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Nutrition Support in Acute Kidney Injury

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Abstract

Acute kidney injury is a frequent complication affecting many hospitalized patients and is associated with increased morbidity and mortality. Acute kidney injury often occurs in conjunction with critical illness, which is a hypermetabolic state presenting with hyperglycemia, insulin resistance, hypertriglyceridemia, and increased protein catabolism. In addition to addressing these changes, the clinician should evaluate the important nutrition implications of decreased kidney function. These include vitamins, electrolytes, minerals, trace elements, and the presence and type of renal replacement therapy. Optimal nutrition management in acute kidney injury includes providing adequate macronutrient support to correct underlying conditions and prevent ongoing loss, supplementing micronutrients and vitamins during renal replacement therapy, and adjusting electrolyte replacement based on the degree and extent of renal dysfunction.

Acute renal failure is a common complication affecting approximately 5% of hospitalized patients and 10%–30% of patients managed in intensive care units. No universal definition for acute renal failure currently exists, although the Acute Dialysis Quality Initiative (ADQI) has proposed updating the nomenclature from *acute renal failure* to the more current *acute kidney injury* (AKI). In addition, ADQI has proposed a consensus definition for AKI summarized by the acronym RIFLE. RIFLE contains 3 stages of kidney injury stratified by severity (risk, injury, and failure) and 2 outcomes (loss and end-stage kidney disease). These criteria are based on the combined measurements of serum creatinine or glomerular filtration rate and urine output.

AKI is associated with a sudden decline of glomerular filtration rate with an accumulation of metabolic waste products (eg, urea), toxins, and drugs along with alterations in the intrinsic functions of the kidney. The kidneys are responsible for many regulatory functions, including acid-base equilibrium, fluid and electrolyte balance, gluconeogenesis, and secretion of the hormones erythropoietin and the conversion of vitamin D3 into its active form. These functions are impaired to varying degrees based on the extent, magnitude, and duration of the AKI. Arising and escalating dysfunction of these processes results in necessary alterations in the patient's fluid, macronutrient, and micronutrient management.

Glucose

The most common glucose disorders encountered in critically ill patients are hyperglycemia and increased insulin resistance. Hepatic glycogenolysis and gluconeogenesis are increased from the actions of the catabolic hormones (glucagon, epinephrine, and cortisol). Critically ill patients have decreased insulin-dependent glucose utilization in skeletal muscle and adipose tissue, which contributes to insulin resistance and hyperglycemia.[1] Under normal conditions, the kidneys contribute 15%–25% of gluconeogenesis and approximately 10%–20% of glucose uptake, and they are responsible for 30% of insulin catabolism.[2,3] Patients with AKI are prone to exacerbated insulin resistance due to decreased renal gluconeogenesis and decreased hormonal clearances of insulin and glucagon. The exact contribution of the altered carbohydrate metabolism in AKI in critically ill patients is unclear; however, the severity of insulin resistance in AKI is correlated with mortality and remains significant after correction for severity of illness, cortisol, diabetes, and other patient-related factors.[4]

Lipid

Impaired lipolysis in AKI results in an increase in plasma triglycerides, very low-density lipoproteins, and low-density lipoprotein, whereas the total circulating cholesterol and high-density lipoprotein are decreased.[5] AKI also results in decreases of hepatic triglyceride lipase and peripheral lipoprotein lipase activity by 50%, increasing the risk of hypertriglyceridemia,[3] and the activity of lipoprotein lipase is further decreased if metabolic acidosis is present.[6] With these lipid metabolism derangements, parenteral administration of lipids has shown to have reduced clearance in patients with AKI. These changes can partially be attenuated by the administration of amino acids and glucose.[5] Although the clearance of lipids is decreased in AKI, fatty acid oxidation is preserved; lipids remain an important energy source in this patient population.

Protein

The liver uses amino acids, lactate, and glycerol for glucose and acute-phase protein production in critical illness. Although critical illness is associated with an increase in protein catabolism, AKI alone does not always result in a catabolic state. However, if both AKI and critical illness are present, the result is a prolonged intense state of catabolism.[3] Metabolic acidosis in AKI, along with increased insulin resistance in critical illness, further promotes increased protein catabolism. Transport of amino acids into skeletal muscle is altered, and synthesis of proteins, other than visceral and acute-phase proteins, is inhibited.[7] The ability to correct these protein deficiencies with exogenously administered amino acids is frequently insufficient to correct the catabolic state, but supplementation may decrease the net rate of body loss.[7] The clearance of most amino acids in these patients is increased up to 1.3–1.8 g/kg/d.[8] A few noteworthy changes in amino acid concentrations occur in AKI. The serum concentrations of phenylalanine, methionine, taurine, and cysteine are elevated, whereas serum valine and leucine levels are decreased. Also, several non–essential amino acids (EAA; tyrosine, arginine, and glutamine) become conditionally essential or indispensable. Last, the conversion of phenylalanine to tyrosine in these patients becomes inadequate.[9]

With this understanding, specialty amino acid solutions were marketed for use in patients with AKI; however, no appreciative outcome differences were observed. Mirtallo and colleagues[10] compared EAA solutions with a combination of EAA and non-EAA solutions in 45 patients receiving parenteral nutrition (PN) but not receiving dialysis. Although significant differences were observed between the groups with respect to urea nitrogen appearance and net protein utilization, these differences did not result in any significant differences in estimated protein nitrogen balance or mortality. Other studies have investigated various combinations of specialty amino acid administration, including hypertonic glucose plus EAA solution to hypertonic glucose alone, high EAA delivery to low EAA delivery, and glucose plus EAA solutions plus histidine to glucose plus standard amino acid solution to glucose plus standard amino acid solution plus lipids.[11-14] Recovery from AKI and an increased rate of survival on dialysis were observed in the groups receiving hypertonic glucose plus EAA vs hypertonic glucose alone, but again, no outcome differences were observed between any of the specialty amino acid solutions. At this time, the international and national guidelines do not support the use of the specialty renal amino acid products.[14-16]

Energy Expenditure

Provision of energy and protein in adequate amounts of nutrients may help prevent protein energy wasting (PEW) by promoting tissue repair and supporting the immune system. The kidneys, although only approximately 0.5% of total body mass, are responsible for nearly 10% of the resting energy expenditure. AKI, without critical illness, does not appear to have a direct effect on the resting energy expenditure.[17] In patients with AKI and sepsis, metabolic rates were found to be increased compared with nonseptic patients with normal renal function. The increase in metabolic rates also persisted after correction for increases in metabolic demand secondary to fever. Energy expenditure requirements are therefore a function of the severity of the underlying conditions, prior nutrition status, and comorbidities rather than AKI alone.[18] AKI is often associated with critical illness, which is associated with significant changes to the metabolic rate. These concomitant disorders make it difficult to distinguish AKI's precise contribution to metabolic disorders.

Critical illness is a hypermetabolic state with increases in energy expenditure proportional to the amount of stresses experienced.[19] In the AKI population, the maximal metabolic energy expenditure is limited to approximately ~130% of normal.[17] In critically ill patients, plasma concentrations of catecholamines, cortisol, and glucagon are increased along with inflammatory mediators and cytokines, resulting in increased skeletal muscle catabolism, insulin resistance, and increased gluconeogenesis/glycogenolysis. These changes are thought to be beneficial in the acute phase to provide energy and substrates for protein synthesis and replication in immune cells, as well as hepatic and gastrointestinal tissue. However, during prolonged intense stress, a severe depletion of body stores may adversely affect recovery and may be detrimental to morbidity and mortality.[1]

Nutrition Goals

The goals of nutrition support in patients with AKI are consistent with the goals for critically ill patients and include delivery of energy, protein, and micronutrients to prevent PEW; preservation of lean body mass; maintenance of nutrition status; avoidance of further metabolic derangements; enhancement of wound healing; support of immune function; attenuation of the patients' inflammatory status; and improvement of the oxygen radical scavenging system and of endothelial function and reduction in mortality.[16,20]

Enteral nutrition (EN) is the preferred method of nutrition delivery in patients with a functioning intestine. PN should be reserved for those patients unable to tolerate EN or if EN does not meet their energy and protein requirements.

Nutrition Assessment

PEW is the standard terminology established by the International Society of Renal Nutrition and Metabolism to define the recognized increased energy expenditure, muscle loss, and malnutrition associated with AKI.[21] PEW in AKI results from nonspecific inflammatory processes, catabolic illnesses, nutrient losses from dialysis, metabolic acidosis, and endocrine disorders, including resistance to insulin, growth hormone, and insulin-like growth factor 1 (IGF-1); hypergluconemia; and hyperparathyroidism.[21] In addition, comorbid conditions and complications, including trauma, thermal injury, surgery, and infections, further worsen the patient's nutrition status. Hospital length of stay; complications, including sepsis and cardiovascular and respiratory failure; and hospital mortality significantly increase when nutrition status is impaired.[22] Accurate assessment of the patient's nutrition status is imperative.

PEW is diagnosed if 3 characteristics are present: (1) low serum levels of albumin, prealbumin, or cholesterol; (2) reduced body mass (low or reduced body or fat mass or weight loss with reduced intake of protein and energy); and (3) reduced muscle mass (muscle wasting or sarcopenia, reduced mid-arm muscle circumference). However, diagnosis of PEW in patients with AKI may be challenging. Although hypocholesterolemia and low serum albumin concentrations are suggested as nutrition markers and have been linked to survival in AKI, well-known limitations with these biochemical markers preclude them from being truly diagnostic. Prealbumin is renally excreted, thereby decreasing its utilization as a nutrition marker in patients with AKI. In addition, a negative acute-phase response due to inflammation is associated with suppression of prealbumin. Associated edema and fluid shifts from the AKI may alter somatic protein test (eg, mid-arm muscle circumference), making it difficult to obtain an accurate measurement.[23]

Recognizing these complications, alternative markers have been suggested to help identify patients in whom nutrition support should be considered. IGF-1 has been investigated as a mortality predictor in patients with AKI and as a specific marker for malnutrition in patients undergoing hemodialysis, but limited information precludes its recommendation as a routine

Table 1. Nitrogen Balance, Urea Nitrogen Appearance, and Protein Catabolic Rate Equations

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Nitrogen balance, g/d = Nitrogen intake - UUN + nonurea urinary nitrogen (2 g/d) + fecal nitrogen (2 g/d)
Urea nitrogen appearance, g/d = UUN + [(BUN2 - BUN1) × 0.6 × BW1] + [(BW2 - BW1) × BUN2]

where net protein breakdown = UNA × 6.25; BUN1 = initial concentration of BUN, postdialysis, g/L; BUN2 = final concentration of BUN, predialysis, g/L; BW1 = postdialysis weight, kg; BW2 = predialysis weight, kg.

PCR, g/d = UNA × 6.25

UUN, urinary urea nitrogen; BUN, blood urea nitrogen; BW, body weight; PCR, protein catabolic rate.

nutrition marker.[24] C-reactive protein, a marker of inflammation, may be useful in identifying patients at high risk for mortality and, used in conjunction with visceral protein markers (eg, albumin, prealbumin), can improve patients' nutrition assessment.[15]

Nitrogen balance (measurement of nitrogen intake minus nitrogen output), urea nitrogen appearance (UNA; measurement of the net rate of protein catabolism), and protein catabolic rate (PCR; measurement of net protein degradation) may be measured to assess the patient's protein breakdown (Table 1). For an accurate determination, the standard method for measuring a patient's nitrogen balance requires a creatinine clearance of >50 mL/min/1.73 m,[2] making utilization of the nitrogen balance in patients with AKI difficult. In patients with AKI, ascertaining the UNA is less laborious and may be more accurate; however, protein intake fluctuation and varying catabolic presentations may result in calculated erroneous results.[9,25]

To best assess the nutrition status of patients with AKI, the clinician must recognize the inherent complications associated with the anthropometric markers, implementing good clinical judgment and an appreciation for the patient's history, presentation, and clinical course.

Nutrient Requirements

Macronutrients
Energy delivery in patients with AKI is recommended from 25–35 kcal/kg/d.[15,16] Nutrition support should be based on estimated metabolic stress and protein energy requirements. In patients presenting with stage 1 AKI (see Table 2),[26] caloric requirements are based on their underlying disease state or complication because stage 1 AKI has limited effects on the patient's energy expenditure. Patients presenting with stage II or III AKI (see Table 2),[26] however, will usually have greater caloric requirements because of the advanced disease presentation and concomitant underlying disease state or complication.

Higher caloric delivery has been studied but does not appear to improve patient outcomes. Fiaccodori and colleagues[23] studied patients with AKI and hemodialysis receiving either higher calorie PN (40 kcal/kg/d) or lower calorie PN (30 kcal/kg/d). Nitrogen intake for both groups was 0.25 g/kg/d. Patients receiving the higher PN did not show a significant improvement in their estimated nitrogen balance, PCR, or urea generation rate but did present with increased

Table 2. Staging System for Acute Kidney Injury (AKI)

AKI Stage	Serum Creatine	Urine Output
I	Increase in serum creatine ≥0.3 mg/dL or increase to ≥150%-200% (1.5- to 2-fold) from baseline	<0.5 mL/kg/h for more than 6 hours
II	Increase in serum creatine >200%-300% (>2- to 3-fold) from baseline	<0.5 mL/kg/h for more than 12 hours
III	Increase in serum creatine to >300% (>3-fold) from baseline or serum creatine ≥4 mg/dL with an acute increase of at least 0.5 mg/dL	<0.3 mL/kg/h for more than 24 hours, or anuria for more than 12 hours

Adapted from Mehta et al.[26]

metabolic complications, including increased serum triglycerides and glucose concentrations, and insulin requirements.

Protein delivery in patients presenting with stage I AKI should be based on the patient's underlying disease or complication. Lowering the protein delivery may be necessary to avoid azotemia. However, restricting protein or delivering inadequate amounts of protein is not advised because it increases the patient's risk for protein malnutrition and associated complications.[25] Advanced presentations of AKI in acutely ill patients usually require renal replacement therapy (RRT), including intermittent hemodialysis (IHD) and continuous RRT (CRRT), because of the catabolism associated with the critical illness, metabolic acidosis, and increased insulin resistance. Recommendations for protein delivery in patients with AKI receiving RRT range from 1.5–2.5 g/kg/d and depend on the patient's severity of AKI, the underlying disease states and complications, and the type of RRT employed.[14-16] Patients receiving CRRT demonstrate positive nitrogen balance when dosages of 1.8–2.5 g/kg/d of protein are delivered, whereas protein dosages from 1.5–2.0 g/kg/d may be sufficient for patients undergoing IHD.[15]

Electrolytes/Minerals
The kidneys are responsible for regulating many electrolytes,[27] vitamins, and trace elements. The breakdown in electrolyte and micronutrient regulation along with the addition of RRT produces a complex clinical scenario. It is generally recommended to withhold or minimize exposure to these renally regulated electrolytes and micronutrients in patients with AKI who are not receiving RRT. However, the initiation of RRT and/or nutrition support therapy (NST) can have a dramatic effect on consumption and utilization of many micronutrients. Brown and Compher,[15] in conjunction with the American Society of Parenteral and Enteral Nutrition, published guidelines for NST in patients with AKI. The recommendations for electrolyte and micronutrient management were to adjust intake based on serum concentration monitoring. The recommendation was provided as grade D, suggesting limited data to clearly delineate further recommendations.

Potassium
Potassium, a monovalent cation, is found extensively in the intracellular compartment and is tightly regulated by the kidney.[27] Potassium is important in many aspects of cellular homeostasis,

and imbalance can have severe adverse effects, including arrhythmias, rhabdomyolysis, and death. Along with primarily renal regulation, many other factors may influence serum potassium concentrations, including losses via the gastrointestinal (GI) tract and plasma pH. With regards to patients with AKI, it is common to see hyperkalemia due to decreased renal excretion, acidosis, and GI losses. In general, in patients with AKI not receiving RRT, it is acceptable to withhold potassium until/unless the patient becomes hypokalemic. In the setting of hypokalemia, there are multiple approaches to the management of potassium for patients receiving RRT. Many patients may simply be managed by manipulation of the dialysis prescription. In the event of continued hypokalemia after altering the dialysis prescription, as needed replacement may be administered. Modest bolus doses of potassium, 10–20 mEq for mild to moderate hypokalemia (2.5–3.4 mEq/L) and 20–40 mEq for severe hypokalemia,[27,28] should be considered a starting point. Continuous daily boluses of potassium may warrant an adjustment to the PN or NST but should also be modestly added. With many factors affecting serum potassium concentrations and endless clinical case scenarios, sound judgment is imperative.

Calcium
Calcium has many important physiologic roles, and AKI can dramatically alter a patient's calcium regulation. Calcium is tightly regulated by parathyroid hormone (PTH) and activated vitamin D3, along with the kidneys. The final step of activation for the conversion to 1,25 dihydroxy vitamin D3 occurs in the kidney and is extensively limited in patients with AKI. This loss of vitamin D3 activity can lead to a lack of enteral calcium absorption. Additional causes for hypocalcemia in AKI include hyperphosphatemia, as well as significant losses from RRT effluent and citrate anticoagulation.[29] Subsequently, hypocalcemia is commonly observed in patients with AKI, which can result in hypotension and clotting disorders. As with potassium, there are multiple approaches for the management of hypocalcemia in patients with AKI depending on the presence and type of RRT. Patients receiving IHD may require manipulation of the dialysis prescription. For patients receiving CRRT, the postdialysis circuit continuous infusion of calcium may be adjusted based on serum ionized calcium concentrations. For patients not on CRRT and requiring additional calcium, recommendations established by Kraft and colleagues[27] may be followed. These recommendations are as follows: (1) for mild to moderate hypocalcemia (total serum calcium concentration of <8.6 to 7.5 mg/dL or ionized calcium concentration of <1.1 to 0.9 mmol/L), patients should be administered calcium gluconate 1–2 g intravenously over 30–60 minutes, repeating every 6 hours as needed. (2) For symptomatic or severely hypocalcemic patients (total serum calcium concentration of <7.5 mg/dL or ionized calcium concentration of <0.9 mmol/L), either calcium gluconate 3 g intravenously or calcium chloride 1 g intravenously should be administered over 10 minutes. If calcium chloride is the chosen salt, it should be administered via a central line only to prevent extravasation and tissue necrosis.

Phosphorus
Phosphorus is an important intracellular electrolyte necessary in cellular metabolism and the production of adenosine triphosphate (ATP), necessary for cardiac and diaphragmatic contraction. Phosphorus, like calcium, is also regulated by vitamin D, PTH, and the kidneys; in patients with AKI, hyperphosphatemia is commonly observed. Hyperphosphatemia not only

Table 3. Advantages and Disadvantages of the Pharmacological Agents Available for the Treatment of Hyperphosphatemia

Products	Advantages	Disadvantages
Calcium salts	Effective Low cost	Possible increase in serum calcium concentrations; hypercalcemia
Aluminum hydroxide	Effective Low cost	Aluminum concentrations may accumulate; aluminum toxicity Not recommended for long-term usage
Magnesium hydroxide	Effective Low cost	Possible increases in serum magnesium concentration; hypermagnesemia. May cause diarrhea.
Sevelamer hydrochloride	Effective	Expensive; hypercalcemia associated with long-term usage Nausea/vomiting (~20%)
Lanthanum carbonate	Effective	Expensive; hypercalcemia associated with long-term usage Nausea/vomiting (~10%)

exacerbates existing hypocalcemia but may also lead to calcium-phosphate crystal deposition in soft tissues, resulting in additional or worsening organ dysfunction. Treatment of phosphorus disorders in patients with AKI can vary widely depending on the type and presence of RRT, as well as the presence or lack of NST. Patients not receiving RRT typically require phosphorus restriction and, in many cases, phosphate binders (Table 3). IHD commonly results in hyperphosphatemia as there is not sufficient dialysis time to remove adequate amounts of phosphorus. Conversely, patients receiving CRRT typically have hypophosphatemia and require supplemental phosphorus. It is common to replace phosphorus on an as needed basis in increments of 15–20 mmol per dose.

Magnesium

Also highly regulated by the kidney, magnesium performs a variety of different roles in vivo. Magnesium is an integral cofactor for many enzyme systems, such as the Na/K ATPase pump, which is responsible for maintaining the normal potassium gradient. In the setting of AKI, hypermagnesemia may occur due to a lack of renal excretion. If severe, hypermagnesemia may lead to exacerbation of hypotension. Withholding magnesium is generally advised for patients with AKI not receiving RRT. In the setting of RRT, patients will require supplementation. Some clinicians suggest supplementation in the form of continuous infusion, but as needed replacement boluses of 2–4 g magnesium sulfate may also be a viable option.[30]

Micronutrients

Much discussion and research regarding micronutrients is focused on low serum concentrations. The interpretation of these "low" serum concentrations should be tempered with the thoughtfulness that the acute-phase response commonly occurs in patients with AKI.[31-33] This activation of the acute-phase response causes a rapid redistribution of carrier proteins (eg, retinol binding protein) for vitamins as well as the distribution of trace elements into the tissues (eg, selenium and zinc). This response is in an effort to distribute these critical elements and compounds to the tissues for incorporation into enzyme systems. These enzyme systems have a plethora of actions, from tissue reconstruction to immunologic enhancement. In the setting of AKI, the homeostasis of these micronutrients can be drastically altered, resulting in a

complicated picture. Supplementation of micronutrients should be initiated preemptively only when quality research supports its implementation and reliable dosages are recommended.

Vitamins

B Vitamins: Folic Acid/Pyridoxine/Thiamine

Loss of water-soluble vitamins is common in patients receiving RRT, and supplementation may be required. Several studies have assessed B vitamin needs in AKI patients receiving CRRT. Fortin and colleagues[34] studied CRRT clearance and removal of folic acid and pyridoxal-5′-phosphate by analyzing the daily concentrations of each micronutrient. The investigators found significant losses of both folic acid and pyridoxal-5′-phosphate and recommended supplementation of each micronutrient to a minimum of 2–3 times the Recommended Daily Allowance (RDA). In patients with AKI receiving CRRT, folate 1 mg daily and pyridoxine 10 mg daily are recommended.

The dose of thiamine for patients undergoing CRRT varies widely in the literature. Berger and colleagues[35] demonstrated losses of ~4 mg/d of thiamine. Fiaccadori and colleagues[36] suggested thiamine losses of 1.5 times the standard dose contained within typical intravenous multivitamin (MVI) preparations, whereas Chiolero and Berger[37] recommended supplementing thiamine at a dose of 100 mg/d in patients receiving CRRT. This represents a wide range in dosing possibilities. As thiamine is a water-soluble vitamin with little toxicity, it would be reasonable to provide 25–100 mg per day of thiamine supplementation in patients receiving CRRT.

Vitamin C

Vitamin C has been found to be problematic in patients with AKI. Vitamin C is converted to oxalate, which can accumulate in renal tubules as a toxin, leading to renal dysfunction.[38,39] Recognizing this complication, it is recommended to not exceed 100 mg/d of vitamin C in patients with AKI not receiving RRT in an effort to minimize risk of further renal injury. Story and colleagues[40] compared serum concentrations of multiple vitamins and trace elements in 8 patients receiving CRRT with a "normal" control group. The CRRT group had lower concentrations of selenium, zinc, vitamin E, and vitamin C. The CRRT group was also found to have vitamin C, copper, and chromium in the ultrafiltrate. With this extra loss of vitamin C from CRRT, it may be permissible to increase vitamin C to 200 mg/d in patients receiving CRRT. However, dosages of vitamin C >250 mg/d are not advised because of the risk of secondary oxalosis and further renal injury.[20]

Vitamin A

Vitamin A has been linked to toxicity in patients with renal dysfunction. Gleghorn and colleagues[41] reported 3 cases of vitamin A toxicity with associated hypercalcemia in patients with renal failure receiving an MVI in the PN. The hypercalcemia resolved with the removal of vitamin A delivery. The reported dosage these patients were receiving was 1500 mcg/d of retinol. The current formulation of injectable MVI provides 990 mcg/d, which is slightly above the

dietary reference intake of 700 mcg/d in women and 900 mcg/d in men. Changes to vitamin A dosage delivery are not recommended but warrant monitoring for patients with AKI.

Trace Elements

Deficiency in trace elements can lead to an imbalance in the regulation of oxidative stress, which is important in combating the acute-phase reaction. Trouble arises in the patient receiving CRRT —because trace elements are naturally small molecules, they may be easily removed during therapy. However, much like PN, CRRT dialysate fluids may also contain trace element contaminants. As discussed below, depending on the amount of contamination, this may impart a positive or negative balance during CRRT.

Zinc

Multiple reports of achieving a positive zinc balance have been reported in patients receiving CRRT.[30,35] This has been postulated to occur due to zinc contamination of CRRT dialysate and citrate use as an anticoagulant. Thus, supplementation of zinc beyond the standard dose contained within the nutrition support prescription is not recommended.

Selenium

Conversely, selenium deficiencies have been reported due to CRRT removal, with deficits estimated from 35–91 mcg/d.[35,41] Cumulative losses of selenium via CRRT are likely to result in deficiency if not corrected. An additional 100 mcg/d of selenium in addition to the standard multiple trace element preparation is recommended.[20]

Copper

Research studies have suggested a negative copper balance of approximately 400 mcg/d in renal failure patients receiving CRRT.[35,41] The suggested Dietary Reference Intake (DRI) is 300–500 mcg/d.[42] The standard multiple trace element preparation delivers 1000 mcg/d, which exceeds the DRI and the additional losses attributed to CRRT; therefore, additional supplementation is not necessary.

Conversely, it is quite common for critically ill patients to present with hepatobiliary dysfunction (defined as a total bilirubin >3 mg/dL). Many clinicians advocate the removal of copper from PN in patients with hepatobiliary dysfunction to prevent toxicity. Thus, depending on the clinical situation, it may be prudent to omit copper delivery.

Aluminum

Potassium phosphates, sodium phosphates, and calcium gluconate have been identified as major contributors to aluminum contamination in PN.[43] Brown and colleagues[44] evaluated the risk of aluminum exposure in AKI patients. The results indicated that few patients (7/36) were exposed to excessive amounts of aluminum, defined as aluminum content >5 mcg/kg/d. The investigators found that calcium gluconate contributed the greatest amount of aluminum to the PN product. It is prudent to recognize that patients with AKI receiving PN are at higher risk for aluminum

accumulation, but most patients will not receive excessive exposure to aluminum from the PN formulation.

Conclusion

Complications from AKI and critical illness include increased metabolism, hyperglycemia, insulin resistance, hypertriglyceridemia, and increased protein catabolism. Nutrition support is frequently required, and appropriate nutrition delivery, tailored to the patient's clinical presentation, is imperative. Energy requirements must be assessed, and macronutrient and macronutrient adjustments, based on the presence and type of renal replacement therapy, must be implemented.

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