Optimal Nutrition for Acute Rehabilitation in the PICU

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Abstract

Keywords

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Achieving optimal nutrition for a child who is receiving acute rehabilitation in the pediatric intensive care unit requires an individualized approach. Nutrition screening and assessment is necessary to identify children at high risk for complications who require targeted interventions. Early enteral nutrition can improve outcomes, and is thus preferred over parenteral nutrition in the absence of gastrointestinal contraindications. Measurement of caloric requirements with indirect calorimetry is essential to accurately prescribe nutrition support, while monitoring body composition can determine efficacy of nutrition therapies employed. The complex care of critically ill children receiving acute rehabilitation is composed of treatments that compete with delivery of prescribed nutrition. Repeated feeding interruptions can lead to nutrition deficits and prolonged recovery. Nutrition bundles that incorporate evidenced-based nutrition algorithms, methods to overcome nutrition barriers, and nutrition monitoring parameters can direct and optimize nutrition care for critically ill children in need of acute rehabilitation.

Introduction

Recent literature demonstrates that impaired muscle performance limits functional recovery of adult patients with acute respiratory distress syndrome more than their intrinsic lung disease.¹ In response to these findings, several institutions have initiated early mobilization protocols (or acute rehabilitation) in mechanically ventilated critically ill adults. Through their innovative efforts, intensive care unit mobility is shown to be safe and effective in adults despite high illness acuity, including the use of veno-venous extracorporeal membrane oxygenation.^{2–7} Limited evidence supports early mobilization in pediatric intensive care units (PICU); however, case reports suggest similar outcomes are possible in children.^{8–10}

Preillness nutritional state, as well as the nutrition provided during critical illness, impacts both the ability to perform rehabilitation and subsequent clinical outcomes

during and beyond the PICU stay. Children who are malnourished upon admission to the PICU are more likely to have electrolyte and nutrient deficiencies, immunosuppression, muscle weakness, and a longer duration of mechanical ventilation.¹¹ Once in the PICU, inadequate provision of nutrition can result in loss of lean body mass and impaired functional recovery, regardless of preexisting nutrition status. Specifically, cumulative calorie and protein deficits in critically ill children are associated with reduced weight and mid-upper arm circumference standard deviation scores, increased risk of infection, poor wound healing, longer mechanical ventilation requirements, and increased length of PICU stay.¹² Conversely, overfeeding is associated with the risk hyperglycemia, increased carbon dioxide production, prolonged mechanical ventilation, hepatic steatosis, and immune dysfunction. In addition, obese critically ill children with traumatic injuries have a higher

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incidence of decubitus ulcers, deep venous thrombosis, and a longer length of PICU stay.^{13,14} Therefore, assessing nutritional state, current needs, and optimizing intake will not only improve PICU outcomes but also provide the nutritional resources that patients need to achieve the most gains from acute rehabilitation in the PICU. A bundle that includes a nutrition assessment, an algorithm for monitoring and achieving nutritional targets, and strategies to avoid barriers to feeding can help achieve these goals.

Nutrition Assessment

Nutrition screening is conducted on admission by a dietetic technician, dietitian, nurse, physician, or other healthcare provider to identify the risk and presence of nutrition risk factors. The nutrition screen consists of an evaluation of weight, recent weight change, appetite, feeding difficulties, and admission diagnosis and determines whether a more detailed nutrition assessment by a registered dietitian is indicated.¹⁵ A nutrition assessment includes both a medical and dietary history, laboratory values, anthropometric measurements, and physical findings such as edema, abdominal distention, increased or decreased muscle and adipose tissue, signs of nutrient deficiency, and pressure ulcers. Furthermore, a nutrition assessment guides the nutrition algorithm by evaluating nutritional status and requirements, and creating a plan for tailored nutrition support and monitoring. Documentation of a nutrition assessment by a registered dietitian is associated with an increased caloric intake and use of the enteral feeding route in a multicenter study of critically ill children.¹⁶

Assessing caloric requirements is best done by indirect calorimetry (IC).^{15,17,18} IC determines energy expenditure through measurement of oxygen consumption and carbon dioxide production and is considered the gold standard. IC is preferred over potentially inaccurate predictive equations which can result in underfeeding and overfeeding of critically ill children, especially those who are underweight and overweight/obese, have neurologic trauma, burn injury, suspected hypermetabolism or hypometabolism, weight loss, and prolonged ventilation or PICU stay.¹⁵ Hypermetabolism is defined by measured energy expenditure >110% and hypometabolism is identified at <90% of calculated basal metabolic rate (BMR), respectively.

Recent evaluations of mechanically ventilated pediatric patients with severe traumatic brain injury unexpectedly reveal a lack of hypermetabolism,¹⁹ while an enteral intake that meets 120% of calorie and protein requirements during recovery improves infants' head circumference and brain growth.²⁰ Alternatively, excessive energy intake (>120% of measured energy expenditure) leads to accumulation of body fat and fails to attenuate erosion of lean body mass in children with severe burn injury.²¹

In circumstances where IC is not feasible due to lack of equipment, staff, or patient contraindications such as increased ventilator or oxygen requirements, BMR¹⁵ is calculated as shown in ►Table 1. BMR equations are derived from resting IC measurements in healthy children.^{22,23} Most PICU patients are hypometabolic compared with calculated BMR secondary to sedation and mechanical ventilation, increasing the potential for overfeeding with this method; however, no studies have evaluated clinical outcomes with caloric intake guided by IC measurements versus BMR calculations.¹⁸ The use of stress factors multiplied by BMR is discouraged, as it further increases the risk of overfeeding.¹⁵ However, a small subset of PICU patients, including those with burn injury, hyperthermia, dysautonomia, status epilepticus, and increased work of breathing, are likely to be hypermetabolic and require calories in excess of the calculated BMR.¹⁵ With adjustment of BMR for predicted metabolic state and physical activity, a caloric goal can be identified, with routine monitoring of nutrition parameters to periodically reassess requirements (►Table 2).

Nutrition Algorithm

Consistent, step-wise evidence-based nutrition protocols or bundles can optimize feeding tolerance and intake in critically ill children²⁴ (►Table 2, ►Fig. 1). Assessment of nutritional status and caloric requirements, an algorithm to direct route of feeding, nutrition initiation, and advancement, interventions for intolerance or barriers, and monitoring parameters are all important components of a nutrition bundle.²⁵ Periodic nutrition audits to identify deficiencies, address barriers, and provide feedback can improve adherence to the nutrition bundle.

A nutrition algorithm standardizes the choice between enteral nutrition (EN), parenteral nutrition (PN), or a

Table 1 Equations to estimate basal metabolic rate

Age	Sex	World Health Organization ²²	Schofield ²³
0–3 y	Male	60.9W – 54	0.167W + 15.174H – 617.6
0–3 y	Female	61W – 51	16.252W + 10.232H – 413.5
3–10 y	Male	22.7W + 495	19.59W + 1.303H + 414.9
3–10 y	Female	22.5W + 499	16.969W + 1.618H + 371.2
10–18 y	Male	17.5W + 651	16.25W + 1.372H + 515.5
10–18 y	Female	12.2W + 746	8.365W + 4.65H + 200

Abbreviations: H, height (cm); W, weight (kg).

Table 2 Nutrition monitoring parameters

Parameter	Daily	Weekly
Intake, output	X	
Calorie and protein intake versus goal	X	
Abdominal girth	X, as needed	
Glucose, electrolytes, blood urea nitrogen, creatinine, calcium, magnesium, phosphorus	X, as needed	X, as needed
Hematocrit		X, as needed
Weight	X	X, when weight stable
Length (age <2 y)		X
Weight-for-length (age <2 y)		X
Head circumference (age <2 y)		X
Body composition (bioelectrical impedance: age >1 mo)		X
Indirect calorimetry		X
Nitrogen balance		X
Handgrip strength (age >6 y)		X, if able
25-hydroxy vitamin D level		Check level if risk factors present for deficiency; recheck 6–12 wk after initiation of supplementation or dose change

combination of both, which can influence outcomes in critically ill and injured patients (►Fig. 1). The enteral route is preferred unless specific contraindications exist, such as gastrointestinal (GI) obstruction, ischemia, pneumatosis, severe bleeding, or intractable vomiting and diarrhea.¹⁵ A systematic review of studies evaluating EN protocols in PICUs revealed their use is associated with reduced time to initiate and achieve enteral feeding goals, and decreased GI and infectious complications.²⁴ PN is used in critically ill children when EN is contraindicated or inadequate; however, the appropriate timing of initiation has yet to be proven.¹⁵ Expert guidelines recommend initiation of PN by days 5 to 7 of EN deprivation in children, or by day 3 in infants and malnourished children.^{26–28} In critically ill adults, provision of PN when EN is contraindicated or inadequate reduces muscle loss and duration of mechanical ventilation.²⁹ Despite this, adverse outcomes, including cholestasis, infections, prolonged mechanical ventilation, and increased length of PICU stay, are seen when PN is used to supplement inadequate EN.^{30,31} In addition, in a multicenter PICU study, use of PN is associated with an increased mortality³² and PN supplementation of suboptimal EN in trauma patients in the first week after injury is associated with increased nosocomial infections.³³ The combination of EN and PN has the potential to improve functional outcomes in critically ill children requiring acute rehabilitation; however, due to the risks with supplemental PN, EN intake and tolerance should be optimized.

When able to feed enterally, standard infant and pediatric formulas are most convenient; however, none are designed for the critically ill child. Protein-enriched enteral feedings

are necessary to improve protein balance in critically ill infants and children^{34,35} and semi-elemental formulas or soluble fiber may be provided to ameliorate diarrhea.³⁶ If slow GI motility or constipation is a problem, whey-protein-based enteral formulas can help accelerate gastric emptying.³⁷ Modification of formula concentration and macronutrient distribution, addition of protein supplements, and use of formulas containing higher calories and/or protein are common strategies employed in the PICU to achieve an optimal intake.

Determining the route of enteral feeding is typically based on perceived aspiration risk. Gastric feeds may be implemented earlier if experienced staff or technology is not available for small bowel feeding tube placement.^{38,39} Randomized trials comparing gastric with post-pyloric feeding have not demonstrated reduced aspiration in critically ill children fed via the post-pyloric route. However, a reduced incidence of pneumonia with post-pyloric feeding, without a difference in aspiration or vomiting, is revealed by a meta-analysis of 966 critically ill adult and pediatric patients randomized to gastric or post-pyloric feeding.⁴⁰ A multicenter trial of critically ill adults randomized to early gastric or jejunal EN showed no difference in feeding tolerance, intake, ventilator-associated pneumonia, or other clinical outcomes.⁴¹ Given the paucity of pediatric data, current guidelines for critically ill children recommend gastric feeding, except in cases of intolerance or high aspiration risk when the post-pyloric route is preferred.¹⁵

Early implementation of feeds and consistently achieving the daily calorie and protein intake goals is associated with better disposition status at hospital discharge.⁴² In a

Fig. 1 Nutrition algorithm.

multicenter study of 5,000 critically ill children, early EN is also associated with reduced mortality.⁴³ In three randomized controlled trials, children with severe burns receiving early enteral feeding within 24 versus 48 hours had a decreased caloric deficit and improved anabolism with increased endogenous insulin production, decreased protein breakdown, and reduced weight loss.⁴⁴⁻⁴⁶ Compared with delayed feeding, early EN (within 24 hours) significantly reduces mortality and length of hospital stay in children with burn injury.⁴⁶ Earlier initiation of nutrition and achievement of goal calories in children with severe traumatic brain injury is associated with a shorter PICU stay and improved recovery by hospital discharge.⁴²

Both intermittent and continuous nasogastric and orogastric feedings are well tolerated in a small study of critically ill children.⁴⁷ However, EN is typically administered continuously in critically ill children due to concerns for slow GI motility or intolerance. The post-pyloric route should be used when gastric feeding is not tolerated, but a continuous administration is necessary to avoid a rapid delivery of feeds into the small bowel. When critical illness or GI intolerance resolves, the 24-hour post-pyloric feeding volume may be gradually condensed as tolerated to 16 to 20 hour/day, or an intermittent (bolus) gastric feeding schedule can be provided, until the child can resume ad libitum oral feeding.

Strategies to Avoid Nutrition Barriers

The complex care of critically ill children is composed of interventions that often preclude delivery of adequate nutrition. Common nutrition barriers are fluid restriction, cessation of feedings for extubation, procedures, GI intolerance, feeding tube issues, and delayed EN initiation with increased severity of illness and hemodynamic instability.^{48–50} In critically ill children and adults receiving vasopressor therapy, EN is tolerated by the majority of patients.^{51,52} The most common adverse event reported is vomiting, although three adults (0.9%) experienced bowel perforation. Decreased mortality is also observed in adults requiring vasopressor therapy and mechanical ventilation who receive EN within 48 hours versus those with delayed feeding.⁵³ A greater reduction in mortality risk is demonstrated with early EN in the most severely ill patients.⁵³ Although more study is required, cautious EN may be considered in hemodynamically stable patients receiving stable, low doses of vasopressor agents, with close monitoring of abdominal exam and function.³⁶

Oral and enteral feedings are often withheld in patients requiring noninvasive ventilation, as it can cause aerophagia, gastric distention, and aspiration.⁵⁴ While no evidence is available to evaluate the safety of enteral tube feeding concomitant with noninvasive ventilation or high flow nasal cannula oxygen delivery in the PICU, infants, children, and adults with neuromuscular and swallowing disorders often receive both tube feeding and noninvasive ventilation at home. Therefore, feeding tube placement can be considered for children receiving acute noninvasive ventilation once respiratory support stabilizes and intubation is not anticipated. The post-pyloric route can be chosen to minimize risk of aspiration or for simultaneous drainage of gastric fluids and air.

After the commencement of EN, extubation, surgery, and bedside or radiologic procedures are among the most common reasons for prolonged cessation of feedings.^{49,50} In a critically ill patient with a stable airway, fasting may not be necessary for minimally invasive bedside and radiology procedures. Reduced procedural fasting improves nutritional intake without adverse events in small studies of critically ill children and adults.^{55,56} Feedings are commonly held before physical, occupational, speech, and respiratory therapies for children requiring acute rehabilitation in the PICU. A 20-hour, or daily, feeding plan where the goal volume is administered in less than 24 hours, versus a continuous 24-hour EN target, improves intake in critically ill adults.^{57,58} Intermittent (bolus) enteral feedings are also desired for children requiring acute rehabilitation to promote oral intake and scheduling of therapy sessions during the day. Fluid restriction, subjective or objective feeding intolerance, and issues with feeding tubes, such as difficult placement, malposition, kinks, and clogs can also limit EN intake.^{48,50} Concentrated enteral formulas can be used to optimize nutritional intake when fluid restriction is necessary. Without recognition and intervention, delayed initiation and repeated feeding interruptions can lead to nutrition deficits and prolonged recovery.

Objective measures to assess GI tolerance are elusive, but important, to help maximize enteral feeding. Gastric residual volumes do not correlate with gastric emptying, vomiting, or aspiration in critically ill adults, and are unlikely to benefit children in the PICU.⁵⁹ When gastric residuals are not assessed, critically ill patients receive more EN without an increased incidence of ventilator-associated pneumonia.^{60,61} Although abdominal girth is affected by introduction of air into the GI tract, edema, ascites, and hepatomegaly, it helps to objectively assess abdominal distention in response to feeding.⁶² Constipation and poor motility may result in abdominal distention or emesis, necessitating interventions such as continuous post-pyloric feeding and laxatives. Diarrhea can be caused by antibiotics, hyperosmolar and sorbitol-containing medications, infections, formula contamination or composition, malabsorption, or a rapid infusion rate.⁶² Probiotics are beneficial for adults with antibiotic-associated diarrhea, and recent randomized trials in the PICU population suggest they reduce urine and GI *Candida* colonization.^{63–65} Proactive management of diarrhea and constipation is essential to help prevent unnecessary feeding interruptions (► Fig. 1).

Micronutrient Supplementation

Critical illness and injury cause increased inflammation and oxidative stress, which can be exacerbated by micronutrient insufficiency. Low plasma zinc is associated with increased inflammation and organ failure in critically ill children.⁶⁶ Vitamin D deficiency is prevalent in critically ill children in North America and Canada, and is correlated with septic shock, catecholamine use, increased severity of illness, and increased length of PICU stay.^{67,68} In addition, low blood thiamine levels are observed in critically ill children with C-reactive protein (CRP) levels >20 mg/dL.⁶⁹

Various micronutrients have the potential to benefit outcomes. A randomized trial comparing enteral supplementation of vitamin C, E, and zinc to placebo in children with burn injury demonstrated reduced lipid peroxidation and time for wound healing in the intervention group.⁷⁰ A recent multicenter study randomizing critically ill children to zinc, selenium, glutamine, and metoclopramide (to maintain prolactin levels) versus a whey-protein placebo did not show reduced mortality, infections, or other beneficial outcomes. However, a subset of those with immunosuppression from acquired immunodeficiency syndrome, cancer, transplantation, primary immune deficiency, or chronic immune suppressant therapy receiving the intervention had reduced sepsis and nosocomial infections.⁷¹ Although the evidence is conflicting and more information is needed, specific patient populations are at risk for nutrient insufficiency and may benefit from individualized repletion.

Special Patient Populations

Critically ill children with malnutrition, obesity, respiratory failure, neuromuscular disorders, burns, and other injuries require specialized interventions and monitoring to assure optimal nutrition. These individuals have altered metabolism and nutrient requirements for recovery. Monitoring energy requirements with IC, adequacy of energy and protein

intake, and body composition are essential to promote appropriate nutritional status while avoiding underfeeding and overfeeding.

Pediatric malnutrition is caused by societal factors and the inflammatory response of acute or chronic illness. It is identified by anthropometric z-score values of less than -1 , including weight, height, body mass index (BMI, a measure of weight adjusted for height), and mid-upper arm circumference.⁷² Moderate severity is classified by z-scores of -2 to -3 , and severe malnutrition is designated as less than -3 .

Children with malnutrition or limited muscle reserves require a sufficient glucose supply when fasted to prevent hypoglycemia. Both hypoglycemia and hyperglycemia are associated with increased mortality in malnourished critically ill children.⁷³ Critically ill children with malnutrition are also susceptible to refeeding syndrome, a constellation of metabolic and physiologic derangements that occur when starved individuals are given any form of nutrition. Additional risk factors for refeeding syndrome are weight loss, prolonged poor intake or fasting, persistent vomiting or diarrhea, malabsorption, and child abuse or neglect.⁷⁴ Metabolic abnormalities commonly reported include hypophosphatemia, hypokalemia, and hypomagnesemia.⁷⁵ Cardiac, pulmonary, neurologic, GI, and hematologic failure are potential complications of refeeding syndrome.⁷⁶ Prevention necessitates identification of individuals at risk; correction of low phosphorus, potassium, and magnesium; restriction of fluid and sodium; and initiation of nutrition at 50 to 75% of resting energy expenditure, or 80 to 100% of current intake.^{76,77} Nutrition should be introduced with optimal protein, phosphorus, potassium, magnesium, and a multivitamin. With biochemical and physiologic stability, calories are subsequently advanced 10 to 20% per day to reach the goal intake.

Critically ill obese children, defined as BMI z-score for age >3 ,⁷⁸ are predisposed to hyperglycemia, insulin resistance, hyperlipidemia, low vitamin D status, and anemia.^{79,80} Nutrition guidelines for critically ill obese children recommend assessment of caloric requirements with IC; however, there is no evidence to evaluate appropriate energy or protein targets in this population.⁸⁰ Several equations using actual weight and height have been developed from IC measurements in children with obesity; however, none were obtained during critical illness.^{81–84} For critically ill obese adults, high protein, hypocaloric feeding is promoted to benefit nutrition and clinical outcomes, with protein targets of 2 to 2.5 g/kg/day of ideal body weight.³⁶ No standard definition of ideal body weight exists for children, but it is typically calculated from height in meters² multiplied by the median BMI for age (z-score of 0).⁸⁵ Owing to a lack of evidence and concern for potential harm, hypocaloric feeding is not recommended for critically ill children with obesity.⁸⁰ In the absence of IC, goals for weight maintenance of critically ill children with obesity requiring acute rehabilitation can be estimated by comparing at least two predictive caloric equations using actual weight, providing 2 to 2.5 g/kg/day protein based on ideal body weight, and with close monitoring of nutrition parameters (► Table 2).

Children who sustain severe burns remain hypermetabolic and hypercatabolic for up to 2 years following injury, which negatively impacts growth, lean body mass, and bone mineralization.⁸⁶ IC is necessary to guide optimal caloric intake, and protein requirements for wound healing are estimated at 2.5 to 4 g/kg/day. EN, initiated within 24 hours of injury, is preferred over PN for burn patients. A high carbohydrate diet increases endogenous insulin production and muscle retention. A daily multivitamin plus additional vitamins A, C, E, and zinc are needed for wound healing, and vitamin D is provided to prevent deficiency. Anabolic hormones and bisphosphonates are therapeutic interventions to improve muscle protein synthesis and bone mass during acute rehabilitation of children with severe burn injury.^{86,87}

Early EN is achievable in patients with spinal cord injury; however, it has not been widely studied.⁸⁸ Decreased gastric motility can occur with neurogenic shock, with an increased risk for aspiration.⁸⁹ These patients demonstrate high urinary nitrogen losses and hypometabolism, and exhibit a prevalence of malnutrition and obesity.⁹⁰ Interventions to optimize muscle and bone mass to maintain appropriate growth are desired for children after spinal cord injury.

Infants and children with chronic lung disease may have increased caloric needs due to increased respiratory work, while those with neuromuscular disorders such as spinal muscular atrophy and Duchenne muscular dystrophy show reduced muscle mass, energy expenditure, and subsequently lower caloric needs.^{91–93} As micronutrient intake, especially vitamin D, may be suboptimal in this population, monitoring and supplementation is also necessary.^{92,94}

Nutrition Monitoring Parameters

A nutrition bundle incorporates guidelines for monitoring the efficacy of nutrition support. The cumulative caloric debt or excess over the course of illness is important to evaluate in the context of unintentional weight change, failure to wean from mechanical ventilation, biochemical abnormalities, and poor wound healing. Routine monitoring of the child requiring acute rehabilitation in the PICU is essential to optimize nutrition therapy (► Table 2), although it is difficult for many reasons.

Several factors can alter the ability to identify unintended weight changes in critically ill children; thus, serial measurements are necessary. Fluid balance, medical devices, and scale error can lead to inaccurate weights. Length or height is also difficult to precisely measure in critically ill patients; however, it is needed to calculate BMI, body surface area, and to classify nutrition status. Weekly monitoring of weight (and for children ≤ 2 -year-old, length, head circumference, and weight for length) is important to assure appropriate growth during acute rehabilitation. Assessment of body composition can detect alterations in adipose and muscle tissue not revealed by changes in weight. Measurements of mid-upper arm circumference are compared with reference standards to identify malnourished infants, children, and adolescents.⁷² In addition, skin fold thickness is assessed in conjunction with mid-upper arm circumference to calculate muscle and fat

mass. These bedside tools are affected by fluid retention and clinician experience. Bioelectrical impedance analysis is another technique to determine body composition at the bedside in patients ≥ 1 month of age; however, it is also altered by fluid status.⁹⁵ Decreased handgrip strength is associated with malnutrition in hospitalized children and may be a useful monitoring tool in conscious and alert PICU patients ≥ 6 years of age requiring acute rehabilitation.⁹⁶ More reliable methods to assess body composition are available but impractical for use in the PICU. Owing to the challenges with assessment of body weight and composition, routine measurement of several parameters is necessary to monitor optimal nutrition in this population (**Table 2**).

Calculation of nitrogen balance can quantify protein intake targets for anabolism. Collection of 24-hour urine is preferred, although if clinical condition and nutritional intake are stable, a shorter time period is acceptable.⁹⁷ Measurement of total urinary nitrogen is more accurate than urinary urea nitrogen in critically ill patients. If this is not feasible, urinary urea nitrogen can be multiplied by 1.25 to estimate total urinary nitrogen and correct for nonurea nitrogen.^{34,35} An additional 20% of urinary losses can be added to account for skin and stool nitrogen output.

Prealbumin and CRP are parameters proposed to assess adequacy of nutritional intake in hospitalized patients, but are more sensitive to changes in inflammation. Decreased CRP signals a return of anabolic function and need for increased caloric intake to support growth in infants recovering from surgery.⁹⁸ Normal prealbumin levels are associated with complete skin graft healing in children and adults with burn injury.⁹⁹ In hospitalized adults receiving EN, decreased CRP predicts improved prealbumin without relationship to nutritional intake.¹⁰⁰ In critically ill children and adults, common biochemical markers to evaluate nutrition status, including albumin, prealbumin, retinol-binding protein, transferrin, hemoglobin, and total lymphocyte count, do not correlate with nutrition or clinical outcomes.^{101,102} Decreased prealbumin levels are not specific to increased CRP or inadequate nutrition; therefore, they have limited value in assessing appropriate nutrition in the presence of acute and chronic inflammation.

Electrolyte abnormalities, including hypophosphatemia, hypokalemia, hyponatremia, hypocalcemia, and hypomagnesemia, frequently occur in critically ill children. Hypophosphatemia is associated with malnutrition, refeeding syndrome, delay to reach the EN goal, use of dopamine, increased duration of mechanical ventilation, and a longer PICU stay.^{103,104} Routine monitoring and repletion of electrolytes are justified in critically ill children, until biochemical values and nutritional intake demonstrate stability.

In conclusion, nutritional status and the adequacy of calorie, protein, and micronutrient intake during critical illness impact the ability of children to perform acute rehabilitation in the PICU. An evidence-based nutrition bundle incorporates nutrition assessment with IC to determine caloric needs, a nutrition algorithm to standardize initiation of early EN, avoidance of unnecessary feeding interruptions, and nutrition monitoring parameters to optimize intake. A

variety of tailored interventions are required to provide the nutritional resources patients need to achieve the most gains from acute rehabilitation in the PICU.

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