Continuous Renal Replacement Therapy for the Management of Acid-Base and Electrolyte Imbalances in Acute Kidney Injury

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Continuous renal replacement therapy (CRRT) is used to manage electrolyte and acid-base imbalances in critically ill patients with acute kidney injury. Although a standard solution and prescription is acceptable in most clinical circumstances, specific disorders may require a tailored approach such as adjusting fluid composition, regulating CRRT dose, and using separate intravenous infusions to mitigate and correct these disturbances. Errors in fluid prescription, compounding, or delivery can be rapidly fatal. This article provides an overview of the principles of acid-base and electrolyte management using CRRT.

Key Words: CRRT, Hyponatremia, Acidosis, Alkalosis, Hyperkalemia

INTRODUCTION

Acute kidney injury (AKI) may present with life-threatening electrolyte or acid-base disorders. Intermittent or continuous forms of renal replacement therapies (RRTs) are used for blood purification in AKI. Critically ill patients who require renal support are often hemodynamically unstable and may require continuous renal replacement therapy (CRRT) for the management of acid-base and electrolyte imbalances.

Occasionally, the CRRT prescription may also need to be individualized depending on the duration and/or severity of a specific disorder. A variety of CRRT techniques may be applied in such settings to achieve controlled correction of electrolytes such as adjustment of replacement fluid (RF) or dialysate composition, regulation of CRRT dose based on kinetic modeling, or using separate electrolyte infusion(s). As CRRT can be most effective over longer periods of time, serious disturbances in electrolyte homeostasis may occur in the absence of thoughtful design and monitoring of the intervention. Understanding the principles of electrolyte and acid-base management with CRRT is necessary as errors in fluid prescription, compounding, or delivery may lead to significant complications or even death.

The makeup of the dialysate/RF in combination with the specifics of the dialysis technique is of paramount importance in safely accomplishing treatment goals.

DIALYSATE OR REPLACEMENT FLUID QUALITY

In the United States, sterile substitution fluid is used in continuous venovenous hemofiltration (CVVH), continuous venovenous hemodialysis (CVVHD), and continuous venovenous hemodiafiltration. The fluid is either prepared and prepackaged by a manufacturer or occasionally custom-made in a compounding pharmacy. Customized injection (spiking) of electrolyte solutions into commercial fluid bags by the pharmacy or at the bedside should be avoided and considered only when absolutely necessary as with cases of severe dysnatremia. Spiking of CRRT fluids carries the risk of contamination with endotoxins or bacteria and the risk of human error (incorrect dose).[1,2]

FLUID COMPOSITION

Many commercial, sterile CRRT solutions with varying electrolyte compositions are available and provide a range of fluid options to treat different electrolyte disorders. There is little practical difference in the composition of replacement or dialysate fluid, however, and many dialysate fluids are used off-label as RF. These solutions contain the following concentrations of electrolytes and glucose: sodium 136 to 140 mEq/L, chloride 100 to 113 mEq/L, potassium 0 to 4 mEq/L, calcium 1.5 to 3.0 mEq/L, magnesium 1.0 to 1.5 mEq/L, and glucose 0 to 100.0 mg/dL. Hyponatric and calcium-free solutions are also available and seem to be designed for use with regional citrate anticoagulation (RCA); although this may not be explicitly stated. Lactate or bicarbonate is used as the alkalinizing anion in a concentration range of 25 to 40 mEq/L. When RCA is used for maintaining the patency of the CRRT circuit, the citrate also serves as a source of base to replace bicarbonate losses across the filter. Patients receiving high-volume exchanges or those with severe tissue acidosis and/or liver failure may be unable to convert the lactate or citrate load effectively, resulting in hyperlactatemia or hypercitratemia and metabolic acidosis.[3,4] Bicarbonate-based fluids are available as twin-bag systems, one containing the bicarbonate solution and the other at least glucose and the divalent cations calcium and magnesium, and the 2 compartments are mixed immediately before use.[5] Most commercially available CRRT solutions do not

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contain phosphate, and separate phosphate supplementation is generally required to prevent hypophosphatemia during CRRT.

SODIUM

Sodium disorders can be present with dialysis-requiring AKI, CKD, or ESRD.[6-8] The treatment guidelines (2013 Expert Panel Recommendations, 2014 European Hyponatraemia Guideline Development Group) do not address the unique situation where dysnatremias and dialysis-requiring kidney failure coexist. However, although the overall strategy for the management of dysnatremias must include RRT in renal failure, the rate of correction should not be different from the nondialysis population. Controlled correction of sodium disorders is necessary to avoid development of cerebral edema in hypernatremic patients and osmotic demyelination syndrome in hyponatremic patients. For serum sodium that is only mildly decreased or increased, the hemodialysis dialysate sodium could be adjusted to stay within 6 to 8 mEq/L above or below the patient's serum sodium. However, patients with more extreme dysnatremia (<120 mEq/L or >165 mEq/L) would be best treated using CRRT.

Strategies to avoid overly rapid correction of chronic dysnatremias include adjusting the dialysate or the RF sodium concentration,[8-10] regulating the overall and hourly clearance delivered by RRT,[8] with or without the additional use of separate hypotonic or hypertonic infusions.

CLINICAL SUMMARY

- Controlled, predictable correction of electrolyte and acid-base derangements is feasible with continuous renal replacement therapy (CRRT).
- Eliminating CRRT system downtime and declining dialyzer performance preferably with regional citrate anticoagulation may enhance our ability to apply simplified kinetic modeling to the CRRT control of select solutes, for example, sodium and bicarbonate.
- CRRT can mitigate and thereby mask profound pathophysiologic processes that are disturbing the electrolyte and acid-base balance.
- Embracing a kinetic analytical approach to the understanding of solute fluxes during CRRT allows for the prompt recognition of pathologic conditions such as ongoing tissue breakdown and ischemia.

MANAGEMENT OF CHRONIC HYPONATREMIA WITH RENAL FAILURE

Diluting Dialysate/RF [Na^+] in CRRT

Commercial hyponatric dialysate or RFs are lacking. The few available hyponatric dialysate solutions (sodium 120-130 mEq/L range) are calcium-free and used with RCA along with hypertonic sodium citrate– and calcium-containing infusions, making them impractical for highly predictable and safe correction of severe hyponatremia. Therefore, commercially available CRRT fluids need to be diluted with free water to achieve any desired sodium concentration in institutions with adequate pharmaceutical support. A stepwise switch every 24 hours to fluid bags with 8 to 10 mEq/L higher sodium concentration than the patient's current serum sodium can be considered. This approach of using solutions with successively higher sodium may be reliable in avoiding any overcorrection in the serum sodium due to CRRT. The dilution can be achieved by injecting free water into the dialysate/RF bag or exchanging a specific volume of dialysate/RF with an equivalent amount of water. We have previously described both methods in detail.[8]

Controlling Sodium Change in Hyponatremia with CRRT by Applying Kinetic Principles

Changes in sodium are slower with CRRT when compared with hemodialysis due to the lower delivered sodium dialysance with the low volumes of dialysate/RF used per hour and/or the lower blood flow rates. Nevertheless, attention should be given to factors that influence the rate of change in serum sodium for each individual during the CRRT procedure. Sodium kinetic models have been shown to predict end-dialysis plasma water sodium concentration.[11] Most reported equations are complex and may be prohibitive for daily use. Instead, a single-pool, fixed-volume, sodium kinetic equation may be used in a manner similar to urea kinetics for the quantification of sodium changes during CRRT.[8] This is because sodium and urea have similar dialyzer solute transfer characteristics as both are nonprotein-bound small solutes with similar effective blood water flow (QBe). Therefore, effective urea clearance (K) can be used to estimate sodium dialysance (D).[12] Modifiers introduced by the Donnan effect and the laboratory reporting of serum sodium cancel each other and may be ignored while preserving clinically acceptable accuracy.

The validity of using single-pool urea kinetics to describe intradialytic urea changes during sustained low-efficiency hemodialysis and CRRT has been demonstrated.[13,14] Sodium kinetic modeling will require quantitative measurement and/or estimation of variables involved in the transfer of sodium ions across the dialyzer or the filter such as estimating the dialysance of sodium, its generation rate (nonisotonic sodium and potassium gain or loss from the body), and apparent volume of distribution (total body water). The application of kinetic modeling to CRRT will also require elimination of system downtime, which could be best achieved by effective anticoagulation. Although kinetic models may be helpful in predicting the rate of change in sodium level with a certain CRRT dose, frequent laboratory confirmation is still advised. Variables that affect sodium change may change over time, and readjustment of the CRRT dose may be necessary.

A clinical application of the sodium kinetic model during CRRT treatment to a patient presenting with severe hyponatremia and AKI has been described by our group.[8] By applying fixed-volume single-pool