRT patients is improved as a result of my participation in the advanced CRRT training course.	4.73	0.458

Four months of pre-intervention CRRT-specific data from the CRRT Management Report (BHC, 2021) was used to establish a baseline, and four months of post-intervention CRRT-specific data from the CRRT Management Report (BHC, 2022) was used to evaluate the

impact of the advanced CRRT training course. The average number of patients, hours of treatment, and treatment days per month are shown in Table 5.

The means for the four months of pre-intervention and post-intervention CRRT-specific outcome data are presented in Table 5. The change in the post-intervention mean scores from baseline was evaluated. The findings indicate a statistically significant difference in the post-intervention number of filters used ($t_3=7.106$, $p<.006$), total treatment time ($t_3=4.232$, $p<.024$), total treatment days ($t_3=4.232$, $p<.024$), and overall filter expense ($t_3=7.01$, $p<.006$). Although not statistically significant, a considerable reduction (change in score 7.25, SD: 4.6) in the number of unnecessary filter changes was noted post-intervention.

Table 5

Pre- and Post-intervention CRRT-specific Outcome Data Results

Characteristics	Benchmark (if applicable)	Pre-intervention Mean (SD)	Post-intervention Mean (SD)	Change in score Mean (SD)	t-test	df	p-value (2-sided)
Number of patients		22 (6.16)	13 (2.58)	9.00 (6.05)	2.973	3	.059
Number of filters used		81.25 (19.34)	41.25 (12.17)	40.00 (11.40)	7.016	3	.006
Total treatment time (hours)		1592.75 (494.31)	780 (150.35)	812.00 (383.70)	4.232	3	.024
Total treatment days		66.36 (20.59)	32.53 (6.26)	33.83 (15.98)	4.232	3	.024
Downtime (% treatment time lost)	<10%	19.25 (6.75)	16.00 (2.1)	3.25 (7.97)	0.815	3	.475
Dosing Target Accuracy (mL/kg/hr)	20-25 mL/kg/hr	27.45 (2.34)	23.25 (4.99)	4.2 (5.7)	1.45	3	.241
Ave. Filter Life (hrs./filter)	>30 hours	16.25 (1.5)	17.75 (1.5)	-1.5 (2.8)	-1.441	3	.245
Unnecessary filter changes		15.5 (4.79)	8.25 (2.06)	7.25 (4.6)	3.121	3	.052
Unnecessary Filter Changes (% of total filters)		18.82 (2.29)	20.50 (5.06)	-1.67 (7.35)	-.456	3	.680
Filter/treatment days		1.25 (0.15)	1.25 (0.13)	.005 (0.26)	0.038	3	.972
Filter expense/treatment day (dollars)		292.35 (34.87)	291.16 (31.14)	1.18 (61.3)	0.39	3	.972
Filter expense (dollars)		18927.18 (4506.5)	9609.18 (2836.35)	9318.0 (2656.0)	7.01	3	.006

Note. Bold text indicates a statistical significance with a p-value<0.05.

Contextual Elements Affecting the Intervention

The implementation period occurred during the COVID-19 pandemic, and the limitations imposed by the pandemic were highly influential on the intervention. The most obvious change was from in-person to virtual training courses, but beyond that, the CVICU was operating under the stress of the pandemic. It was originally agreed upon that all CVICU RNs would participate in the training courses, but prior to implementation, it was decided that it wasn't the best time to ask more of the RNs while staffing was limited. Instead, participation in the training course became purely voluntary. The project team leader and the vendor's clinical educator agreed to set a minimum of five participants per training course, and two scheduled training courses were cancelled because fewer than five participants were confirmed.

The COVID-19 pandemic also influenced CRRT delivery in the CVICU. It is now widely understood that patients with COVID-19 who develop AKI suffer from a systemic inflammatory response (Robbins-Juarez et al., 2020). Inflammatory mediators in a patient's blood can shorten the lifespan of a CRRT filter. The CVICU also has an extracorporeal life support (ECLS) program, and qualifying COVID-19 patients who failed ventilation were transferred to the CVICU for venovenous extracorporeal membrane oxygenation (ECMO), a method of providing oxygenation and carbon dioxide removal for patients with severe lung disease. The CRRT machine was commonly attached to the ECMO machine, and this configuration greatly affects nearly all relevant CRRT-specific outcomes of interest. Similarly, the Oxiris CRRT filter was given emergency use authorization through the U.S. Food and Drug Administration to be used for COVID-19 patients. This filter, used in the CVICU during the intervention period, has a heparin lining to reduce clotting and prolong filter life (Baxter, n.d.).

Scheduling the CRRT training courses was also an influencing factor. Unfortunately, the clinical educator's availability was limited due to family and personal health emergencies during the implementation period. Likewise, several CVICU RNs who were interested in attending, were not available for the scheduled training courses due to personal or professional preexisting commitments.

Missing Data

Of the 25 participants, five (from one session) confused the pre-intervention survey for the pre-intervention CRRT knowledge test and therefore did not complete the pre-intervention CRRT knowledge test. This was discovered after the training course was started, so that group was discouraged from completing the post-intervention CRRT knowledge test because a change in knowledge could no longer be evaluated. Two other participants completed either the pre-intervention knowledge test or the post-intervention knowledge test, but not both tests. These missing scores were discovered (after the tests were graded at the end of the implementation period) because the participants' code words did not have both tests associated with them. These scores were eliminated from the data set leaving 18 sets of CRRT knowledge test scores.

Discussion

Summary

Key findings from this intervention directly address the problem statement and specific aims previously identified. Prior to this intervention, RNs and APPs received little formal training on CRRT despite the literature supporting the need for extensive training. Participants corroborated this finding in their responses to the pre-intervention survey.

The intervention aimed to increase participants' CRRT knowledge and to improve management and troubleshooting skills. As a result of participating in the advanced CRRT

training course, participants had a statistically significant increase in knowledge as evidenced by the difference between pre-and post-intervention CRRT knowledge test scores.

With increased knowledge, it was theorized that the quality of CRRT delivery would also be increased as evidenced by measurable improvements in CRRT-specific outcomes. Although there was a statistically significant improvement in filter expense, it was likely due to a statistically significant reduction in the number treatment days in the post-intervention sample. Other outcomes were improved, but they were not statistically significant.

Finally, the intervention aimed to evaluate participants' perception of training program effectiveness. As a result of participating in the advanced CRRT training program, participants reported an increase in CRRT competency and satisfaction as evidenced by their responses to the post-intervention survey and feedback.

Strengths of the project included institutional and CRRT vendor support, preexisting tools for evaluation, user-friendly online survey software, data analysis tools, and positive participant feedback. The project had the full backing of CVICU leadership throughout the development and implementation period. An established relationship between the facility and the CRRT vendor simplified the adaptation of training materials and development of the training course with the clinical educator. The vendor provided training course materials, the educator, the CRRT knowledge test, and the CRRT Management Report free of charge. Using Qualtrics online survey software made building surveys and the knowledge test easy. Participants had no issues accessing or completing the surveys or tests. They indicated that the training course was useful to improving their knowledge of CRRT management and increasing their competency.

Interpretation

As a result of participating in the advanced CRRT training course, participants had a statistically significant increase in knowledge as evidenced by the difference between pre-and post-intervention CRRT knowledge test scores. Participants' average CRRT knowledge test score increased from 59.37% to 82.54% after completing the training course. The number of times participants answered "I don't know" dropped from 41 times on the pre-intervention test to just one time on the post-intervention test.

Participants reported an increase in CRRT competency and satisfaction as evidenced by their responses to the post-intervention survey and feedback. They felt that the intervention improved their overall understanding of CRRT, that the troubleshooting skills learned in the advanced training course have been valuable to their practice, and they perceive an improvement in their understanding of CRRT and the management of patients receiving CRRT. Przybyl et al. (2015) also found an increase in nurses' satisfaction, understanding the CRRT principles, and critical thinking skills with the operation of CRRT.

This project could have a positive impact on providers responsible for managing CRRT, institutions where CRRT is available, and patients who are receiving CRRT. The intervention has been shown that participants who attended the advanced CRRT training course (regardless of role or years of experience) came in with a knowledge deficit as evidenced by the average score of 59.37% and answering "I don't know" 41 times on the pre-intervention CRRT knowledge test. Current research suggests that RNs must be highly trained in the management and understanding of CRRT to ensure patients receive high-quality, effective treatment aimed at recovering kidney function (Cerda et al., 2016; Rewa et al., 2018; Shen et al., 2018; Przybyl et al., 2015; Przybyl et al., 2017).

As mentioned previously, the impact of the COVID-19 pandemic greatly affected the intervention. At least one participant mentioned that they would have preferred an in-person training course. It's possible that the change in knowledge could have been even greater with in-person training courses. The CRRT-specific data was inconsistent with anticipated outcomes. In the context of the COVID-19 pandemic these data are at risk of being influenced by many confounding variables.

Participating in the advanced CRRT training course resulted in an increase in knowledge and perceived improvement in troubleshooting skills. This intervention could improve RNs' troubleshooting skills and reduce the number of unwarranted filter changes. The baseline data on just the five CRRT machines designated for this project showed that an average of 15.5 filters per month were discarded unnecessarily (BHC, 2021). At a cost of \$232.95 per filter, the institution is spending an average of \$3,610.73 per month on wasted filters for just those five machines. Considering training course cost the institution \$675.28 for 23 participants, the cost savings on filters alone could be significant for the institution.

Limitations

The intervention may not be generalizable to institutions with a different CRRT machine vendor, clinical educator, or without access to their evaluation tools. Virtual versus in-person education may also limit generalizability of the intervention.

Internal validity may have been limited due to the CRRT knowledge test and the surveys not being validated evaluation tools. Also, there is no way to know for sure that participants didn't use other sources to find answers or guess when answering the CRRT knowledge test questions. Another limitation was the previously described issue of missing scores. The impact of participating in the advanced CRRT training course on participants' perceived competency

could not be evaluated for a significance because the same questions were not used for the pre-intervention and post-intervention surveys.

To minimize these limitations, several steps were taken. The same CRRT knowledge test was used for the pretest/posttest design. Participants were discouraged from using other sources and the fact that the test was anonymous and their test scores could not be associated with them was repeated in every communication. Furthermore, the answer choice of “I don’t know” was added to each question to limit guessing and improve the likelihood that correct answers reflected participant knowledge.

The CRRT-specific outcomes were subject to several confounding variables. There was no way to know for sure that the five CRRT machines designated to be used only in the CVICU were not used in other units. The accuracy of the CRRT dose recorded in the data sample is dependent on RNs inputting the patient’s daily weight into the machine, and there is no way to know that this was done consistently. In addition to the issues of utilizing Oxiris filters, when CRRT machines are attached to an ECMO patient who is on systemic anticoagulation, the filters are less likely to clot. Also, connecting to an ECMO circuit eliminates a lot of potential alarm conditions that are common with dialysis catheters. There was no way to tell if the CRRT machines were attached to ECMO circuits or were used in the treatment of COVID-19 patients. Only 25 providers participated in the advanced CRRT training course, and there is no way to know whether the CRRT machines in the post-intervention period were being managed by a provider who participated in the training course. When a CRRT machine alarms, it is common for several RNs to respond and attempt to troubleshoot the issue. There may have been peer-to-peer education occurring outside of the advanced CRRT training course during the implementation period; some later participants may have been educated by earlier participants.

As previously described, several steps were taken to try to minimize limitations on CRRT-specific outcomes including designating five machines for CVICU use only and making the staff of all ICUs aware of this practice change. A practice change requiring RNs to input daily patient weights into the CRRT machines was implemented to minimize incorrect CRRT dosing data. There was little that could be done to minimize the other limitations.

Conclusions

Przybyl et al. (2015) argued that “The complexity of CRRT therapy and the potential for loss of life due to a failure to critically problem-solve complications compels the need for standardization in continuing education for nurses performing CRRT” (p.136). Implementing an advanced training program to improve nurses’ management of CRRT is an essential first step toward improving the quality of care for patients in the CVICU who are receiving CRRT.

The advanced CRRT training course could greatly benefit CRRT providers and patients in the CVICU. According to their feedback, participants found it helpful and felt it should be offered at least yearly if not more frequently. If CVICU leadership agrees that increased CRRT knowledge and improved troubleshooting skills could translate into fewer unnecessary filter changes, the cost of the training course would pay for itself multiple times over in filter cost savings. Additionally, if increased CRRT knowledge translates into better care for CVICU patients undergoing CRRT, this project supports the organizations mission and vision by providing the best care to its patients “through excellence in patient care, research, and education”.

It is recommended that the project continue in the CVICU and that the clinical preceptors coordinate with the CRRT vendor’s clinical educator to continue providing the advanced CRRT

training course to CVICU providers. It's possible that this project could be implemented in other ICUs within the facility.

In the future, the project could expand into a formal training program offering beginner, intermediate, and advanced CRRT training courses like the one described by Przybyl et al. (2017). The CRRT Management Reports should be used to evaluate the CRRT program, and efforts should be made to ensure accuracy of the data and to improve CRRT-specific outcomes.

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Appendix A

Literature Search Log

Date	Database	Search Terms (key words)	Number of hits	Limits applied	Number of relevant articles/ Scholarly evidence	Notes
6/9/20 #1	PubMed	("continuous renal replacement therapy"[All Fields]) AND (training)) NOT ("pediatrics"[All Fields])	78	English, years 2010-present	20	20 articles for further review
6/9/20 #2	PubMed	((continuous renal replacement therapy) AND (nurse)) AND (training)) NOT (pediatric)	56	English	19	After review of abstracts, 19 relevant articles were selected (12 duplicates with search #1) 7 articles for further review
6/9/20 #3	PubMed	("continuous renal replacement therapy"[All Fields] OR "continuous renal replacement therapy CRRT"[All Fields]) AND ("quality improvement"[All Fields])) NOT (pediatric)	18	English, years 2010 to present	5	After review of abstracts, 5 relevant articles were selected (4 duplicates with searches #1 and 2) 1 article for further review

Date	Database	Search Terms (key words)	Number of hits	Limits applied	Number of relevant articles/ Scholarly evidence	Notes
6/9/20 #4	Academic Search Complete, CINAHL with Full Text, Education Research Complete, Health Source: Nursing/Academic Edition, MEDLINE	(continuous renal replacement therapy or crrt) AND training AND (nurse or nurses or nursing) NOT (pediatric or child or children or infant or adolescent)	13	English, years 2010 to present	7	After review of abstracts, 7 relevant articles were selected. (6 duplicates with searches 1-3) 1 article for further review
6/9/20 #5	Academic Search Complete, CINAHL with Full Text, Education Research Complete, Health Source: Nursing/Academic Edition, MEDLINE	(continuous renal replacement therapy or crrt) AND training NOT (pediatric or child or children or infant or adolescent)	44	English, years 2010 to present	7	After review of abstracts, 7 relevant articles were selected. All duplicates of searches 1-4 0 additional articles for review.
6/10	Review of reference lists				1	8 total articles included.

Appendix B

Evidence Table

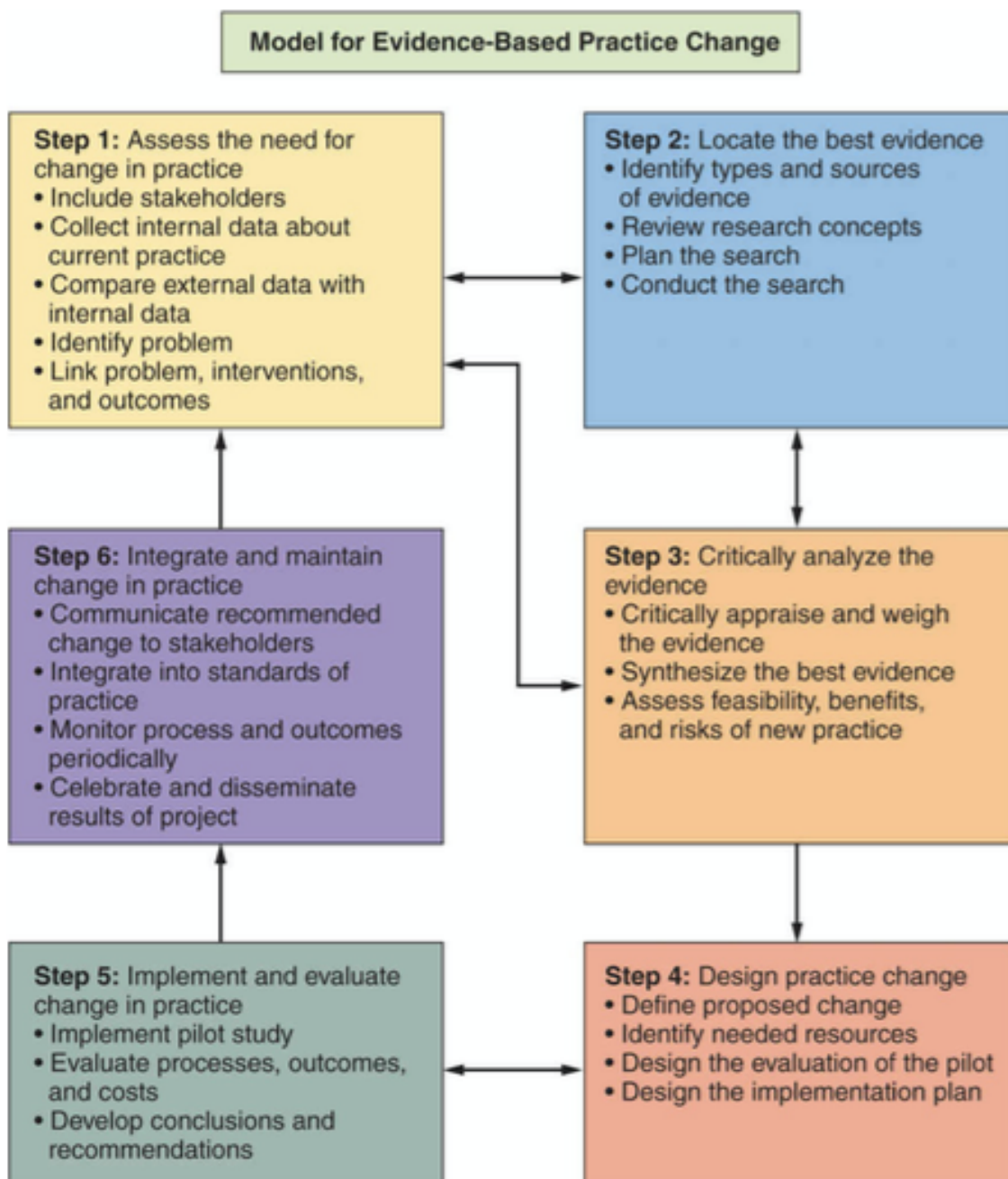
Author and date	Purpose & Variables	Design/Method	Sample/Setting	Data Analysis	Findings	Appraisal: how does it apply to practice
Palevsky et al., 2013	Created the KDOQI work group to comment on the applicability of KDIGO CPG in the United States	Expert Consensus Panel Delphi process	N/A	N/A	Endorsed KDIGO CPG of CRRT dose 20 to 25 mL/kg/hr Recommends QI strategies to ensure adequate CRRT dose is actually delivered.	Gives high level evidence to support strategies to achieve adequate CRRT dosing. Supports DNP project objectives.
Cerda et al., 2016	Reported the findings of the ADQI Consensus Group	Expert Consensus Panel	N/A	N/A	Gives “staff training” a Grade A rating. Excellent staff training is essential for success and can lead to decreased downtime and fewer patient complications.	Supports the importance of training Relates staff competency to decreased downtime.

Author and date	Purpose & Variables	Design/Method	Sample/Setting	Data Analysis	Findings	Appraisal: how does it apply to practice
Rewa et al., 2018	Created a consensus panel to develop a prioritized list of key QIs for CRRT care	Expert Consensus Panel Delphi process.	N/A	N/A	Evaluating downtime, filter life, and delivered dose all received high agreement among panelists Staff training should be a QI but is limited by variability across institutions.	QIs such as downtime, filter life, and delivered dose are appropriate outcomes measures.
Author and date	Purpose & Variables	Design/Method	Sample/Setting	Data Analysis	Findings	Appraisal: how does it apply to practice
Shen et al., 2018	Literature review	Donabedian quality control framework	N/A	N/A	Proposed quality measures: ratio of delivered dose to prescribed dose, filter life, downtime, and professional education Professional education needs further validation due to heterogeneity in clinical practice.	Quality measures such as ratio of delivered dose to prescribed dose, filter life, downtime, and professional education are all applicable to project. Recommend validating training

Author and date	Purpose & Variables	Design/Method	Sample/Setting	Data Analysis	Findings	Appraisal: how does it apply to practice
Przybyl et al., 2015	Describe a high-fidelity simulation program to enhance CRRT training	Pre-Post study Questionnaire	93 ICU RNs with more than 1-year experience	t-test	. Participants reported increased satisfaction, understanding of CRRT principles, and critical thinking skills	Supports the use of training to improve RNs' CRRT competency Postulates decreased filter expense
Przybyl et al., 2017	Provides a comprehensive guide to training staff and developing a CRRT program	Descriptive	Large academic medical center in AZ	N/A	Describes, in detail, a comprehensive guide to developing a CRRT training program for ICU RNs	Excellent guide to my QI project

Legend: ADQI = Acute Dialysis Quality Initiative. CPG = Clinical Practice Guideline. CRRT = continuous renal replacement therapy. DNP = Doctor of Nursing Practice. EMR = electronic medical record. KDIGO = Kidney Disease: Improving Global Outcomes. KDOQI = Kidney Disease Outcomes Quality Initiative. N/A = not applicable. QI = quality improvement.

Appendix C

Larrabee's Adaptation of the Iowa Model

Note. From Melnyk, B. M., & Fineout-Overholt, E. (2019). *Evidence-based practice in nursing & healthcare: A guide to best practice*. p. 446. Wolters Kluwer. doi: 978-1496384539

Appendix D

Letter of Site Approval



WVUMedicine.org

One Medical Center Drive
Morgantown, WV 26506-8121
Phone / 304-598-4000

July 24, 2020

To: To Whom It May Concern

From: Christopher M. Lindsey
Nurse Manager, CVICU

Re: Letter of Site Approval

This letter is to confirm that I am aware and support Mr. Shane Brost's CRRT project within the CVICU. If you have any questions please do not hesitate to contact me at 304-598-4555, or christopher.lindsey@wvumedicine.org.

Regards,

A handwritten signature in blue ink, appearing to read 'Chris Lindsey'.

Chris Lindsey
Nurse Manager, CVICU

Appendix E

NRC Letter of Support

October 19, 2020

Shane M. Brost
West Virginia University
School of Nursing/Nurse Anesthetist Program
Morgantown, WV 26506

To the WVU Institutional Review Board

The WVUH Research and Evidence-Based Practice Council supports the research project undertaken by Shane M. Brost, "Implementing an Advanced Training Program to Improve Nurses' Management of Continuous Renal Replacement Therapy." This is a particularly important project as it has implications that will help to improve the care that patients receive and support the staff that care for them. All necessary resources will be provided to them as they undertake this project. The project outcomes will be used to revise/modify clinician practice as necessary.

The Nursing Research, Evidence-Based Practice and Quality Improvement Council at WVUH grants you permission to complete your project with the following stipulations:

- 1) Permission is granted based on the project being carried out precisely as defined in your methodology
- 2) Permission is granted contingent upon approval and/or recommendations of the WVU Institutional Review Board
- 3) At the mid-point and at the completion of the study, you are requested to share your findings with the Nursing Research and Evidence-Based Council

Please forward me the WVU IRB approval letter for our files.

Best wishes to you in this endeavor!

Cordially,

Lya M. Stroupe

Lya M. Stroupe DNP, APRN, CPNP, NEA-BC, NPD-BC
Manager of Nursing Research and Professional Development/Magnet® Program Director/Transition to Practice
Program Director
Nursing Administration/WVU Medicine
One Medical Center Drive /PO Box 8227
Morgantown, WV 26506-8227
304.293.1417 stroupel@wvumedicine.org

Appendix F

CRRT Knowledge Test

Question 1

Return pressure is:

- A. Negative
- B. Positive
- C. Negative or positive
- D. I don't know

Question 2

Filter pressure monitors the amount of pressure required to:

- A. Pull blood from the patient
- B. Push blood back to the patient
- C. Push blood into the filter
- D. Deposit ultrafiltrate into the effluent (waste) bag
- E. I don't know

Question 3

Please select the word that matches the definition.

Definition: The movement of solutes from an area of higher concentration to an area of lower concentration:

- A. Ultrafiltration
- B. Diffusion
- C. Convection
- D. Adsorption
- E. I don't know

Question 4

The Prismaflex® Blood Flow Rate is set in:

- A. ml/hr
- B. ml/min
- C. cc/hr
- D. ml/kg
- E. I don't know

Question 5

The hemofilter set lines are color coded for safety and ease of use. On the hemofilter set the dialysate solution line is color coded:

- A. Purple
- B. Blue
- C. Red
- D. Green
- E. I don't know

Question 6

The Prismaflex® completes the Prime Test in order to:

- A. Check the hemofilter set performance
- B. Check the machine performance
- C. Ensure the machine is working properly with the hemofilter set
- D. I don't know

Question 7

Normal Effluent should consist of:

- A. Spent dialysate
- B. Ultrafiltrate
- C. Red blood cells
- D. A & B only
- E. I don't know

Question 8

Choose all the pressures that the Prismaflex® continually monitors during treatment:

Select all that apply

- A. Dialysate pressure
- B. Return pressure
- C. Effluent pressure
- D. Access pressure
- E. Filter pressure
- F. Arterial pressure
- G. I don't know

Question 9

Effluent Pressure is:

- A. Negative
- B. Positive
- C. Negative or positive
- D. I don't know

Question 10

In CRRT Therapy, select the solution that is utilized to create diffusion:

- A. Priming solution
- B. Anticoagulant
- C. Dialysate
- D. Replacement
- E. I don't know

Question 11

The hemofilter set lines are color coded for safety and ease of use. On the Hemofilter set the access line is color coded:

- A. Purple
- B. Blue
- C. Red
- D. Green
- E. I don't know

Question 12

Gambro recommends that the fluid level in the deaeration chamber should be monitored every:

- A. Hour
- B. Day
- C. Minute
- D. Nanosecond
- E. I don't know

Question 13

If New Patient is selected, the Prismaflex® machine:

- A. Deletes all treatment history
- B. Retains only pressure trending
- C. Deletes only effluent pressures
- D. Retains all treatment history
- E. I don't know

Question 14

When an Incorrect Weight Change alarm is received for the Effluent scale, excess fluid could be:

- A. Removed from the patient
- B. Given back to the patient
- C. Fluid balance is not altered
- D. I don't know

Question 15

The Prismaflex® hemofilter is the “Kidney” of the CRRT circuit and has two main internal compartments. The compartment where blood circulates is:

- A. Inside the semipermeable membrane fibers
- B. Outside the semipermeable membrane fibers
- C. Both
- D. I don't know

Question 16

Potential causes for the Incorrect Weight Change alarm are:

- A. Clamped bag
- B. Swinging bag
- C. Incomplete breakage of frangible pin
- D. All of the above
- E. I don't know

Question 17

Except the Blood Flow Rate, all other Prismaflex® machine flow rates are set in:

- A. ml/hr
- B. ml/min
- C. cc/hr
- D. ml/kg
- E. I don't know

Question 18

When changing solution bags, the operator must physically open and close scales.

- A. True
- B. False
- C. I don't know

Question 19

Please select the word that matches the definition. Definition: Movement of solutes with water flow or “Solvent Drag”:

- A. Ultrafiltration
- B. Diffusion
- C. Convection
- D. Adsorption
- E. I don't know

Question 20

When an Incorrect Weight Change alarm is received for the Replacement, PBP or Dialysate scale, excess fluid could be:

- A. Removed from the patient
- B. Given back to the patient
- C. Fluid balance is not altered
- D. I don't know

Question 21

The NORMALIZE BLD command can be found in:

- A. Flow rates screen
- B. System tools screen
- C. History screen
- D. Help screen
- E. I don't know

Question 22

The Physician prescribes a Net Patient Fluid removal of 100 ml/hr, patient IV fluids delivered per hour is 100 ml/hr and the patient output is 80 ml/hr. The appropriate setting for Patient Fluid Removal is:

- A. 280 ml/hr
- B. 350 ml/hr
- C. Zero
- D. 120 ml/hr
- E. I don't know

Question 23

The patient goals for CRRT Therapy include:

- A. Fluid balance
- B. Acid/base and electrolyte balance
- C. Waste product removal
- D. All of the above
- E. I don't know

Question 24

Filter Pressure is typically:

- A. Negative
- B. Positive
- C. Negative or positive
- D. I don't know

Question 25

When the EXCESS Patient Loss or Gain LIMIT is REACHED, the options are:

- A. Press the override button and continue treatment
- B. Attempt to return blood and change the set
- C. End treatment
- D. Both B & C
- E. I don't know

Question 26

Access pressure monitors the amount of pressure required to:

- A. Pull blood from the patient
- B. Push blood back to the patient
- C. Push blood into the filter
- D. Deposit ultrafiltrate into the effluent (waste) bag
- E. I don't know

Question 27

Ultrafiltration or plasma water removal can be utilized in what CRRT mode(s) of Therapy:

- A. SCUF only
- B. SCUF, CVVHD, CVVH, CVVHDF
- C. CVVHDF only
- D. CVVH only
- E. I don't know

Question 28

In CRRT Therapy, select the solution that is utilized to drive convection:

- A. Priming solution
- B. Anticoagulant
- C. Dialysate
- D. Replacement
- E. I don't know

Question 29

The Pressure Drop and TMP graphs are located on the status screen. The monitoring and trending of these pressures can assist when assessing:

- A. Access patency
- B. Filter efficacy
- C. Effluent pump
- D. Patient hemodynamic stability
- E. I don't know

Question 30

The primary goals of the Prismaflex® Prime sequence and priming solution are to:

- A. Remove air
- B. Remove residual sterilant
- C. Both A & B
- D. I don't know

Question 31

The acronym "CRRT" stands for:

- A. Continuous Renal Replacement Therapy
- B. Careful Renal Replacement Therapy
- C. Continuous Renal Reduction Therapy
- D. Continuous Renal Replacement Treatment
- E. I don't know

Question 32

Some factors that affect the different pressures within the CRRT Circuit are:

- A. Individual patient characteristics
- B. Location and condition of vascular access and catheter size
- C. Therapy delivered and flow rates applied
- D. All of the above
- E. I don't know

Question 33

Please select the word that matches the definition.

Definition: The movement of fluid through a semipermeable membrane:

- A. Ultrafiltration
- B. Diffusion
- C. Convection
- D. Adsorption
- E. I don't know

Question 34

A "BLOOD LEAK DETECTED ALARM" has occurred. No BLOOD is noted in the effluent and the Effluent lab test is negative for blood. The patient conditions that could potentially trigger this alarm are:

- A. Presence of bilirubin and/or myoglobin
- B. Liver failure
- C. Burns
- D. All of the above
- E. I don't know

Question 35

Access Pressure is typically:

- A. Negative
- B. Positive
- C. Negative or positive
- D. I don't know

Appendix G

Pre-intervention Survey: Perceived CRRT Competency Questionnaire

Please indicate to what degree you agree with the following statements by circling the corresponding numbers

1. I feel that the training I have received regarding CRRT management and troubleshooting has been sufficient. (Circle the best answer.)				
Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
1	2	3	4	5
2. How would you rate your current understanding of CRRT management? (Circle the best answer.)				
Novice		Comfortable		Expert
1	2	3	4	5
3. How would you rate your CRRT troubleshooting skills? (Circle the best answer.)				
Novice		Comfortable		Expert
1	2	3	4	5

Appendix H

Post-intervention Survey: Advanced CRRT Training Course's Perceived Impact on Competency Questionnaire

Please indicate to what degree you agree with the following statements by circling the corresponding numbers

	Strongly Disagree	Disagree	Neither agree or disagree	Agree	Strongly agree
I feel that participating in the advanced CRRT training course improved my overall understanding of CRRT.	1	2	3	4	5
I have found the troubleshooting skills learned in the advanced training course to be valuable to my practice.	1	2	3	4	5
My overall understanding of CRRT and management of CRRT patients is improved as a result of my participation in the advanced CRRT training course.	1	2	3	4	5

Please feel free to provide any further feedback on the Advanced CRRT Training Course here:

Participant Responses:

- “I believe this class should be offered once or twice a year to CVICU nurses. This was an extremely helpful class.”
- “I would have preferred to have the course in person for hands on practice. It took a while after the course before I took care of a CRRT patient again, and I felt my skills were still not quite there. I’d like to take the advanced course again as a refresher. I think the advanced course should be required training after a year of nursing practice.
- “I enjoyed the course. It was well taught, and the instructor helped me to make sense of CRRT.”
- “I felt that the CRRT course was incredibly beneficial! The only thing I would suggest for improvement, based on my own personal learning style, is a small takeaway sheet of the highlights so I can jog my memory as needed until the information sticks permanently. Great job overall! Very helpful, especially in this unit.”

Appendix I

Vendor's CRRT Course Evaluation

CRRT machine type	<input type="checkbox"/> PrismaFlex	<input type="checkbox"/> PrisMax
--------------------------	--	---

Baxter Course Trainer Name	Carey Ann Johnson
-----------------------------------	--------------------------

Training Course			
<input type="checkbox"/> Comprehensive	<input type="checkbox"/> Trainer	<input type="checkbox"/> Troubleshooting	<input type="checkbox"/> TPE

Facility:	Date
Facility Address:	Participant Name: <i>Optional</i>

Please rate each question	Strongly agree	Agree	Undecided	Disagree	N/A
The trainer was prepared and organized					
The trainer presented the material in an appropriate and understandable manner					
The course training presentations and materials enhanced my understanding.					
The hands on set up enhanced my knowledge of the CRRT					
The trainer was knowledgeable about the equipment.					

We want your feedback!

- What would you add or change to enhance your CRRT Training Experience?**

Thank you!! Your comments and feedback will help us to continue to deliver educational programs that meet your needs.