



4-17-2018

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Brittany Stoltman

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Continuous Renal Replacement Therapy: Educating Nurses for Prevention of Complications

by

Brittany Stoltman

Bachelor of Science in Nursing, University of North Dakota, 2008

College of Nursing and Professional Disciplines

N997- Independent Study

Submitted to the Graduate Faculty of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota

April 29, 2018

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PERMISSION

Title Continuous Renal Replacement Therapy: Complications and Prevention

Department Nursing

Degree Master of Science

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Abstract

Acute kidney injury is a common complication of critically ill patients and the incidence is climbing (Akhoundi et al., 2015). Continuous Renal Replacement Therapy (CRRT) is ordered 70% of the time for acute kidney injury patients (Przybyl et al., 2017). With the high incidence of the use of CRRT therapy, this literature review was performed as the basis for training of CRRT nurses. Nurses play a vital role in the management and maintenance of this high-risk treatment. Nurses need to understand the prevalence of complications and have competence to prevent them. The literature review revealed a lack of standardization of training of nurses caring for CRRT patients, which effects the delivery of safe, quality care. Without standardization, the variability of therapy management, patient monitoring, clinician training, and quality monitoring contribute to the risk of complications and adverse outcomes (Schell-Chaple, 2017). Complications and adverse events associated with CRRT management and mismanagement are common and potentially life threatening (Windt, 2016). It was found that 35%-40% of adverse events are due to human error (Bray et al., 2013; Rewa, Mottes, & Bagshaw, 2015; Roeder, Atkins, Ryan, & Harm, 2013).

Data bases searched for evidence for this review included PubMed and CINAHL, utilizing MESH terms and filters. The search criteria were evidenced-based journals/texts, English, and dates of publications within 5-10 years. The literature reviewed included training of CRRT nurses and complications related to CRRT. Forty-five articles were critically analyzed and 30 retained as evidence for the purpose of the project.

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Continuous Renal Replacement Therapy

Introduction

Continuous Renal Replacement Therapy (CRRT) is utilized in intensive care units for patients with acute kidney injury caused by numerous reasons, including, but not limited to acidosis, electrolyte imbalances, fluid overload, and sepsis (Richardson & Whatmore, 2014). The incidence of acute kidney injury is increasing and often corresponds with an aging population that has multi-morbidity and high illness acuity (Akhoundi et al., 2015). Continuous renal therapy is used instead of traditional hemodialysis for hemodynamically unstable patients, because of the risk of systemic hypotension (Richardson & Whatmore, 2014). There are various dialysis modes in CRRT related to ultrafiltration, diffusion, and convection, which may be used individually or combined in different modes (Tolwani, 2012). The blood flow rates, modes of therapy, and anticoagulation type are decided by the nephrologist or the intensivist. Although the physician places the order, the ICU nurses' role in the care of the patient and management of CRRT is important, as they are the professional who starts, monitors, assesses, and discontinues the therapy (Richardson & Whatmore, 2014).

Care of critically ill patients with acute/chronic renal failure, who require CRRT, can be challenging at times for nurses. Complications may arise with this therapy including: (a) air embolus or thrombosis, (b) electrolyte imbalances (c) fluid imbalances, (d) hypotension, (e) hypothermia, (f) and anticoagulation. It may be difficult to differentiate mortality due to adverse events and those due to comorbid conditions or the illness they presented with (Akhoundi et al., 2015). With a 70% incidence of using CRRT for acute kidney injury patients, it is important for nurses to detect and address the complications or adverse events that may occur during treatment (Przybyl, Evans, Haley, Bisek, & Beck, 2017).

Nurses that are charged with the role of caring for the patient experiencing CRRT require comprehensive training that focuses on the concept of renal failure. Evidence based resources and

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standardized education are necessary for nurses to provide safe care to gravely ill patients requiring CRRT. It is essential for the nursing staff to be very proficient when using the therapy while caring for a very critically ill patient. Education is a key essential of the CRRT therapy and safe care of the patient. This project sought to identify current evidence to be utilized in an educational event for RNs who are caring for patients experiencing CRRT, with the goal to enhance safety and promote positive patient outcomes.

Purpose

The nurse plays a crucial role in preventing, reducing, and detecting complications during therapy. With an increased use of CRRT for acute renal failure and the aging populations with multi-morbidity and high illness acuity, it is imperative the nurses caring for these patients are afforded evidenced-based education prior to caring for these patients. The purpose of this project was to develop a standardized, evidenced-based educational plan for RNs who will be responsible to care for patients receiving CRRT to increase patient safety and promote positive patient outcomes.

The evidence for the content emerged from an extensive literature search on complications that are potentially encountered when caring for a patient with CRRT and methods to prevent or mitigate them. Every patient on CRRT is at risk for these complications (Przybyl et al., 2017). Some of the complications are not always preventable; however, it is imperative the nurse has the competence to recognize the complications and reduce the negative effects.

Details related to complications and evidenced-based interventions necessary for nurses to safely care for patients receiving CRRT were identified from the literature for placement in the educational plan. The educational plan was developed using the Quality and Safety Education for Nurses (QSEN) and its six essential competencies as the framework (see conceptual framework for more details).

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Significance

Healthcare and technology are always improving and advancing, so initial certification or training does not deem one competent for a lifetime. There is a lack of standardization in the education and training of nurses who perform CRRT, which is a high risk/low-volume therapy (Windt, 2016). Training courses for nurses who provide this therapy range from 4 hours to 12 hours, which is a wide variation for this complex therapy (Przybyl et al., 2017). Minimal research has been done on education practices of nurses performing CRRT, continuing education, and relationship to adverse events and complications (Przybyl et al., 2017). There is minimal literature that discussed maintenance of nursing competency of CRRT once the initial training was completed, such as measuring knowledge, skills, and attitudes of those nurses upholding this therapy (Przybyl, Androwich, & Evans, 2015). One-time training for this therapy would not be adequate for upholding safe, competent care (Przybyl et al., 2015). Without standardization, the variability of therapy management, patient monitoring, clinician training, and quality monitoring contribute to the risk of complications and adverse outcomes (Schell-Chaple, 2017).

Patient safety is an important factor in the delivery of high-quality healthcare; however, the lack of standardization on educating nurses who perform this high-risk CRRT negatively influences prevention of avoidable complications (Schell-Chaple, 2017). The hospitals that utilize this therapy create their own educational training or the company that provides the equipment offers training; however, after the initial certification, there is often no programs designated to maintain competency or provide continuing education (Przybyl et al., 2015).

Continuous renal replacement therapy is utilized 70% of the time for the treatment of acute kidney injury in the intensive care units (Przybyl et al., 2017). Nursing staff who do not implement this therapy on a regular basis may not have the competency required to provide safe, quality patient care (Windt, 2016). Complications and adverse events associated with CRRT are common and potentially life

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threatening (Windt, 2016). The most common adverse event was electrolyte imbalances, which was indicated in 97% of patients, including ionized hypocalcemia, ionized hypercalcemia, and hyperphosphatemia (Akhoundi et al., 2015). In addition to electrolyte imbalances patients endured at least 1 other adverse event including: hypotension on initiation (43%), hypothermia (44%), arrhythmias (29%), new onset anemia (31%), and thrombocytopenia (40%) (Akhoundi et al., 2015, p 333). These complications and adverse events may not always be preventable due to the high risk of this therapy; however, competency assessment and maintenance of nurses implementing CRRT will help decrease the risk for these adverse events (Przybyl et al., 2017). The variability in education of nurses, standardization of practice, and training of clinicians along with the high-risk nature of CRRT related to adverse events has given researchers a new motivation to identify quality indicators and best-practice recommendations for CRRT programs (Schell-Chaple, 2017).

An evidenced-based, standardized educational plan and maintenance of competency would greatly benefit nurses who must provide this complex therapy. This standardized educational plan and maintenance of competency was shown to be effective in the increasing nurse satisfaction, understanding of CRRT principles, and critical thinking skills with the operation of CRRT (Przybyl et al., 2015). The literature review found details related to complications and evidenced-based interventions necessary to safely care for patients receiving CRRT. The evidence from the literature review was used to create an educational plan that included detailed information of adverse events that can occur with CRRT, as well as evidenced-based interventions and prevention methods required to provide safe patient care.

Theoretical Framework

The conceptual framework used for the proposed educational plan created from the evidence identified in this project was based on the Quality and Safety Education for Nursing and its six essential competencies. Quality and Safety Education in Nursing competencies address the challenge of

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preparing nurses with the knowledge, skills, and attitudes necessary to continuously improve the quality and safety of healthcare systems (Dolansky & Moore, 2013).

The driving force for quality and safety began in 1999 by the Institute of Medicine (IOM), when it was estimated that up to 98,000 deaths each year were caused by medical error. In 2016 this number was estimated to be 251,000, which made medical errors the third leading cause of death (Makary & Daniel, 2016). With these astonishing numbers, the IOM led the way by focusing attention to the issues in healthcare quality and safety including, regulatory changes, new roles and responsibilities for healthcare professionals, and calls for new educational paradigm (Sherwood & Barnsteiner, 2017).

Nurses constitute the largest division of the healthcare workforce, and the skills and knowledge they possess can directly affect quality, safety, and efficiency (Sherwood & Barnsteiner, 2017). The QSEN project was developed to change the approach to a practice based on inquiry. These inquiries question the focus on how to continuously improve care, develop and use evidence-based standards and interventions, investigate outcomes and critical incidents from a system perspective, and work intra- and interprofessional teams (Sherwood & Barnsteiner, 2017). For this reason, QSEN developed the six essential competencies for healthcare professionals to improve healthcare, which include patient-centered care, teamwork and collaboration, evidence-based practice, quality improvement, safety, and informatics. Each of these competencies will be defined throughout this section.

Patient-centered Care

Relationships between the nurse and patient have always revolved around care; however, the relationship has changed over the years. Instead of the healthcare professional making the decision, the patient and family are in a full partnership with their healthcare team. Patient-centered care shows the increasing recognition that the person receiving care needs to be a partner with their providers to increase effectiveness and quality of their care.

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Important principles of patient-centered care that are related to the development of staff include effective treatment delivered by staff you can trust, respect for patient preferences and involvement of patients in making decisions, reliable healthcare advice, comprehensive information and support for self-care, physical comfort and safe environment, empathy and emotional support, family involvement, and continuity of care and smooth transitions (Sherwood & Barnsteiner, 2017). These principles become ever so important when caring for a critically ill patient and concerned family members. Confident, safe, and empathetic care is especially crucial during the critical phase of treatment.

Teamwork and Collaboration

Teamwork and collaboration is the second essential principle. Collaboration and teamwork of the healthcare team is vital to decrease the threat to patient safety and quality care due to the increasing complexity of healthcare and heightened roles of nurses (Sherwood & Barnsteiner, 2017, p. 103). With this growing complexity of tasks, an individual's cognitive ability may be consumed, so a team approach is necessary.

Another aspect of teamwork and collaboration and the growing complexity of tasks is communication. Hughes (2008) discovered that ineffective communication and breakdowns in working together caused 66% of healthcare errors. Many of the errors occur during transition points in care and handoff from one nurse to the next (Hughes, 2008). Teamwork and collaboration are essential for coordinating complex care involving several healthcare disciplines (Sherwood & Zomorodi, 2014, p. 17). Knowing the roles and responsibilities of other team members can help nurses direct the complicated network of communication and hierarchy that is so widespread in healthcare (Sherwood & Zomorodi, 2014). Nurses need to speak up when care is compromised and know the available resources to continue safe care (Sherwood & Zomorodi, 2014).

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Quality of Care

Nurses play a vital role in improving quality of care in all settings. The third essential competency is quality of care. Nurses need to be able to use data to measure quality of care and implement the improvement process based on this data (Sherwood & Barnsteiner, 2017). Nurses need to possess a quality of inquiry that will promote an attitude of continuously improving care every day (Sherwood & Zomorodi, 2014). Quality improvement starts with the difference between ideal and actual care and then provides ways to minimize these differences.

Quality improvement processes can be used to track adverse events and potential safety threats (Preheim, Armstrong, & Barton, 2009). These processes help staff make the connection between the differences of ideal and actual care and look for evidenced-based solutions to provide safe, quality care. “Nurses can change the landscape of quality and significantly reduce injury and death due to harm caused by errors.” (Sherwood & Barnsteiner, 2017, p. 125). Utilizing the literature search for forming this staff-based education to reduce adverse events and complications of CRRT is a way of incorporating this essential competency of quality of care.

Evidenced-Based Practice

Evidenced-based practice (EBP) is the fourth essential competency. EBP is defined “as the best available evidence that also incorporates patient values and preferences and clinician judgement and expertise” (Sherwood & Barnsteiner, 2017, p. 131). Part of improving quality of care is having the best possible evidence to support the care we are providing.

Continuous Renal Replacement Therapy may be the most common renal support in Intensive Care Units: however, there has been a gap in evidence-based practice guidelines (Schell-Chaple, 2016). These gaps were recently discovered due to a wide variety of monitoring and management during CRRT that has put patients at a high risk for serious adverse events (Schell-Chaple, 2016). These potentially

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negative outcomes have pushed the envelope for identification of evidenced-based quality indicators for the creation of successful CRRT programs for nurses that provide CRRT.

Safety

The fifth essential competency is safety. Nurses need to possess the necessary knowledge, skills, and attitudes about safety science and how it improves the quality of care for patients, and the weak areas of a system and how to address them (Sherwood & Barnsteiner, 2017). The goal of safety is to minimize the risk of harm to patients and providers throughout both system effectiveness and individual performance (Cronenwett et al., 2007). With multiple areas of potential threat to patient safety and errors that can occur in healthcare, it is imperative to be aware of these areas in all interfaces of healthcare delivery. Creating a culture of safety begins with how to learn about safety in education and the practice environment.

A safe, effective delivery of patient care requires an understanding of the complex healthcare system, the limits of human factors, safety design principles, characteristics of high reliability organizations, and patient safety sources (Sherwood & Barnsteiner, 2017, p. 167). Research in CRRT has shown a relationship between education of nurses and adverse effects, so it will be imperative to implement a more standardized educational training for those who administer CRRT.

Informatics

Informatics is the sixth competency and is the collaboration of all of the competencies. The American Nurses Association defines the specialty of nursing informatics as, “the facilitation of the integrations of data, information, knowledge, and wisdom to support patients, nurses, and other providers in decision making” (American Nurses Association, 2008). Fast advancing technology can cause a problem in keeping up with informatics and safe use of technology. Compiling all six competencies together can assist in the fast-changing complexities of the healthcare field.

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Windt (2016) wrote since healthcare is always advancing and technology is always improving, initial licensure at one point in time does not deem one competent for a lifetime career. How can we provide initial licensure, maintain competency, and evaluate those competencies to keep up with the ever-changing healthcare and technology? Using a wide variety of didactic lessons, bedside orientation, simulation, and refresher courses with adequate evaluations are necessary to keep up certifications and licensures (Przybyl et al., 2017). It is the responsibility of every nurse to be competent and provide safe care in this increasingly technological environment.

Quality and Safety Education in Nursing's six competencies for all healthcare professionals will enable them to lead and work in systems that focus on the safety and quality of patient outcomes (Sherwood & Barnsteiner, 2017). These competencies provide an excellent framework for the staff based educational plan for CRRT. Patient care management requires nurses to balance competing patient priorities and manage complex processes (Sherwood & Barnsteiner, 2017). Nurses have a responsibility to address problems that threaten patient safety or when care falls short of evidenced-based standards.

Definitions

Continuous Renal Replacement Therapy or CRRT is a continuous, 24-hour mode of dialysis. This therapy is reserved for patients who are hemodynamically unstable and unable to undergo traditional intermittent hemodialysis (Tolwani, 2012). Continuous Renal Replacement Therapy allows for slower solute clearance and fluid removal in a unit of time, which is better tolerated for hemodynamic instability (Tolwani, 2012).

Throughout this paper the use of circuit and filter are used interchangeably. Filter or circuit is referring to the fibrinous, porous membrane that allows for transport of solutes and removes metabolic wastes and excess fluid, which is attempting to mimic the native kidney (Thompson, Li, & Gross, 2017).

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Adverse events and complications are also interchangeable throughout the paper. These terms refer to the negative events that can occur during therapy and deem this therapy high-risk (Schell-Chaple, 2017).

Process

I performed a literature search of evidence that included the prevalence of complications, types of complications, and prevention of these complications. Data bases searched for evidence included PubMed and CINAHL, utilizing MESH terms and filters. The search criteria were evidenced-based journals/texts, English, and dates of publications within 5-10 years. I searched the literature for each complication individually in relationship to CRRT. Specific complications of interest for this project included: (a) air embolus; (b) electrolyte imbalances; (c) fluid imbalance; (d) hypotension; (e) hypothermia; and (f) anticoagulation.

During this literature search, I also searched for nurses training and management of patients on CRRT. For this portion of the literature search, I included PubMed and CINAHL databases, with the use of MESH terms and filters. The search criteria for nurse training for managing patients with CRRT included evidenced-based journals/texts, English, and dates of publications within 5 years.

The outcome of this literature search allowed me to synthesize results of educational training and complications related to CRRT to develop staff-based education on the types of complications of CRRT and how to prevent these complications. These searches found articles that were specifically related to CRRT as follows: (a) five articles on nurses training; (b) three articles on air embolus; (c) five on electrolyte imbalance; (d) five on fluid imbalance; (e) four on hypotension; (f) one on hypothermia; (g) and seven on anticoagulation. The theoretical framework for this project utilizes the QSEN competency of safety and quality for patient outcomes. The staff education that was developed based on the evidence included the knowledge, skills, and abilities/attitudes related to CRRT therapy, including the complications and prevention of those complications.

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Review of Literature

The first part of the literature review is organized to present the evidence related to effective continuing education strategies for nurses caring for critically ill patients and those who are being treated with CRRT. The remaining sub-sections reviews evidence associated to risks of complications of CRRT, effective prevention, and interventions when complications occur.

Continued Education/Training For Competence Development and Maintenance

As many as 35%-40% of the adverse events and complications of CRRT were related to how the patients were managed by nurses and other staff (Bray et al., 2013; Rewa et al., 2015; Roeder, Atkins, Ryan, & Harm, 2013). Continuous Renal Replacement Therapy training for nurses is not widely researched and no set guidelines were found in relationship to how facilities provide training, evaluate training, or maintain nurse competency for this therapy (Schell-Chaple, 2017). Educational training for managing patients experiencing CRRT ranged from 4-12 hour courses with a wide range of methods of training (Przybyl et al., 2017). The focus of educational training sessions was mainly based on the equipment and equipment failures; however, competency of patient care and safety must also be addressed (Windt, 2016). Multiple studies recommend utilizing several methods of training for initial training and maintenance of competency. For instance, didactic theory, simulation, online learning modules, and utilizing specialized CRRT teams were suggested methods (Przybyl et al., 2015; Przybyl et al., 2017; Windt, 2016). By establishing standardized training for nurses caring for patients undergoing CRRT could help decrease the number of adverse events. The standardized training should include equipment and equipment malfunctions, patient care before, during, and after therapy, complication prevention, and facility specific protocols.

“The American Association of Colleges of Nursing (2013) and the National League for Nursing (NLN) (2003) have both released guidelines indicating that educators are responsible for developing educational experiences that foster critical thinking, reflection, and development of hands-on skills to

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use in clinical practice (Przybyl et al., 2015, p 138).” For this education, the theory that best fit the staff education was Novice to Expert. The basis of this theory is that nursing expertise develops over time (Billings & Halstead, 2016). Continuous Renal Replacement Therapy is an extensive therapy, which requires continuous patient assessments, maintenance of intravenous medications, calculation of fluid, acid, base balances, monitoring of frequent lab draws, and prevention of complications, and as such a novice to expert-based staff education would assist the nurse in developing the skills and knowledge pivotal to patient safety and positive patient outcomes.

The remainder of the literature review examines evidence related to complications most prevalent in the review and potential solutions to these complications. This information will be used to create evidenced-based staff education related to CRRT and the prevention of potential complications.

Air Embolus

An air embolus is a rare and preventable complication that can have serious consequences (Brull & Prielipp, 2017; Sahutoglu et al., 2017). The true incidence of air embolus is unknown as many are undiagnosed or unreported (McCarthy, Behraves, Naidu, & Oklu, 2016). Studies reviewed indicated the prevalence of air embolus was less than 1 % (Brull & Prielipp, 2017; McCarthy et al., 2016; Sahutoglu et al., 2017). Brull & Prielipp (2017) completed a retrospective study that reviewed Manufacturer and User Facility Device Experiences reports of “air embolus” from 2011-2016. This database search found 700 reports of air embolism from 2011-2016. Of these incidences 95 events (14%) resulted in death, 416 (59%) patient injury, and 167 (24%) resulted from device malfunction (Brull & Prielipp, 2017, p 258). McCarthy et al. (2016) found an incidence of 1 in 772 in a study of 11,000 central venous catheter placements during the review of cases.

McCarthy et al. (2016) reviewed the precautions and techniques to prevent this complication from occurring and how to treat an air embolus. Air embolus occurs when there is a connection between the air and the vascular system. For instance, vascular, heart, and lung surgeries open the

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vascular system and create a connection with the air. Additionally, trauma and intravenous accesses such as, central lines, peripheral intravenous lines, and hemodialysis lines expose vessels and create the connection to the air (McCarthy et al., 2016). After studying the effect of air entering vascular systems of animals, Brull & Prielipp (2017) concluded that it would only take 1.4 milliliters of air to enter the vascular system and affect the coronary circulation to cause a fatality.

To lower the risk for air embolus, the line connections need to be properly maintained during line placement and vascular procedures (McCarthy et al. 2016). Physicians and nurses should be well equipped to prevent, identify, and manage air embolism due to the high risk of mortality with an air embolus (McCarthy et al., 2016). A common error found was from misdiagnosis of air embolism as thrombosis, which would also would make the treatment ineffective for mitigating the damage of an air embolus (McCarthy et al., 2016). The early recognition of an air embolus has been reported as crucial to the patient survival and level of injury. Signs and symptoms include dyspnea, cough, tachypnea, hypoxia, hemodynamic alterations, and altered mental status (Sahutoglu et al., 2017). When symptoms are identified quick actions of placing patient in a left lateral recumbent position in Trendelenburg to assist in dislodging the embolus by gravity (Sahutoglu et al., 2017). Sahutoglu et al. (2017) stated that no randomized control trials have been completed on the treatment of air embolus due to the low level of incidence and misdiagnosis of the air embolus (p. 31).

Continuous Renal Replacement Therapy machines have air detectors built into their systems to detect even the smallest of air bubbles. Reviews reported that the risk of air embolus is present during the machine priming, returning of patient blood, loose connections, and accessing hemodialysis line (Amlani, 2012; Finkel & Podell, 2009; Gambro, 2016). The nurse caring for a patient and maintaining this therapy needs to use assessment skills to check the equipment for air bubbles prior to connecting or returning blood to the patient (Amlani, 2012; Baldwin & Fealy, 2009; Dirkes & Hodge, 2007; Richardson & Whitmore, 2012). As stated previously, no studies were found to have a direct connection between

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air embolus and continuous renal replacement therapy. The articles found reported this as a potential complication and discussed potential prevention methods.

Electrolyte Imbalances

Electrolyte imbalances are the most common complication related to CRRT therapy (Fall & Szerlip, 2010; Jung et al., 2016; Schell & Chaple, 2017). Jung et al. (2016) conducted a post-hoc analysis of data from a prospective randomized control trial. In this analysis 210 patients were observed and 67% were reported to have at least one electrolyte or mineral abnormality (Jung et al., 2016). Bellomo et al. (2013) completed a prospective, randomized trial of 115 patients undergoing CRRT. They found the incidence of each specific electrolyte and specific fluid imbalances were difficult to report due to variability in each patient and the length of time completing the study (Bellomo et al., 2013). According to research studies, electrolyte abnormalities occur in >50 % of the cases and the most common electrolyte abnormalities are hyponatremia, hypokalemia, hypocalcemia, and hypophosphatemia (Bellomo et al., 2013; Fall & Szerlip, 2010; Jung et al., 2016; Schell & Chaple, 2017). Of the four previously mentioned studies only 2 of them were prospective randomized control trials, however, there was a strong agreement among all of the researchers' conclusions.

Patients' requiring CRRT are already fighting fluid and electrolyte complications related to their acute kidney injury; however, these complications do not resolve once CRRT is initiated. In CRRT electrolytes can be removed in a non-selective way, which could exacerbate complications if electrolyte levels are not monitored (Richardson & Whatmore, 2014). Electrolytes, water, and molecules get filtered across the semi-permeable membrane during CRRT by diffusion, convection, ultrafiltration, and adsorption (Amlani, 2012; Jung et al., 2016).

Nurses caring for patients receiving CRRT therapy need to be diligent on monitoring laboratory values and following replacement protocols set forth by the physician. One study indicated the problem with electrolyte disturbances and management of patients with CRRT was human error. Bray et al.

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(2013) completed a retrospective case review study that included patients being treated with CRRT between 2008 and 2011. Of the 5923 patients treated with CRRT, 1551 died. This study examined human error as being a contributing factor to mortality. This study found that 32% of the 1551 patients who died, expired from cardiovascular complications, 2.1% of those deaths were caused from hyperkalemia (Bray et al, 2013). Due to the significance of the complications related to electrolytes and relationship to mortality, a peer review and root cause analysis of 22 deaths between 2008 and 2009 were studied. Of these deaths studied, five main factors that contributed to patient mortality were discovered. The inability to recognize electrolyte imbalances and lacking knowledge for appropriate management of those imbalances were two factors that affected mortality (Bray et al., 2013). Another factor was the staff who were not empowered to challenge physician assessment (Bray et al., 2013). The final two factors included poor communication of urgent treatment decisions and how quickly those urgent treatments were carried out (Bray et al., 2013). Errors frequently reported in the studies included delayed lab draws, abnormal results were not reviewed and addressed in a timely manner, and incorrect dialysate fluid based on lab values infused (Bray et al., 2013). Two systematic review articles reviewed included findings from CRRT studies on standardization in practice. Summaries of best practice in the delivery and application of therapy were also interpreted (Connor & Karakala, 2017; Schell-Chaple, 2017). Conclusions also advised that diligent monitoring, reviewing, and replacing electrolytes can significantly reduce electrolyte imbalances and complications during CRRT (Connor & Karakala, 2017; Schell-Chaple, 2017).

Another cause of electrolyte imbalance is related to the anticoagulant citrate, which causes hypocalcemia. Citrate chelates to ionized calcium in the blood and inhibits the clotting cascade and the chelated citrate and calcium are removed by the filter (Dirkes & Wonnacott, 2016; Fall & Szerlip, 2010). Continuous renal replacement programs have implemented citrate protocols to follow for calcium replacement and machine adjustments (Stucker et al., 2015). Complications related to electrolyte

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disturbances may include altered mental status, seizures, hypotension, arrhythmia, and cardiac death.

Nurses need to be meticulous about monitoring for and preventing these complications, i.e. drawing labs and replacing the electrolyte deficit per protocol (Bray et al., 2013; Fall & Szerlip, 2010; Jung et al., 2016; Schell & Chapple, 2017; Uchino, Bellomo, & Ronco, 2001).

Fluid Imbalance

Fluid overload or positive fluid balance is another complication that is addressed in CRRT. In critically ill patients, fluid is infused in large amounts to optimize hemodynamics (Han, Park, Shin, & Kim, 2016). The goal is to obtain optimal fluid status for optimal hemodynamic stability, which often causes fluid accumulation and tissue edema (Han et al., 2016). Fluid accumulation is especially detrimental to patients with acute kidney injury, who are often oliguric or anuric, and are unable to excrete the fluid given (Bouchard & Mehta, 2009; Davies, Leslie, & Morgan, 2017). Fluid overload is defined as an increase in body weight greater than 10% from baseline (Kim et al., 2017; Bagshaw et al., 2017). Kim et al. (2017) completed a retrospective study on 341 patients who received CRRT from January 2007 to December 2013. The patients were assessed for association of total fluid overload with survival (Kim et al., 2017). Kim et al., (2017) concluded that mortality rate increased with percentage of fluid overload >10%, which was 66.9% versus 45.6% with <10% fluid overload.

Davies et al. (2017) did a retrospective chart review of daily fluid balances of 46 CRRT patients. Of the 46 patients receiving CRRT, 26% did not achieve fluid removal targets for the day and 59% required extra fluid within the first 2 consecutive days (Davies et al, 2017). On the last treatment 37% of patients still had a positive fluid balance (Davies et al, 2017). Continuous renal replacement therapy is initiated to change fluid balance from positive to negative. In other words, fluid is removed from the body and the body weight decreases. The other articles referenced were not randomized control or retrospective studies. Nevertheless, the authors from these reviews of assessment and management of volume status in CRRT patients strongly concluded fluid overload and management presented a

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challenge to care for these critical patients (Bouchard & Mehta, 2009; Davies et al., 2017; Han et al., 2016).

Hypotension

Hypotension is often a complication of critical illness. However, CRRT frequently exacerbates hypotensive episodes, especially during initiation. The body's volume status is depleted by 100-250 mL of blood during initiation as it begins to circulate through the filter, which is dependent on filter size used by the hospital facility (Dirkes & Wonnacott, 2016; Oh et al., 2012; Richardson & Whatmore, 2014). Brand of filter and filter size are dependent on the CRRT vendor in which each hospital uses. In a single center study of 57 patients examined intradialytic hypotension (defined as a drop in systolic blood pressure by greater than 20 points), and found 30% of CRRT initiations were complicated by hypotension (Sharma & Waikar, 2017). In a prospective cohort study, Silversides et al. (2014) found that of 492 CRRT patients in the study 428 of them experienced hypotension on one or more occasions (p. 3).

Acute kidney injury is a common complication of intensive care unit admissions and often requires the use of CRRT (Sharma & Waikar, 2017). Sharma & Waikar (2017) completed a multi-national AKI-EPI study of 1802 critically ill patients admitted to the intensive care units, where 243 of them developed acute kidney injury within one week of admission and 60% of them required CRRT (p. 553). Oh et al. (2012) completed a retrospective study that included 108 patients who had acute kidney injury and hypotension and were treated with CRRT. This study correlated acute kidney injury with the treatment of CRRT and its relationship to hypotension and mortality. Out of 67 patients, 18 (27%) survived 90 days after CRRT initiation. However, the patients in this study, also had one or more additional etiologies related to their acute kidney injury, which could not be ruled out as causes of mortality (Oh et al., 2012). The other comorbid conditions included: cardiovascular shock (30%), septic

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shock (55%), and hypovolemic shock (15%) that made the outcome inconclusive of specifically hypotensive related mortality (Oh et al., 2012, p. 215).

Hypotension after therapy has started is most likely related to acidosis, so frequent laboratory monitoring will assist in prevention and early intervention of hypotension (Bellomo et al, 2013). Patients with acute kidney injury often experience metabolic acidosis and this can be an independent predictor of unfavorable outcomes in this population (Bellomo et al., 2013). Acidosis causes a decrease in mean arterial pressure, which is the difference between systolic and diastolic blood pressure. This population of patients is already at risk for further hypotension related to their acidosis. The exact mechanism of the metabolic acidosis in acute kidney injury are complex and this excess of retained metabolic acids along with acid-base disorders of critical illness are contributing factors and require different levels of intervention (Bellomo et al., 2013, p. 430). Bellomo et al. (2013) completed a multicenter, prospective, randomized study during the first 24 hours after initiating therapy that included 1508 patients from 35 intensive care units. During this study arterial blood pH, plasma lactate, PaCO₂, potassium, magnesium, sodium, ionized calcium, phosphate, albumin, creatinine, urea levels, mean arterial pressure, and dose of vasopressor was recorded every 2 hours for 24 hours (p. 430). Bellomo et al. (2013) found that early correction of acidosis and electrolyte imbalances increased the blood pressure and decreased the vasopressor requirements within the first 24 hours (p. 433). Monitoring of labs can facilitate early correction of acidosis and other electrolytes. The body goes under physiologic stress upon initiation of CRRT therapy in attempt to maintain plasma volume, systemic blood pressure, and cardiac output all under critical illness (Sharma & Waikar, 2017). The treatment and prophylactic strategies to prevent hypotension during CRRT have not been comprehensively tested and future research is needed (Sharma & Waikar, 2017).

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Hypothermia

All CRRT patients are at risk for developing hypothermia, as each patient has blood exposed to cooler outside air (Kaur, Banoth, Yerram, & Misra, 2017; Schell-Chaple, 2017). Hypothermia is commonly defined as a body temperature of 36 degrees Celsius or less (Sequeira, Mohamed, Hakimi, Wakefield, & Fine, 2017). Hypothermia is common among the critically ill and is associated with mortality (Sequeira et al., 2017). As stated above, the filter for CRRT holds 110-200 mL of blood to circulate the machine (Oh et al., 2012; Richardson & Whatmore, 2014). The circulating blood is outside the body, which contributes to hypothermia, and the decrease in body temperature is potentiated by removal of the large amount of fluid in a short time. Hypothermia can be detrimental to the already critically ill state of these patients. For example, hypothermia can advance cardiac instability, acute renal failure, and electrolyte imbalances (Sequeira et al., 2017). Hypothermia also results in increased metabolic demand related to shivering, altered coagulation, and altered immune function, which increase the risk of CRRT related adverse events (Schell-Chaple, 2017, p. 34).

Hypothermia prevention is essential because patient outcomes are adversely affected if proper temperature is not maintained (Schell-Chaple, 2017). These articles contributed evidence through expert opinion articles, but the literature review did not find significant research related to hypothermia in relationship to CRRT. However, the experts promoted multiple methods to maintain body temperature in a hypothermic state and included: increasing room temperature, fluid warmers, blanket warmers or warm blanket, and frequent monitoring of temperature or utilizing continuous core temperature devices (Dirkes & Hodge, 2007; Richardson & Whatmore, 2014; Schell-Chaple, 2017).

Kaur et al. (2017) began to explore the role of hypothermia and acute kidney injury through a case report specifically related to hypothermia during CRRT. This case report centered on a 64-year-old man with acute kidney injury and started on CRRT 36 hours after arrival to the intensive care unit (Kaur et al., 2017). This patient had critical hypothermia that was recognized early by close monitoring of

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temperature (Kaur et al., 2017). The case study led the authors to expand the examination of additional aspects of hypothermia and hypothermia management related to CRRT (Kaur et al., 2017). A prospective randomized trial was done on 60 circuits of CRRT and included 35 patients that compared the incidence of hypothermia in patients with or without a warming device used (Kaur et al., 2017). The results did not show significant changes in body temperature; however, there were better mean arterial pressures and decreased vasopressor use with those patients that had a warming device used (Kaur et al., 2017). The researchers in this study also recommended room temperature should be between 22.8-24.8 degrees Celsius to assist in preventing hypotension related to therapy (Kaur et al., 2017). Kaur et al. (2017) proposed recommendations to lower the risk of hypothermia for patients that are on CRRT (p. 60). These recommendations included (a) Early recognition of risk factors and signs of hypothermia; (b) team approach in management of patient with CRRT; (c) hospital-based protocols in place before and during CRRT; (d) maintaining room temperature; (e) judicious use of sedatives and paralytics; (f) and individualized prescription of CRRT based on comorbidities (Kaur et al., 2017, p. 60).

Other expert opinion articles discussed other methods of maintaining normothermia while on CRRT. Warm blankets and blanket warmers were the most common methods presented as effective warming methods (Schell-Chaple, 2017; Sequeira et al., 2017). These methods aligned with Kaur et al. (2017) who found warming methods effectively increased temperature 1-2.5 degrees Celsius per hour.

Anticoagulation

Continuous renal replacement therapy requires pumping of the blood through a blood tubing circuit and filter. The complications that can arise during CRRT therapy come with this pumping of blood and the way blood reacts to this change (Dirkes & Wonnacott, 2016). These changes to blood environment, blood depletion, and pumping motion related to complications are explained as follows. The greatest barrier to downtime of the CRRT therapy was clotting. Downtime was caused by pausing therapy to change set or transfer to diagnostic tests (Roeder et al., 2013). When the blood comes in

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contact with tubing, the body treats it as a foreign substance and consequently can activate thrombus formation intrinsically and extrinsically, and thus makes the circuit prone to clotting (Dirkes & Wonnacott, 2016). Clot formation causes flow alarm problems that create complications for implementation and maintenance of the therapy. One of the complications related to clot formation is hypotension. When the CRRT machine alarms the blood flow slows or stops, which stops the return of blood back to the patient creating hypotension. When the circuit slows or stops there is increased risk for increased clot formation related to stagnant blood and potential for clotting that does not allow the blood to be returned to the patient (Thompson et al., 2017). Dirkes & Wonnacott (2016) presented methods for CRRT therapy, anticoagulation, efficacy, and implications for bedside care through expert opinion (p 34). These authors asserted that essential blood loss is the greatest threat to the patient. The blood loss during this critical state could cause significant complications, considering that between 100-250 milliliters of blood trapped in the filter and not able to be returned to the patient (Dirkes & Wonnacott, 2016). Changing the filter set frequently can also cause large changes in volume shifts that these critically ill patients do not tolerate. The blood loss during this critical state could cause significant complications (Dirkes & Wonnacott, 2016).

Continuous renal replacement machines have filter clotting alarms specific to detect clotting or clogging in the filter. When the filter clots or needs to be changed, the patient has potential risks for adverse events related to filter set change (Kee et al., 2015). When therapy is suspended due to clotting of filter and the need to change the set, this could lead to retention of fluid, inadequate net fluid removal as ordered by physician, azotemia, and electrolyte shifting (Kee et al., 2015).

The literature review provided mixed level of evidence for methods of use of anticoagulation as a means for maintain circuit disruption during CRRT. Two articles synthesized evidence for efficacy of anticoagulation and implications for nurses' knowledge of critical care during CRRT. Both group of experts, concluded the nurse's knowledge of the alarm troubleshooting and quick responses to the

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alarms are imperative to minimize circuit disruption and prolong circuit life, because frequent set changes are costly (Dirkes & Wonnacott, 2016; Thompson et al., 2017). The average filter/circuit has a life of 72 hours, which was indicated by manufacturer statement (Dirkes & Wonnacott, 2016). The manufacturer estimation of filter life differed from findings by Roeder et al. (2013). These researchers completed a literature review of three randomized control trials. That review showed the average length of filter life was between 16-21 hours (p 510). Stucker et al. (2015) completed a randomized control study on 103 patients receiving CRRT. Citrate was used on 54 subjects and 49 subjects were given heparin. The average length of a filter was found to be between 23-29 hours. The use of citrate resulted in the longest filter life (Stucker et al., 2015).

There are several options that exist for anticoagulation, but potential complications are associated with the addition of anticoagulation. Anticoagulant can be initiated through systemic and regional anticoagulation strategies (Thompson et al., 2017). Anticoagulation strategies vary among facilities. Unlike the findings of Stucker et al. (2015), two studies found that despite the risk of thrombocytopenia, heparin was the most common for systemic anticoagulation and citrate for regional anticoagulation (Ferreira & Johnson, 2015; Shum, Yan, & Chan, 2015).

Ferreira & Johnson (2015) completed a retrospective study of 49 patients who had significant drops in platelets while on heparin anticoagulation therapy. Thrombocytopenia occurred in as high as 70% of cases using heparin (Ferreira & Johnson, 2015). Fifty-one percent of the patients had a very significant drop in platelets and anticoagulation of filter was held or stopped. Anticoagulation was stopped in 14% of patients due to significant bleeding or prophylactically stopped in 22% of patients due to a dangerously fast drop in platelets.

Shum et al. (2015) completed a review of 5 randomized control trials on citrate use in CRRT and focused on studies published in the past decade from 2014. Heparin was the most common anticoagulant for CRRT, despite the risk for bleeding and thrombocytopenia (Shum et al., 2015, p. 149).

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Citrate was determined to be the safest and most effective anticoagulant for CRRT, when accompanied by a well-developed and practical protocol (Shum et al., 2015, p. 153)

Utilization of heparin or other anticoagulation in implementing CRRT may be inevitable to provide optimal therapy for the patient. However, the research emphasizes the need for nurse monitoring laboratory values and assessing patient, especially for bleeding (Ferreira & Johnson, 2015); Shum et al., 2015). Rapid recognition of risks allows for modification of the therapy to maintain safe patient care (Dirkes & Wonnacott, 2016; Shum et al., 2015; Stucker et al., 2015; Thompson et al., 2017).

Evidence from five articles, three of which were randomized control trials demonstrated electrolyte imbalances are the most common complication of CRRT and the other two articles were concluded by expert opinion and had strong agreement of conclusions (Bellomo et al., 2017; Fall & Szerlip, 2010; Jung et al., 2016; Schell & Chaple, 2017). One study indicated ineffective management of electrolyte imbalances were caused by human error and resulted in patient death (Bray et al., 2013). The literature also demonstrated anticoagulation had an effect on fluid and electrolyte imbalances and hypotension. Evidenced from three studies found disruption of therapy for set changes caused shifts in fluid and electrolytes resulting in hypotension (Kee et al., 2015; Shum et al., 2015; Stucker et al., 2015). Anticoagulation choice was also found to have an effect on electrolyte imbalance (Shum et al., 2015). Although, there was some evidence related to complication of hypothermia and air embolus, the conclusions were not strongly supported by research related to CRRT.

Discussion

Critical care nurses have a 24-hour responsibility in the care and management of patients receiving CRRT. Continuous renal replacement therapy is utilized 70% of the time for the treatment of acute kidney injury in the intensive care units and it is crucial for nurses to be properly educated (Przybyl et al., 2017). There is limited research on the training and education of nurses providing care to these patients. Complications and adverse events associated with CRRT management and mismanagement

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are common and potentially life threatening (Windt, 2016). Nursing staff who do not manage this therapy on a regular basis may not have the competency required to provide safe, quality patient care. Although, complications and adverse events may not always be preventable due to the high risk of this therapy, but nurse competency that has been assessed and maintained will decrease the risk for to patients (Przybyl et al, 2017).

Interpretation

Patient safety is an important factor in the delivery of high-quality healthcare. There is a lack of standardization for educating nurses who perform this high-risk therapy of CRRT. Inconsistent preparation does nothing to establish nurse competence for prevention of avoidable complications. Hospitals that utilize CRRT therapies are responsible in creating their own educational training. Often the equipment vendor provides the initial training. After initial training, there is often no additional educational programs offered for nurses to maintain competency or provide continuing education. Although the Acute Dialysis Quality Initiative XVII conference 2016 developed recommendations on best practices for CRRT to optimize safe and quality care through education and training, no standardizations were set forth (Schell-Chaple, 2017).

This literature review found inconsistencies on correlation of CRRT with certain complications, which is probably due to other comorbidity and etiology factors. Alarming, as many as 35%-40% of CRRT patients suffering adverse events, which were related to therapy management (Bray et al., 2013; Rewa et al., 2015; Roeder, Atkins, Ryan, & Harm, 2013). Standardized education and awareness of potential adverse events has the potential to decrease the risks of human error.

The nurse's role in caring for patients with CRRT is extensive. The role responsibilities include (a) set up and discontinuation of therapy; (b) administration of fluid; (c) adjustment of fluid per physician order; (d) monitoring of electrolytes and replacement of electrolytes per protocols; (e) anticoagulation management; and (f) hemodynamic monitoring, and intake and output (Przybyl et al.,

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2015). These tasks of CRRT are an addition to the other patient routine cares, which include repositioning, oral cares, medication administration, and assessments (Przybyl et al., 2015). Continuous assessments are critical for CRRT patients to provide safe care and avoid preventable adverse events.

To prepare intensive care nurses in the management and maintenance of CRRT therapy, the training should be more standardized in relationship to the care beyond mastering and maintaining the equipment. Education should include individualized patient management, critical thinking, and complications related to CRRT and prevention of those complications. The education for CRRT nurses to be trained should include comprehensive initial didactic training, basic set-up and trouble-shooting, frequent exposure to patients receiving CRRT, a refresher course, and ongoing competency evaluations (Przybyl et al., 2017). This can be accomplished by utilizing the QSEN six essential competencies as a framework in creating an educational plan that incorporates a broader conceptually based program for CRRT.

Continuous Renal Replacement Therapy needs to start with proper education to the patient and family members, so they can collaborate with the healthcare team to increase effectiveness and quality of their care. Every facility that has a CRRT program should have a patient educational tool, which explains the process in laymen terms, so patient-centered decisions can be made. As discussed previously, patients are more involved in their care and need to be informed of expectations of this therapy.

Teamwork and collaboration are important competencies for this therapy. The interdisciplinary team needs to have effective communication to decrease the threats to patient safety during this complex therapy. Nurses need to have a standardized hand-off to maintain accuracy and maintenance of therapy. Ineffective communication and breakdowns in working together accounted for 66% of healthcare errors, which included transition points and handoff from one nurse to the next (Hughes, 2008). Sherwood & Zamorodi (2014) discussed that nurses need to know their roles and responsibilities

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and direct the communication when the care of the patient is compromised. The nurses need to be empowered to speak up when the patient's safety is compromised. Clear communication with the physician and accurate documentation is important for the necessary changes in the prescribed therapy. Effective communication and documentation assists the physician in ordering the correct therapy, fluids, and electrolyte replacements. This effective communication is necessary for multiple disciplines. For instance, timed lab draws needs to be performed on time and the nurses must review the results in a timely manner for safe, effective management of the out of range labs. Ineffective communication and breakdown in collaboration was found to cause 66% of healthcare errors (Hughes, 2008). The complexity of this therapy warrants a collaborative approach.

Providing quality and safe patient care is a goal of healthcare. Patient-centered care has given the patients the opportunity to make choices related to their care. Safety and quality of care starts with having supported evidence-based practices to follow. Nurses have the ability to reduce the amount of errors related to this therapy based on the review of literature. Nurses need to have the knowledge, skills, and attitudes about the complexity of this therapy and the ability to manage all aspects of a patient receiving this therapy. Nurses' need to be competent in CRRT therapy and understand the potential complications that can be prevented while managing patient's requiring this therapy. Electrolyte imbalances, hypotension, and fluid imbalances were found to be the most prevalent complications related to this therapy. Nurses managing these patients can be educated on best practices to monitor, review, and replace electrolytes per protocol to decrease risks of complications (Connor & Karakala, 2017; Schell-Chaple, 2017). Knowing that hypotension is common during initiation of CRRT therapy is essential. Therefore, treatment and prophylactic strategies must be discussed during educational training to decrease risk of these hypotensive episodes (Sharma & Waikar, 2017). To accomplish safer therapy administration a more standardized educational plan and continued competency evaluation needs to be implemented.

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With the ever-changing and technology advancing healthcare, it is important we realize that initial training does not deem one competent for a lifetime (Windt, 2016). The use of evidenced based education including didactic lessons, bedside orientation, simulation, and refresher courses can be helpful in initial and continuing education for CRRT therapy (Przybyl et al., 2017). These methods of training being implemented into training and maintenance of competency will help decrease complications of CRRT by increasing the exposure to complications that can arise and how to prevent and treat them. For instance, utilizing case studies and simulation on anticoagulation citrate and the protocol that goes with it should be part of the education of nurses preparing to implement CRRT therapy. Since there are not standardized educational plans or protocols, compiling QSEN's six competencies can bring together informatics and assist in keeping up with the technology and facilitation of new data, information, and knowledge to support nurses.

Outcomes/Dissemination

This review of literature, confirmed the importance of training and maintenance of competence for nurses providing safe care to CRRT patients, but it also illuminated that current methods are not adequate. The Acute Dialysis Quality Initiative XVII conference 2016 recognized this gap. Subsequently, there is ongoing efforts to identify best practices for CRRT for optimization of safe, quality care (Schell-Chaple, 2017).

The evidence identified in this literature review was used to plan educational programs for nurses who will be caring for patients experiencing CRRT. The program consists of pre-learning modules of self-study, these modules will be used in didactic and simulation sessions related to the content. This program will consist of eight hours for didactic presentations, four hours of simulation, and two 12-hour shifts required with a preceptor caring for CRRT patients.

This review of literature has demonstrated current evidenced-based practices, quality care, and informatics are important considerations for the advancement of healthcare and education of nurses.

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Nurses were proven to play a pivotal role in caring for critically ill patients requiring CRRT (Richardson & Whatmore, 2014). The new advancements in technology and evidence-based updates with CRRT require the nurse to have the knowledge required for the fast-changing technology (Przybyl et al., 2017). Having the most current evidence based on research on patient safety and prevention can assist in the future development of educational plans.

Initial training for nurses caring for patients undergoing CRRT consist of pre-learning modules. These modules will consist of an introduction, ordered components, basic set-up, starting and ending treatment, and management of circuit. Having a pre-learning module gives the nurse a foundation for the class, which will be supplied by the company of choice (Przybyl et al., 2017). These modules will have self-checks, such as quizzes or questions, of the content throughout to assess student learning throughout the modules (Billings & Halstead, 2016). Pre-learning modules are effective for the cognitive and psychomotor domains of these modules, in which the goal is to master information and apply it to practice (Bastable, 2014). Learner will complete a test at the end of the modules to serve as a ticket to continue with the course. Two hours will be allotted to complete the modules and quizzes; however, the learner will have access to review the material as needed (Przybyl et al., 2017).

An unfolding case study will be utilized for the next part of the training, which will be didactic lecture. Unfolding case studies will walk the nurses throughout the steps to initiate and operate CRRT. Allowing the learner to walk through key aspects of this therapy including device and supplies, anticoagulation, fluid balance management, potential complications, and continuous monitoring to assess competency of patient safety while operating CRRT. Case studies allow the learner to provide an in-depth analysis of real-life situations related to the content covered in pre-learning and didactic (Billings & Halstead, 2016). They stimulate the learner to investigate and analyze the situation and apply the knowledge they gained from modules (Hara et al., 2016). Didactic lecture, along with case studies, allows for the review of protocols and standards of practice for CRRT management for the hospital, and

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then implementation of protocols and standards. These well-designed case studies will illustrate the progression of the CRRT therapy, additional complications, prevention, and treatment of those complications, which will allow for a safe, open nonthreatening learning environment to encourage an active learning environment (Billings & Halstead, 2016). Efficient documentation is key to CRRT therapy and maintenance, so after the didactic lesson the learner will move to documentation training. Workflow associated with the order sets related to CRRT, how to enter orders, and documenting hourly charting in the electronic medical record reviewed and demonstrated.

Simulation training is the next step in the initial educational plan. Simulation allows the nurses to provide hands-on care in a safe environment. Simulation promotes patient safety and raises the quality of patient care when used in education (Lavoie & Clarke, 2017). Simulated experiences allow the learner to demonstrate communication and teamwork with the interdisciplinary team, which establishes clear communication and collaboration. This strategy gives the participant an opportunity to experience how the interdisciplinary team works together to maintain the patient's hemodynamic status. This is especially important because inadequate communication was found to cause 66% of errors (Hughes, 2008). For example, physicians are responsible for adjusting therapy based on the response hemodynamically, while the nurses must be diligent about documenting intake and output, vital signs, and net fluid removal. This important role of the nursing team member assures the medical team member has the correct information to make judgements for the therapy (Han et al., 2016). Teamwork and collaboration, efficient documentation, and clear communication will decrease the risk of unnecessary events.

The skills that will be practiced and demonstrated in simulation include: (a) setting up and priming circuit, (b) following physician orders and order sets, (c) properly accessing the hemodialysis catheter, (d) interpreting circuit pressures during therapy, (e) troubleshooting alarms, (f) managing common clinical situations. After the simulated experience is complete, debriefing with the learner

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occurs immediately (Billings & Halstead, 2016). The debriefing environment involves active participation from the instructor to the learner. The debriefing process allows for an opportunity to reference the real-life experience, control behaviors, and acknowledge emotions (Billings & Halstead, 2016).

Debriefing post simulation has been shown to increase teamwork and communication (Freytag, Stroben, Hutz, Eisenmann, & Kammer, 2017).

The last phase of initial training would be two 12-hour bedside orientation shifts with a preceptor on a patient with CRRT. Przybyl et al. (2017) suggested that working with a preceptor for 1-2 twelve hour shifts and a mutual assessment with a detailed checklist be mandatory for initial training to ensure competency. The preceptor in this program will have a competency tool to measure and confirm the nurse's competency to be able to administer this therapy. After initial competency development is confirmed, nurses responsible for CRRT will complete an annual simulation to assess competency. Competency will be measured by a skills and competency tool. Continuous Renal Replacement Therapy is considered a high risk/low volume therapy, so initial competency and maintaining competency is a key piece to this education.

Dissemination of the findings of this literature review will be completed during the first annual College of Nursing and Professional Disciplines Research and Scholarship Day at the University of North Dakota. A poster presentation (Appendix B) of the literature review findings and proposed educational plan will be displayed along with a 3-minute oral presentation.

Implications for Nursing

Nursing practice.

Continuous Renal Replacement Therapy needs to be individualized to each patient specific scenario; however, the training and maintenance of competence for nurses caring for these patients can be standardized. Continuous Renal Replacement Therapy dose and fluid removal targets as patient's weight, fluid balance, and clinical conditions inform decisions of each individual, some areas of

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standardization could benefit current practices and provide decreased errors (Connor & Karakala, 2017).

Standardized educational practices related to the complications and prevention of complication could decrease the amount of human error found to be significant with this therapy.

This extensive therapy requires complex assessments, maintenance of intravenous fluids, calculations of fluid, acid, base balances, frequent lab draws and monitoring, and maintenance of the CRRT machine (Windt, 2016). All of these complex tasks require expert-based education to assist the nurse to develop the skills and knowledge to promote positive patient outcomes (Schell-Chaple, 2017).

Nursing education.

How can we standardize education? Emphasis of training should be placed on patient assessment, troubleshooting, and technical skills to reduce down-time and optimize target CRRT dose delivery (Schell-Chaple, 2017, p. 38). Focus on these areas will encompass the complications and theoretical framework discussed previously. The educational training includes evaluation of the learner and the competency to perform this high-risk therapy. It was found that one-time training does not deem one competent for a lifetime, so requiring ongoing assessments of competency was shown to be critical for this high-risk therapy (Przybyl et al., 2015).

Training and maintaining of competence of this standardization could potentially decrease human error as discussed throughout the review. Przybyl et al. (2015) found that a standardized educational plan and maintenance of competency for CRRT was shown to be effective to increase nurse satisfaction, understanding of CRRT principles, and critical thinking related to the operation of this therapy. Standardized education for CRRT that was recommended included didactic theory, simulation, online learning modules, and utilizing specially trained teams (Przybyl et al., 2015; Przybyl et al., 2017; Windt, 2016). The recommendation for specially trained teams would have an elevated effect on these QSEN competencies patient-centered care, communication, teamwork and collaboration, and safety.

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This standardization was accomplished by utilizing the QSEN six competencies as a framework as it will encompass the safe and quality patient care we are looking for.

Nursing research.

Future research could be directed to complications of CRRT related to nursing education and training. The complications related to CRRT that were not well studied included air embolus and hypothermia. These complications were found to be a problem with CRRT but were not well studied with this therapy. Individual electrolyte problems were also not well studied. The variability in each patient and therapy made this difficult to study. Not only did the patient variability and comorbidities affect electrolyte related studies, it also affected findings related to hypotension and fluid imbalances. While randomized controlled studies would help provide a gold standard for more evidence related to these complications, it is critical to build evidence to assist nurses to safely care for these critical patients is critical. Therefore, other research designs should be considered as a beginning to addressing this gap of evidence.

The second recommendation for research relates to the wide variability in training and maintaining competence of nurses who manage this therapy. Initial training for nurses caring for CRRT patients was found to be between 4-12 hours, which is a significantly different range of time to complete all the education needed for this high-risk therapy (Przybyl et al., 2017). Research to determine the most appropriate methods to educate nurses for competent management of CRRT therapy would provide a firmer foundation for standardized nursing education. Standardization and supported evidence related to high quality randomized control trials would be helpful in determining higher quality standards.

Summary and Conclusions

Throughout this literature review, it was clearly evident that there is a wide variability in CRRT practices and education of those caring for patients requiring CRRT. This variability has been linked to

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adverse events and these events could be potentially life-threatening. Some variability is necessary for specific patient conditions; however, more standardized training of nurses and protocols of therapy could assist in the negative effects of these variabilities.

Adverse events and complications were found to be in as many as 35%-45% of CRRT patients and was related to the management by nurses and other staff (Bray et al., 2013; Rewa et al., 2015; Roeder et al., 2013). Standardized educational practices will benefit the training of the nurses for this complex therapy and create a safer administration and maintenance of therapy. The course (Appendix A) created for initial training for CRRT was based on the Quality and Safety Education for Nursing's six essential competencies. These competencies reflect the challenges of preparing nurses to continuously improve quality and safety of the healthcare system (Cronenwett et al., 2009). The focus of healthcare to involve patient and family in personal health-related decisions is imperative. Patient-centered care can be achieved by having trusted, educated staff caring for them in a safe environment (Sherwood & Barnsteiner, 2017). Teamwork and collaboration, evidenced-based practice, and safety can be achieved together. Safe, quality care can be achieved with communication and teamwork among interdisciplinary teams and providing education using the latest research and technology were shown to improve patient care. Ineffective communication and breakdowns in the working environment caused 66% of healthcare errors (Hughes, 2008). To provide safe effective care for patients experiencing CRRT, facilities need to implement standardized educational practices. The fast-changing complexities of the healthcare field require the healthcare systems to elevate informatics and safe use of technology with these changes.

Quality and safety are important ideals in health care (Rewa et al., 2015). These competencies were designed to address the challenge of preparing the nurses with the knowledge, skills, and attitudes to improve the quality and safety of the health care system (Dolansky & Moore, 2013). Thus, utilizing the Quality and Safety Education for Nursing and its six essential competencies as a basis for this standardized educational plan for CRRT competence development makes quality and safety top priority.

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Standardized education could create a national standard for the high-risk therapy of CRRT. The Acute Disease Quality Initiative in 2016 created best practices for CRRT to optimize patient safety (Schell-Chaple, 2017). A next step for this organization could focus on national certification for nurses who will be managing patients requiring CRRT. This standardized education and national certification will assist in reaching the goal of high-quality CRRT care, improving resource application, and improving positive patient outcomes for patients receiving CRRT.

Continued growth of this therapy should support interest in continued research and creation of better training methods. This literature review provided evidence that underpinned this project. Although, there is a need for continued standardization for education of nurses and the healthcare teams implementing CRRT, this effort provided an important beginning for one institution.

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Appendix A

Initial Training-Continuous Renal Replacement Therapy

Employee: _____**Employee ID:** _____**Date:** _____**Course:** Continuous Renal Replacement Therapy (CRRT) certification**Lesson Plan Content Focus:** QSEN's 6 Competencies of Safety**Venue:** 2E SCCU Conference Room**Previous Knowledge:** Nursing staff that have varying levels of experience. 1 year minimum in the Surgical Intensive Care Unit. Must have BSN and current certifications in TNCC, PALS, and ACLS.**Course Summary:** This is a 2-day course that educates staff on the basic principles of CRRT, basic components of CRRT, basic set-up, and treatment management during CRRT (Richardson & Whatmore, 2014). Pre-Lesson modules and quiz will be completed prior to first session, these modules are supplied by Gambro company. These modules will cover Units 1-3 for the basic understanding of the machine, equipment needed, and how to manage therapy. Didactic lessons of case studies, hands-on demonstration of set-up, and application of Units 1-3 from pre-learning modules for the first 8-hour day. Second day will be 4 hours of Simulation, related to the complications of CRRT and how to manage the complications. If the learner passes the evaluation and test, they will be required to follow a preceptor for two 12-hour shifts managing a CRRT patient (Przybyl, Evans, Haley, Bisek, & Beck, 2017).**Learning Strategies:** Pre-learning modules effective for the cognitive and psychomotor domains of these modules, in which the goal is to master information and apply it to practice (Bastable, 2014). Modules are readily available for access with all the resources for the learner to complete self-study (Bastable, 2014). Didactic lectures and case studies that implement changes in patient condition and requires critical application of knowledge from pre-learning (Ward et al., 2018). Simulations implement safe practice and prevention of complications discussed in previous learning (Billings & Halstead, 2016). Simulations allow for psychomotor demonstration of CRRT machine set-up and evaluation of objectives (Bastable, 2014). Direct patient care with preceptor for safe educational environment to assess competency of caring for the complex CRRT patient (Przybyl et al., 2017; Windt, 2016).

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Lesson Plan:

Unit 1: Basic Principles of CRRT

- CRRT and the associated therapies
- Treatment goals
- Basic principles of solute transport
- Clinical indications for administering CRRT

Unit 2: Basic Components of CRRT

- Access options and locations
- CRRT machine and the components of the system
- Solutions used and indications for different solutions
- Hemofilters and their indications
- Anticoagulation options and when they are indicated

Unit 3: Basic Set-up

- Machine set-up, loading filter, and priming filter
- Connecting patient to CRRT machine
- Discuss how to return blood, change filter, and end therapy

Unit 4: Treatment management

- Patients' hemodynamic stability, lab draws and lab review, fluid removal, and machine flow rates
- CRRT safety management features, pressure monitoring, and fluid balance principles.
- Alarm management and troubleshooting techniques
- Complications of CRRT and how to prevent them
- EPIC documentation on CRRT and intake and output

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Objectives:

After the lesson the learner will be able to:

1. Perform safety interventions throughout simulation by following universal precautions with 100% accuracy (cognitive-comprehension)
2. Initiate CRRT therapy by demonstrating all 5 steps required during the start of therapy (psychomotor-mechanism)
3. Compare the normal range for flow pressures to the simulated ranges of all 4 flow pressures evidenced by adjusting flow of therapy to reach normal. (cognitive-analysis)
4. Discuss the 4 principles of CRRT with 100% accuracy (cognitive- comprehension)
5. Correctly demonstrate modifying settings in the system tools with 100% accuracy (psychomotor-precision)
6. Implement the algorithm to detect the malfunction or failure of the safety system in high priority patient simulation within 1 minute of the alarm sounding. (psychomotor-adaptation)
7. Modify treatment based on clinical condition to prevent complications for patients receiving CRRT evidenced by appropriate intervention with 100% accuracy (cognitive- application)
8. Analyze changes in patients' hemodynamic stability while receiving CRRT evidenced by making the appropriate changes to CRRT machine and medication drips (cognitive-analysis)
9. Assume responsibility for maintaining patients' safety during CRRT simulation (affective-valuing)
10. Correctly demonstrate appropriate documentation in EPIC flowsheets
11. Demonstrate appropriate shift report handoff

Skills and/or Associated Procedures	Initial Validation	Remediation	Objective/s	QSEN Competency/ies	Objective Met: Initial and Date
CONTINUOUS RENAL REPLACEMENT THERAPY Education <ul style="list-style-type: none"> ○ Provide education to Patient/family 	<ul style="list-style-type: none"> ○ Observation- provide educational materials related to CRRT and the therapies and equipment 			Patient-centered care	
Safety <ul style="list-style-type: none"> ○ *Hand Hygiene ○ *Verify consent forms (CRRT and HIV) 	<ul style="list-style-type: none"> ○ Observation- proper hand hygiene ○ Verbal discussion- 2 consent forms verified and signed 		1,2,9	Safety, patient-centered care	
Initiation of Therapy <ul style="list-style-type: none"> ○ Gather supplies ○ *Verify correct patient ○ *Verify CRRT physician orders ○ *Prime prismaflex filter ○ Scheduled laboratory tests 	<ul style="list-style-type: none"> ○ Observation- correctly primes filter ○ Verbal discussion- verbalizes supplies needed, patient identification, and labs needed 		1,2,9	Safety, Quality Improvement, Evidenced-based practice	
Normal Range for flow pressures (*correctly adjust 2 of the 4 flow	<ul style="list-style-type: none"> ○ Observation- adjusts flow of therapy to 		3,4	Evidenced-based practice, Informatics	

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<p>pressures to reach normal range)</p> <ul style="list-style-type: none"> ○ Access pressures ○ Return pressures ○ Filter pressures ○ Effluent pressures 	<p>reach normal range of flow pressures.</p> <ul style="list-style-type: none"> ○ Verbal discussion- verbalizing alterations made and why? 				
<p>Principles of CRRT modes (*one mode must be correctly set up and goal must be verbalized)</p> <ul style="list-style-type: none"> ○ SCUF- fluid removal only, no replacement or dialysate pump ○ CVVH- fluid removal, all size molecule clearance, replacement pump only ○ CVVHD- Fluid removal, small molecule clearance, dialysate pump only ○ CVVHDF- fluid removal, all size molecule removal, uses both 	<ul style="list-style-type: none"> ○ Observation- correct set-up of ordered mode ○ Verbal discussion- goal of therapy mode being set-up 		<p>1,4</p>	<p>Evidenced-based practice, teamwork/collaboration</p>	

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replacement and dialysate pumps					
System Tools <ul style="list-style-type: none"> ○ *Modify Settings ○ Mute self-test ○ *Self-test 	<ul style="list-style-type: none"> ○ Observation- correctly modifies settings per orders and mutes self-test ○ Verbal discussion- what is self test?, why are they important? 		1,2,5	Safety	
Alarms/Troubleshooting <ul style="list-style-type: none"> ○ *Implemented correct algorithm used to detect alarm ○ *Identify resources for troubleshooting ○ How to contact 24 hour a day Gambro representative? 	<ul style="list-style-type: none"> ○ Observation- correct algorithm for alarm ○ Verbal discussion- where to find resources and how to reach representative? ○ Timed- Implement algorithm within 1 minute of alarm 		5,6,7,9	Evidenced-based practice, safety, informatics, quality improvement	
Complications associated with CRRT (*correctly implement intervention of 1 complication)	<ul style="list-style-type: none"> ○ Observation- appropriate intervention of 		6,7	Evidenced-based practice, safety, informatics, quality improvement	

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<ul style="list-style-type: none"> ○ Anticoagulation ○ Electrolyte imbalance 	<p>1 of 2 complications</p> <ul style="list-style-type: none"> ○ Verbal discussion- discuss rationale of changes made 				
<p>Hypotension during CRRT therapy</p> <ul style="list-style-type: none"> ○ *Decrease BFR ○ Call MD/add pressor ○ Increase BFR as tolerated to optimal rate for filter 	<ul style="list-style-type: none"> ○ Observation- correctly identifies hypotension, carries out appropriate intervention ○ Verbal discussion- when can BFR be increased? 		5,6,7,8,9	Evidenced-based practice, safety, informatics, quality improvement	
<p>Emergency Procedures initiated during cardiac/respiratory arrest</p> <ul style="list-style-type: none"> ○ *Decrease BFR ○ *Decrease patient fluid removal rate 	<ul style="list-style-type: none"> ○ Observation- correct machine interventions ○ Verbal discussion- initiate code blue team 		5,6,7,8,9	Evidenced-based practice, safety, informatics, quality improvement	
<p>Responsibility of patient's safety</p> <ul style="list-style-type: none"> ○ The scenario will be based on the value of safety and the interaction of colleague with patient family 	<ul style="list-style-type: none"> ○ Verbal Discussion- debriefing questions- do you agree with the nurses interaction with the family, 		1,9	Patient-centered care, teamwork and collaboration, quality improvement, safety, and informatics.	

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<p>during emergency procedure. Interaction will demonstrate a lack of care about the patient safety and family concern.</p>	<p>why or why not?; How would you change the interaction, why or why not?</p> <ul style="list-style-type: none"> ○ Response (*address 3 of the 6 QSEN competencies of quality and safety)- Patient-centered care, teamwork and collaboration, quality improvement, safety, and informatics. 				
<p>Documentation- EPIC flowsheet, I&O documentation</p>	<ul style="list-style-type: none"> ○ Observation- correctly documents in EPIC: CRRT, vitals, I&O flowsheets 		<p>1, 10</p>	<p>Safety, Teamwork/Communication, informatics</p>	
<p>Shift Handoff-</p>	<ul style="list-style-type: none"> ○ Observation ○ Verbal 		<p>1, 11</p>	<p>Safety, Teamwork/Communication</p>	

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Appendix B



**Continuous Renal Replacement Therapy:
Educating Nurses for Prevention of Complications**
Brittany Stoltman, Masters Candidate, Nurse Educator Track
Grand Forks, ND



Introduction

- Acute kidney injury common in critically ill patients (Akhoundi et al., 2015)
- Continuous Renal Replacement Therapy (CRRT) is used 70% of the time to address this complication (Przybyl et al., 2017)
- Complications of CRRT are life threatening (Windt, 2016)
- Nurses are vital to caring for patients and safe implementation of CRRT
- Preparation of nurses for managing the complex therapy is crucial to safe patient care (Windt, 2016)
- Programs to prepare nurses are not standardized and contribute to the risk associated with CRRT (Schell-Chaple, 2017)

Purpose

“The purpose of this project was to develop standardized, evidenced-based educational plan for RNs who will be responsible to care for patients receiving CRRT to increase patient safety and promote positive patient outcomes. The educational plan is framed by Quality Safety Education for Nurses (QSEN)”

Methodology

- Search engines used were PubMed and CINAHL
- Focus: renal replacement therapy
- Keywords included: continuous, hypotension, hypothermia, electrolyte imbalances, fluid imbalances, anticoagulation, nurse education
- Filters included: 5-10 years and English
- Related Citations and Related MeSH terms in the pertinent articles reviewed.

Theoretical Framework

- Quality and Safety Education for Nursing and its six essential competencies
 - Address the problem of preparing nurses with knowledge, skills, and attitudes to improve quality and safety in healthcare (Dolansky & Moore, 2013).
1. Patient-Centered Care
 2. Teamwork and Collaboration
 3. Evidence-based practice
 4. Quality Improvement
 5. Safety
 6. Informatics



References

Available upon request

Advisor: Dr. Linda Shanta, PHD, RN ANEF

Significant Findings

- 35%-40% of adverse events are due to human error (Bray et al., 2013; Rewa, Mottes, & Bagshaw, 2015; Roeder, Atkins, Ryan, & Harm, 2013).
- The most common complications found were electrolyte imbalances, hypotension, and fluid imbalances.
- Variability of therapy management and monitoring contribute to the risk of adverse outcomes (Schell-Chaple, 2017).
- Standardized education should include (Przybyl et al., 2017):
 - Comprehensive initial didactic training
 - Basic set-up and troubleshooting
 - Frequent exposure to patients receiving CRRT therapy
 - Refresher courses and ongoing competency evaluations

Outcomes

- Standardized educational plan provide nurses caring for patient's with CRRT therapy to increase safe quality care.
- Standardized initial training practices and ongoing maintenance of competency (Schell-Chaple, 2017)
- Initial training consists of 2 day course with eight hours didactic presentations, four hours of simulation, and two 12-hour shift required with a preceptor
- Educational and competency training including:
 - Pre-learning modules are effective for the cognitive and psychomotor domains to master information and apply it to practice (Bastable, 2014).
 - Didactic lectures and case studies that implement changes in patient condition and requires critical application of knowledge from pre-learning (Ward et al., 2018).
 - Simulations to implement safe practices and prevention of complications discussed in previous learning (Billings & Halstead, 2016)
 - Direct patient care with preceptor for safe educational environment to assess competency (Przybyl et al., 2017; Windt, 2016).