Continuous Renal Replacement Therapy: Case Vignettes

Charlotte Garwood, RN, MS, CCRN
Cass Piper Sandoval, RN, MS, CCNS
Robert Wonnacott, RN, MSN
Craig Sadler, RN, BSN
Susan Dirkes, RN, MSA, CCRN

ABSTRACT

The most common indication for continuous renal replacement therapy (CRRT) in critically ill patients is acute kidney injury with hemodynamic instability. Typically, the patient has metabolic disturbances and potential or actual fluid overload that require intervention. Certain critical care diagnoses and/or conditions or therapies present unique CRRT management approaches. Case vignettes are used to present the unique management of CRRT in critically ill patients with rhabdomyolysis, heart failure, and respiratory failure requiring extracorporeal membrane oxygenation. Keywords: CRRT, ECMO, heart failure, rhabdomyolysis, continuous renal replacement therapy, extracorporeal membrane oxygenation

Continuous renal replacement therapy (CRRT) is an option for management of fluid, electrolyte, metabolic, and acid-base disturbances related to either acute or chronic renal disorders in critically ill patients. The broad subpopulations of critically ill patients present unique challenges to management of CRRT related to their critical cardiopulmonary status and/or the additional therapies common to the intensive care unit (ICU). This article presents 3 of these unique situations to highlight CRRT management in a case vignette format.

Case Vignette 1: Rhabdomyolysis

Mr Z was a 63-year-old man admitted to the hospital for thoracic surgery following new findings of a mediastinal mass on the left side and pulmonary and periesophageal lesions on the right side. His medical history included a fibrosarcoma (treated 5 years ago), gastrointestinal reflux disease, depression, and obesity with a body mass index (BMI) of 41 (calculated by dividing his weight of 130 kg by his height of 1.79 m squared). Results of his preoperative urinalysis and his renal function were normal, with a serum creatinine level of 0.82 mg/dL (to convert to micromoles per liter, multiply by 88.4). During the surgical

Charlotte Garwood is Registered Nurse 2, Medical Intensive Care Unit, Vanderbilt University Medical Center, 1211 Medical Center Dr, Nashville, TN 37232 (charlotte.l.garwood@vanderbilt.edu).

Cass Piper Sandoval is Clinical Nurse Specialist, Adult Critical Care, University of California, San Francisco Medical Center, San Francisco, California.

Robert Wonnacott is Senior Lead Nursing Informatics, University of Michigan Health System, Ann Arbor, Michigan.

Craig Sadler is Staff Nurse, University of Michigan Health System, Ann Arbor, Michigan.

Susan Dirkes is Staff Nurse, University of Michigan Health System, Ann Arbor, Michigan.

The authors declare no conflicts of interest.

DOI: https://doi.org/10.4037/aacnacc2017686
procedure, Mr. Z was positioned left side down for the right thoracotomy and resection of lesions from the upper, middle, and lower lobes as well as the chest wall. He was in the operating room for 12 hours, and intraoperative events included tachycardia with new-onset atrial fibrillation and episodes of intermittent hypotension. His arrhythmia resolved after treatment with esmolol, metoprolol, and amiodarone, and the hypotension resolved with small doses of phenylephrine. He was extubated at the end of the case and transferred to the ICU for close monitoring.

Initial laboratory results on admission to the ICU were notable for an increase in serum levels of creatinine, potassium, phosphorus, and creatine kinase. (See baseline and subsequent laboratory results in Table 1.) His urine output decreased to less than 0.5 mL/kg per hour, and urinalysis results were positive for glucose, ketones, protein, and large amounts of hemoglobin. Microscopic examination of his urine revealed sediment and muddy brown casts from slough of tubular cells indicating acute tubular necrosis. Standard treatment for rhabdomyolysis was started with a bicarbonate infusion and fluid resuscitation. Because of concern for further fluid overload and new signs of pulmonary edema, additional fluid resuscitation was contraindicated.

Subsequent laboratory results revealed increases in the serum level of creatinine to 1.9 mg/dL and creatine kinase to 39 463 U/L (to convert creatine kinase to μkat/L, multiply by 0.0167), and the nephrology service was consulted to assist with further management of his renal dysfunction. Acute kidney injury (AKI) due to rhabdomyolysis was diagnosed and attributed to his prolonged immobilization in the operating room. The increase in serum creatinine level and the decrease in urine output in the early postoperative period met the diagnostic criteria for AKI.

CRRT was initiated within 12 hours of his arrival in the ICU.

**Rhabdomyolysis**

Rhabdomyolysis is a potentially life-threatening condition that is a result of skeletal muscle breakdown and release of cytotoxic intracellular components into the

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline</th>
<th>At Admission</th>
<th>6 h After Admission</th>
<th>Postoperative Day 1</th>
<th>Postoperative Day 2</th>
<th>Postoperative Day 1</th>
<th>Postoperative Day 2</th>
<th>Hospital Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creatinine, mg/dL</td>
<td>0.82</td>
<td>1.12</td>
<td>1.37</td>
<td>2.61</td>
<td>1.66</td>
<td>1.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea nitrogen, mg/dL</td>
<td>14</td>
<td>15</td>
<td>19</td>
<td>27</td>
<td>18</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium, mmol/L</td>
<td>138</td>
<td>136</td>
<td>137</td>
<td>134</td>
<td>137</td>
<td>138</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium, mmol/L</td>
<td>4.2</td>
<td>5.2</td>
<td>4.9</td>
<td>4.6</td>
<td>4.2</td>
<td>4.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloride, mmol/L</td>
<td>103</td>
<td>105</td>
<td>104</td>
<td>99</td>
<td>101</td>
<td>103</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicarbonate, mmol/L</td>
<td>24</td>
<td>20</td>
<td>21</td>
<td>28</td>
<td>31</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total calcium, mg/dL</td>
<td>8.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ionized calcium, mmol/L</td>
<td></td>
<td>1.18</td>
<td></td>
<td>1.16</td>
<td>1.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnesium, mg/dL</td>
<td>2.2</td>
<td>1.9</td>
<td></td>
<td>1.8</td>
<td>2.0</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phosphorus, mg/dL</td>
<td>6.1</td>
<td>6.6</td>
<td></td>
<td>5.3</td>
<td>3.1</td>
<td>3.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creatine kinase, U/L</td>
<td>15891</td>
<td>39463</td>
<td></td>
<td>14564</td>
<td>4677</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urine output, daily mean, mL/h</td>
<td>WNL</td>
<td>40</td>
<td></td>
<td>15</td>
<td>20</td>
<td>110</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRRT ultrafiltrate volume, mL/d</td>
<td>CVVH started within 12 h of admission to intensive care unit</td>
<td>28900</td>
<td>92725</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 1: Laboratory Values for Patient With Rhabdomyolysis**

Abbreviations: CRRT, continuous renal replacement therapy; CVVH, continuous venovenous hemofiltration; WNL, within normal limits.

SI conversion factors: To convert creatinine to μmol/L, multiply by 88.4; to convert urea nitrogen to mmol/L, multiply by 0.357; to convert total calcium to mmol/L, multiply by 0.25; to convert magnesium to mmol/L, multiply by 0.5; to convert phosphorus to mmol/L, multiply by 0.323; to convert creatine kinase to μkat/L, multiply by 0.0167.

Blank spaces indicate variable was not measured.

Laboratory tests run on serum samples.
The cause of muscle injury may be related to direct trauma or compression, adverse effects of drugs, or other conditions such as malignant hyperthermia and infections.\textsuperscript{2,3} Risk factors associated with rhabdomyolysis are long-term use of lipid-lowering medications, surgery (length of time immobile), and morbid obesity (BMI > 40).\textsuperscript{2} Mr Z had 2 of the risk factors, with his high BMI and prolonged surgical time in the lateral decubitus position most likely leading to secondary compression injury.

Signs and symptoms of rhabdomyolysis are myalgia, muscle weakness, dark tea-colored urine, and serum creatine kinase levels greater than 5 times the upper limit of the normal range.\textsuperscript{2} The first serum level of creatine kinase (15 891 U/L) for Mr Z on admission to the ICU was well above 5 times the upper limit (388 U/L) for the laboratory at Mr Z’s hospital. Potential complications of rhabdomyolysis include electrolyte disturbances, metabolic acidosis, and AKI.\textsuperscript{4} The most common complication of rhabdomyolysis is AKI with an incidence of 13% to 55% and also an associated increase in mortality.\textsuperscript{2,5,6} The release of cytotoxic intracellular components such as myoglobin, creatine kinase, phosphorus, and uric acid from injured myocytes results in endothelial injury, capillary leak, and third spacing of intravascular fluid.\textsuperscript{2} This cascade of injury leads to reduced renal blood flow and direct nephron injury by the myoglobin and its breakdown products.\textsuperscript{5} The acidotic environment promotes crystallization of uric acid and cast formation in the renal tubules leading to obstruction and further injury of the kidneys.\textsuperscript{3,7,8} Although no evidence-based guidelines are available for management of rhabdomyolysis, administration of intravenous fluids and bicarbonate to alkalize the blood and renal environment is standard first-line therapy to prevent AKI. Compared with standard treatment for rhabdomyolysis, CRRT effectively reduces serum levels of myoglobin and creatinine, normalizes electrolyte levels, and reduces hospital length of stay; despite those benefits, the mortality rate is no lower with CRRT than with standard treatment.\textsuperscript{5}

### CRRT Treatment

Implementation of CRRT shortly after recognition and diagnosis of rhabdomyolysis and after bicarbonate fluid resuscitation is intended to prevent renal injury. The CRRT mode implemented for Mr Z was continuous venovenous hemofiltration (CVVH) with off-label use of a commercially available dialysate solution with concentrations of bicarbonate at 35 mEq/L and potassium at 4 mEq/L infused as replacement fluid at 4 L/h (30 mL/kg per hour). After 24 hours of CVVH therapy with 28 900 mL of ultrafiltrate removal, Mr Z’s serum level of creatinine increased to 2.6 mg/dL, creatine kinase level decreased to 14 564 U/L, and urine output decreased to 232 mL/d. The fluid balance order was initially to keep the fluid balance even (net even), yet after 24 hours, the order was changed to -25 mL/h to slowly remove excess volume that was mobilizing back from the extravascular (third spaces) to the intravascular space. After another full day of CVVH with 92 725 mL of ultrafiltrate removal, Mr Z’s serum creatinine
level decreased to 1.6 mg/dL, his level of creatine kinase decreased to 4677 U/L, and his urine output increased to 353 mL daily.

The mode of CRRT recommended for myoglobin clearance in rhabdomyolysis is CVVH with high-volume ultrafiltration rates. Myoglobin has a low diffusion coefficient owing to its large molecular weight of 17 000 daltons and its nonspherical shape, so clearance is not achieved with intermittent and continuous dialysis modes (continuous venovenous hemodialysis [CVVHD]) of renal replacement therapy.9 The mechanism of solute clearance during CVVH is convection, where high volumes of plasma water “drag” solutes of small and midrange molecular weight across the hemofilter membrane to the effluent compartment with fluid removal. Ultrafiltration rates of at least 30 mL/kg per hour are considered adequate to increase the clearance of myoglobin and creatine kinase.

Recent advances in filter membrane technology with capacity for high-cutoff protein permeability to clear larger molecules may offer a more efficient hemofiltration therapy to reduce risk of AKI associated with rhabdomyolysis.10 Two categories of hemofilter membranes behave more like a native glomerulus: super-high-flux and high-cutoff membranes. Cutoff refers to the molecule mass that can pass through the membrane pores. Cutoff ranges reported for the super-high-flux membranes are from 10 000 to 60 000 daltons, and cutoff ranges for HCO membranes hemofilters are up to 100 000 daltons.10-13 The hemofilter used in this case had a high-efficiency polyethersulfone membrane with a surface area of 1.6 m² and a molecular weight cutoff of 65 000 daltons (Purema H Filter, NxStage Medical).

Outcome

Mr Z’s CRRT was discontinued on postoperative day 3 as his creatine kinase level continued to decrease and his urine output increased in the next 2 days to at least 2600 mL/d. One week after surgery, he had a serum creatinine level of 1.3 mg/dL and his urine output was greater than 2500 mL/d. He was discharged home with instructions to avoid renal toxic agents (eg, nonsteroidal anti-inflammatory drugs and contrast dyes) and to maintain a renal protective diet. Five months after his surgery, Mr Z’s serum level of creatinine was 1.1 mg/dL. Although progression to chronic kidney disease was prevented with early detection and early treatment including CVVH for Mr Z, further research is warranted to inform evidence-based guidelines for rhabdomyolysis management.

Case Vignette 2: Heart Failure

Mrs J was a 58-year-old woman with a primary diagnosis of heart failure with a reduced ejection fraction due to nonischemic cardiomyopathy. Her medical history included chronic obstructive pulmonary disease, chronic kidney disease, multiple cardiac arrests associated with ventricular tachycardia (VT), and placement of a cardiac resynchronization therapy device. She arrived at the hospital in cardiogenic shock related to acute decompensated heart failure with an ejection fraction of 32% and mitral valve endocarditis. One week into her ICU stay after stabilization with inotropic agents and diuresis, her cardiac resynchronization therapy device was removed because of concern that it was the source of endocarditis. The following day, she had another VT arrest associated with hypokalemia. She was successfully resuscitated but continued to decompensate during the next several days because of cardiogenic shock.

During this time, her systolic blood pressures ranged from 60 to 80 mm Hg with mean arterial pressures ranging from 50 to 70 mm Hg while she was receiving multiple vasopressors and inotropic agents, including norepinephrine at 20 μg/min, vasopressin at 0.04 U/min, epinephrine at 0.05 μg/kg per minute, and dobutamine at 5 μg/kg per minute. She was also receiving antiarrhythmia infusions of lidocaine at 2 mg/min followed by amiodarone at 0.5 mg/min to treat her recurrent episodes of VT. Central venous oxygen saturation levels during this time were from 40% to 50%, indicating a state of oxygen debt where oxygen delivery is not adequate to meet the oxygen demand. The patient’s poor cardiac output and her chronically low hemoglobin level adversely affected her oxygen delivery through reductions in flow to the tissues and in the oxygen-carrying capacity of the blood.

Mrs J’s baseline serum level of creatinine was 2.1 mg/dL owing to her chronic kidney disease. At the peak of her acute decompensation, her creatinine level increased to 4.1 mg/dL and severe signs and symptoms of volume overload manifested. Her net fluid balance was largely positive, and urine output significantly increased.
decreased despite diuretic therapy with a bumetanide infusion. Her central venous pressure was elevated at 18 mm Hg. Her acid-base balance was normal; however, her potassium levels were fluctuating, resulting in repeated episodes of VT.

With a recent VT arrest in the setting of hypokalemia that was most likely precipitated by diuretic therapy along with Mrs J’s worsening oliguria and hemodynamic instability, the interdisciplinary team decided to initiate CRRT for more precise volume removal and electrolyte control. Potential risks associated with chronic diuretic use include morbidity and mortality related to neurohormonal activation, electrolyte imbalance, and worsening renal function. In addition, Mrs J was now experiencing cardiorenal syndrome, a condition where acute dysfunction of either the heart or kidneys leads to dysfunction of the other organ. The hemodynamic alterations of heart failure have traditionally explained the pathogenesis of cardiorenal syndrome, yet neurohormonal and biochemical abnormalities are also mechanisms of organ dysfunction in cardiorenal syndrome.

To achieve the goal of reversing the exacerbation of the dual organ dysfunction, the plan of care included a diuretic holiday and initiation of CVVHD. During CVVHD, the mechanism of fluid removal (also called ultrafiltration) is a hydrostatic pressure gradient, and the mechanism of solute removal is diffusion. The concentrations of electrolytes and buffer in the commercially available dialysate solution infused at 2.5 L/h were sodium 140 mmol/L, potassium 4 mmol/L, bicarbonate 35 mmol/L, calcium 1.25 mmol/L, magnesium 0.75 mmol/L, and chloride 113 mmol/L. The ordered fluid balance was initially -25 mL/h, which was quickly increased to -100 mL/h within 4 hours because the patient’s hemodynamic status was tolerating the volume removal. The fluid balance order was increased the following evening to -150 mL/h and incrementally increased to -250 mL/h in the following days of therapy.

CRRT was initiated with no additional anticoagulation. Mrs J had an elevated prothrombin time/international normalized ratio due to warfarin treatment for a deep vein thrombosis in an upper extremity. She had hematuria that was being evaluated. After several CRRT circuit failures, a low-dose, prefILTER heparin infusion at 300 U/h was added. The heparin infusion was converted to citrate anticoagulation on day 3 when filter clotting persisted.

Because of her history of multiple VT arrests related to hypokalemia, Mrs J had a customized potassium chloride replacement plan implemented to avoid potassium levels decreasing to less than 4 mmol/L. This individualized CVVHD plan thus primarily focused on fluid removal to achieve the preload that optimized her ejection fraction and simultaneously controlled electrolyte levels to prevent arrhythmias. After 4 days of CVVHD with an 8-kg negative fluid balance, a 5-kg weight loss, and hemodynamic stability achieved with single vasoactive infusion support (dobutamine at 4 μg/kg per minute), therapy was discontinued. Mrs J began responding to diuretics again when she exhibited urine output following test doses of chlorothiazide and bumetanide. Her central venous pressure decreased to 6 mm Hg and her electrolyte levels normalized.

Evidence-based recommendations for use of CRRT and ultrafiltration in the patients with cardiorenal syndrome are lacking. CRRT is recommended for patients with decompensated heart failure and diuretic-resistant, refractory fluid overload. The mode of CRRT selected is based on need for uremic and/or electrolyte control as well as fluid removal. Slow continuous ultrafiltration is effective in volume control and can achieve removal rates up to 500 mL/h, yet it is associated with worsening renal function and other adverse events. Few studies with this population have involved evaluation of the use of the other modes of CRRT that involve solute removal, such as CVVHD and CVVH. It is recommended that CVVH or CVVHD be considered when acid-base, electrolyte, and/or uremic control are indicated along with fluid control.

Outcome

In this case, the benefits of therapy outweighed the risks of CRRT, as Mrs J survived this acute decompensation and was able to return home. The use of CRRT to provide precise and controlled fluid removal and tight control of electrolyte levels, along with inotropic and vasopressor support, broke the vicious cycle of her acute cardiorenal decompensation. The only CRRT-related adverse consequence in this case was a moderate decrease in her hemoglobin level from 9 to 7 g/dL that was associated with frequent clotting in her circuit.
Iatrogenic anemia and thrombocytopenia, most likely related to fibrin deposition and clot formation in the hemofilter and circuit, are associated with CRRT extracorporeal systems. Mrs J’s case highlights the importance of timely monitoring and repletion of electrolytes as well as the tenuous nature and associated risks of fluid overload in acutely decompensated heart failure. Future study of the impact of CRRT modes and methods of management in patients with acute decompensated heart failure is warranted.

**Case Vignette 3: Extracorporeal Membrane Oxygenation**

Mr S was a 55-year-old man admitted to the surgical ICU from a community hospital for further management of his acute respiratory distress syndrome (ARDS) associated with pneumonia. The polymerase chain reaction assay result from his lower airway sputum sample was positive for H1N1 influenza virus. At the outside hospital, severe hypoxemia had developed and he had required intubation and mechanical ventilator support before transport.

His hypoxemia and hypercapnia persisted despite low-tidal-volume ventilation (see ventilator settings in Table 3). The cardiothoracic surgeons evaluated the patient for extracorporeal membrane oxygenation (ECMO) since his ratio of PaO₂ to fraction of inspired oxygen (FiO₂) remained less than 100 after implementation of sedation and neuromuscular blockade interventions to facilitate continuous venovenous hemodialysis started with net balance -75 mL/h.

<table>
<thead>
<tr>
<th>Presentation</th>
<th>Admission to Intensive Care Unit</th>
<th>ECMO Day 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical ventilation and ECMO settings</td>
<td>Mode: assist control</td>
<td>Mode: assist control</td>
</tr>
<tr>
<td></td>
<td>Set rate: 35 breaths per minute</td>
<td>Set rate: 22 breaths per minute</td>
</tr>
<tr>
<td></td>
<td>Tidal volume: 6 mL/kg</td>
<td>Tidal volume: 5 mL/kg</td>
</tr>
<tr>
<td></td>
<td>FiO₂: 0.80</td>
<td>FiO₂: 0.40</td>
</tr>
<tr>
<td></td>
<td>PEEP: 12 cm H₂O</td>
<td>PEEP: 5 cm H₂O</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ECMO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FiO₂: 0.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blood flow: 2.8 L/min</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sweep flow: 1 L/min</td>
</tr>
</tbody>
</table>

**Respiratory parameters**

| | Pao₂/Fio₂ ratio: 90 | Pao₂/Fio₂ ratio: 213 |
| | Plateau pressure: 29 cm H₂O | Plateau pressure: 22 cm H₂O |

**Arterial blood gas values**

| | pH | 7.28 | 7.30 |
| | PaCO₂, mm Hg | 57 | 49 |
| | PaO₂, mm Hg | 90 | 85 |
| | HCO₃, mmol/L | 25 | 22 |
| | Base deficit, mmol/L | -1 | -4 |
| | SaO₂, % | 92 | 93 |

| | Creatinine, mg/dL | 0.81 | 3.5 |
| | Urea nitrogen, mg/dL | 19 | 45 |
| | Sodium, mmol/L | 137 | 132 |
| | Potassium, mmol/L | 4.3 | 5.2 |
| | Chloride, mmol/L | 101 | 96 |
| | Bicarbonate, mmol/L | 24 | 22 |
| | Lactate, mmol/L | | 6.1 |
| | Urine output, mL/h | 70 | 25 |

**Continuous renal replacement therapy**

Abbreviations: FiO₂, fraction of inspired oxygen; HCO₃, bicarbonate; PEEP, positive end-expiratory pressure; SaO₂, oxygen saturation.

SI conversion factors: To convert creatinine to μmol/L, multiply by 88.4; to convert urea nitrogen to mmol/L, multiply by 0.357.
mechanical ventilation and positioning to optimize gas exchange. Cannulas were inserted for venovenous ECMO on ICU day 2 with the outflow/access cannula in the inferior vena cava and the inflow/return cannula in the femoral vein. The ECMO circuit's centrifugal pump rate was set at 2800 rotations per minute, achieving a blood flow rate of 2.8 L/min, and the \( \text{FiO}_2 \) was set at 50% with a sweep flow of 1 L/min.

In Mr S’s first 3 days on ECMO, AKI developed, as evidenced by an increase in serum level of creatinine to 3.5 mg/dL and a decline in urine output to less than 0.5 mL/kg per hour, resulting in a positive net fluid balance of 2.5 L since admission. His blood pressure was maintained at the goal mean arterial pressure of greater than 60 mm Hg with norepinephrine and vasopressin infusions. (See Table 3 for his laboratory results and respiratory parameters on ECMO day 3 when he was evaluated for CRRT.)

The team decided to use the ECMO circuit as blood access for the CRRT rather than inserting a dialysis vascular access catheter and running separate extracorporeal circuits. The ECMO specialist and the bedside nurse collaborated, primed the CRRT circuit, and made access-tubing and return-tubing connections to the ECMO circuit. Both access and return tubing was connected to the ECMO circuit segment that was past the centrifugal pump and before the oxygenator per the standard in the hospital’s ECMO program.

CRRT was started for the indications of fluid overload (he was >10% over his dry weight) and metabolic disturbances (electrolyte levels and acid-base status). CVVHD with a dialysate rate of 2.5 L/h and net fluid removal rate of -75 mL/h was started. Because a heparin infusion was used for ECMO anticoagulation, no anticoagulation was ordered as part of the CRRT plan. The standard electrolyte monitoring and replacement protocol was ordered because excessive loss of solutes, particularly phosphorus, potassium, and ionized calcium is a risk during CRRT.

Management of AKI in Patients Receiving ECMO

According to the Extracorporeal Life Support Organization’s international registry, the number of ECMO centers and patients receiving this therapy for refractory cardiac or respiratory failure has doubled since 2009.

Patients receiving ECMO therapy often have organ dysfunction beyond their primary cardiac or respiratory failure, which may be due to low cardiac output or ischemia related to severe hypoxemia that is experienced before therapy is started. The reported incidence of AKI in patients receiving ECMO is as high as 70%. Approximately 60% of ECMO patients with AKI are treated with CRRT, with CVVH as the most common mode used. The most common indications for use of CRRT in this population are fluid overload, acidosis, and electrolyte disturbances.

Fluid overload is associated with poor outcomes in a variety of critically ill subpopulations, including patients with ARDS and AKI. Achievement of fluid balance goals in patients receiving ECMO therapy is greater with CRRT than with diuretic therapy. Survivors of ECMO therapy who received CRRT have less fluid overload than do those who did not receive CRRT. Although fluid balance targets are more readily achieved with CRRT, the risk of in-hospital mortality is significant for patients receiving ECMO and CRRT when compared with ECMO without CRRT (odds ratio, 5.89; 95% CI, 4.38-7.92). The observed risk of mortality found in this systematic review may be a reflection of the severity of illness or risk of death in patients with AKI as an additional organ dysfunction.

CRRT During ECMO Therapy: Technical Options

No evidence-based recommendations for renal replacement therapy during ECMO therapy are available, and the variation in practice is wide. Because of the gap in best-practice guidelines, decisions for management of combined CRRT and ECMO therapies are usually based on local expertise and experience, supplies and devices available, and expert opinion. It is recommended that facilities develop standard protocols for connection methods to optimize safety. Two main options are available for vascular/blood access for CRRT during ECMO therapy, and 2 CRRT system options are available.

Standard Vascular Access. A standard double-lumen hemodialysis vascular access catheter that is independent of the ECMO circuit can be inserted into a central vein typically used for CRRT access. This option uses standard procedures for CRRT connections and does not add risk of air, thrombus,
or infection complications associated with connecting 2 extracorporeal circuits. However, outflow drainage to the ECMO circuit may be affected by the additional extracorporeal blood volume or excessive fluid removal via the CRRT system. Negative circuit pressures and decreases in measured flow rate changes in the ECMO circuit will reflect reduction in outflow drainage.

**Access Through the ECMO Circuit.** The CRRT circuit can be connected to the ECMO circuit, avoiding the need for an additional central venous catheter, which has risks related to insertion and infection. In a recent survey of centers in the international registry, 51% reported use of a CRRT device and 22% reported use of a hemofilter in-line with the ECMO circuit. The ECMO circuit can be accessed for CRRT by connecting an in-line hemofilter or connecting a CRRT system with a device blood pump.

Hemofilter in-line: The hemofilter can be connected in-line to the ECMO circuit after the pump because the positive pressure enables forward flow through the hemofilter and return to the segment of the ECMO circuit before the pump. This option requires less circuit priming volume and does not require an additional blood pump device. Early detection of clotting is challenging because the CRRT circuit includes no pressure sensors. However, infusion pumps are required to regulate effluent (ultrafiltrate and dialysate) flow and to deliver therapy fluid (dialysate or replacement solutions). Risks of off-label use of infusion pumps to regulate fluid removal include inaccurate volume removal reported as high as 840 mL in 24 hours. Another option is to measure the effluent by weight or volume hourly, but doing that increases nursing workload and requires vigilance by the nursing staff.

CRRT circuit and device connected to ECMO circuit: Connecting a CRRT device to the ECMO circuit is the most precise with fluid removal and therapy fluid delivery. The CRRT access and return tubing can be connected to ECMO circuits in multiple ways, depending on the circuit type and inlet ports available. Regardless of the ECMO type (venovenous or venoarterial), the CRRT return tubing is always connected before the oxygenator, whether using the port before the oxygenator or farther away on the segment before the pump. The oxygenator serves as a “trap” for air or a clot that may form or enter the system. The CRRT access tubing can be connected on either the segment before or the segment after the oxygenator, but is most often connected before the oxygenator and after the pump.

The extracorporeal CRRT circuit volume creates a “shunt” effect, which results in a difference in actual blood flow rate compared with the blood pump setting. The actual blood flow rate can be measured (in liters per minute) with an ultrasonic probe on the return tubing of the ECMO circuit to monitor actual flow to the patient. Because CRRT machines are designed with standard pressure alarm defaults on the access and return pressure sensors, the devices may need adjustments to accommodate ECMO circuit pressures. Five-inch (13-cm) extensions and high-flow stopcocks can be used to alter resistance and manipulate pressures within the CRRT circuit (see Figure).
Knowledge of the principles of circuit flow and related pressure measurements of both ECMO and CRRT extracorporeal circuits is essential for clinicians combining and monitoring therapy circuits. For example, circuit pressures sensed before the blood pump, both centrifugal and roller pumps, are negative and pressures beyond the pump are always positive. Additionally, dual competency is required to optimize safe care for both systems that have different technology for blood pumps, air detectors, and circuit pressure sensors.

Outcome
After 2 weeks of both CRRT and ECMO therapy, Mr S had return of urine output rates of more than 50 mL/h and resolution of his metabolic acidosis. His hemodynamic status was stable without vasopressor medications and his oxygenation improved (Pao2/Fio2 ratio, 220) on ECMO circuit and ventilator Fio2 settings of 40%. Trials of weaning from the ECMO therapy were successful, and the cannulas were removed. The CVVHD therapy was continued another day for additional fluid removal and then discontinued. Renal recovery was anticipated for Mr S because his serum creatinine level was stable at 1.2 mg/dL and his urine output was adequate for the week following discontinuation of CRRT.

Summary
Management of CRRT varies depending on the indication for therapy, the patient’s clinical condition, and the simultaneous critical care therapies being administered. Although CRRT is typically indicated after the diagnosis of AKI or when chronic renal disease exists, it may also be useful in preventing or mitigating the severity of AKI in the context of rhabdomyolysis. Fluid overload has a poor prognosis in patients with decompensated heart failure, cardiorenal syndrome, and ARDS with ECMO support. CRRT is an effective method for control of fluid, electrolyte, and acid-base status in many populations of critically ill patients.

REFERENCES


**CE Test Instructions**

This article has been designated for CE contact hour(s). The evaluation tests your knowledge of the following objectives:

1. Identify the mode of continuous renal replacement therapy (CRRT) most effective for myoglobin clearance.

2. Compare the mechanisms of solute removal for continuous venovenous hemofiltration and continuous venovenous hemodialysis.

3. Describe the 2 main blood access options for CRRT with extracorporeal membrane oxygenation.

Contact hour: 1.0
Pharmacology contact hour: 0.0
Synergy CERP Category: A

To complete evaluation for CE contact hour(s) for test ACC731, visit www.aacnaconline.org and click the “CE Articles” button. No CE test fee for AACN members. This test expires on January 1, 2020.

American Association of Critical-Care Nurses is an accredited provider of continuing nursing education by the American Nurses Credentialing Center's Commission on Accreditation. AACN has been approved as a provider of continuing education in nursing by the State Boards of Registered Nursing of California (#01036) and Louisiana (#LSBN112).