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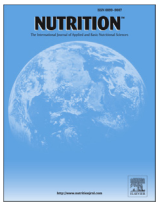

Review

Indirect calorimetry: A guide for optimizing nutritional support in the critically ill child

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ABSTRACT

The metabolic response of critically ill children is characterized by an increase in resting energy expenditure and metabolism, and energy needs of the critically ill child are dynamic, changing from a hypermetabolic to hypometabolic state through the continuum of the intensive care unit (ICU) stay. It therefore appears essential to have a precise evaluation of energy needs in these patients in order to avoid underfeeding and overfeeding, loss of critical lean body mass, and worsening of any existing nutrient deficiencies. However, there are no clear definitions regarding either the exact requirements or the ideal method for determining metabolic needs. In clinical practice, energy needs are determined either by using predictive equations or by actual measurement using indirect calorimetry. Although many equations exist for predicting resting energy expenditure, their accuracy is not clear. In addition, very few clinical trials have been performed so that no firm evidence-based recommendations are available regarding optimal nutritional management of critically ill children and infants. Most studies have come to the same conclusion (i.e., current predictive equations do not accurately predict required energy needs in the pediatric ICU population and predictive equations are unreliable compared with indirect calorimetry). The recent American Society for Parenteral and Enteral Nutrition clinical guidelines for nutrition support of the critically ill child suggest that indirect calorimetry measurements be obtained when possible in pediatric patients with suspected metabolic alterations or malnutrition, according to a list of criteria that may lead to metabolic instability, thus making standardized predictive equations even less reliable. Although the standard use of indirect calorimetry is limited due to equipment availability, staffing, and cost, the accuracy of the commercially available devices continues to improve and the measurements have become more reliable and easier to perform. In the absence of sufficient data, prospective controlled studies need to be conducted in order to evaluate the benefit of tight calorie control achieved by accurately measuring the energy needs of the critically ill child. Optimizing measuring techniques could make this more feasible and decrease the need to rely on inaccurate equations while providing appropriate energy requirements.

Introduction

Resting energy expenditure (REE) is defined as the amount of calories required by the body at rest during a 24-h period and represents 70% to 80% of the calories used by the body. It is the resting metabolic rate that defines the energy released to maintain normal basal physiological functioning. The REE is useful in optimizing and managing nutritional support. However, ideal energy needs have not yet been formulated mainly due to technical difficulties. The metabolic response of critically ill children is characterized by an increase in REE and a precise evaluation of energy needs in these patients would appear to be essential in order to avoid underfeeding and overfeeding, as well as to avoid loss of critical lean body mass and worsening of any existing nutrient deficiencies [1]. Thus, overfeeding has been associated with increased carbon dioxide production, respiratory failure, hyperglycemia, and fat deposits in the liver, whereas

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underfeeding may lead to malnutrition, muscle weakness, and impaired immunity.

Many factors influence metabolic needs during acute illness. Acute injury, burns, inflammation, surgery, or sepsis markedly change the energy needs of the critically ill child. Additionally, therapeutic interventions that are typical in the pediatric intensive care unit (PICU) setting, such as mechanical ventilation and the administration of vasoactive or sedative agents also influence energy needs. It has been suggested that growth ceases during the metabolic response to illness or injury in children. Metabolism and energy needs of the critically ill child seem to be dynamic, changing from a hypermetabolic to hypometabolic state through the continuum of the PICU stay. In light of these changes, determining the exact nutritional requirements for the critically ill child would appear to be essential because adequate nutritional support and optimal nutritional status have been shown to improve physiological stability and outcome.

Validity of predicted versus measured REE

In clinical practice, energy needs are determined either by using predictive equations (Table 1) or by actual measurement using indirect calorimetry. Energy requirements of critically ill infants and children are difficult to predict. In a prospective study of 46 critically ill children, REE measured by indirect calorimetry was not related to severity of illness, nutritional status, or nitrogen balance [2]. Many equations exist for predicting REE, but their accuracy in estimating energy requirements for critically ill patients and children in particular, is not clear. Most predictive equations are typically derived from studies of healthy non- hospitalized individuals and few have been validated in mechanically ventilated patients. Although some studies have evaluated the accuracy of predictive versus measured energy expenditure in critically ill children (Table 2), they compared different sets of equations with the measured energy expenditure and the population studied was different in each of them. One of the problems with developing an accurate predictive equation for critically ill children in the PICU is the large heterogeneity regarding age, weight, muscle mass, level of growth and maturity, diagnosis, and severity of illness. Ideally, predictive equations should provide results within 10% of measured energy expenditure [3]. Vasquez-Martinez et al performed a prospective study of 43 ventilated critically ill children during the first 6 h post-injury, in which they compared measured energy expenditure by continuous indirect calorimetry with predictive energy expenditure calculated using the Harris-Benedict, Caldwell-Kennedy, Schofield, Food and Agriculture Organization (FAO)/World Health Organization (WHO)/ United Nations University (UNU), Maffies, Fleisch, Kleiber, Dreyer, and Hunter equations [4]. Most of the predictive equations overestimated measured energy expenditure, and measured energy expenditure and predictive energy equations differed significantly except for the Fleisch and Caldwell-Kennedy equations, which were found to be the best predictors of energy expenditure. Bott and colleagues compared measured versus predictive resting energy expenditure in 52 children with bronchopulmonary dysplasia (BPD) and in 30 healthy children, using four predictive equations, namely, Schofield-W, Schofield-HW, Harris-Benedict and FAO equations [5]. They concluded that the Harris-Benedict equation best predicted REE in children with BPD while the Schoffield-W was best in healthy children. Only minimal differences were found between predictive equations and calorimetry and the authors concluded that predictive equations might be useful in the management of children with BPD. In a study of 91 severely burned children (> 40% body surface area), Suman and colleagues compared the REE measured by indirect calorimetry with predictive equations in this very hypermetabolic population [6]. Good agreement was obtained between the three sets of equations used to calculate REE, namely, FAO/WHO/UNU, Schofield-HW, and Harris-Benedict equations. However, the predicted REEs were significantly lower than the measured REEs. The authors concluded that indirect calorimetry should be used to determine energy expenditure until more accurate methods are developed for these critically ill patients. In

Table 1
Standard equations used to predict energy expenditure in children

Harris-Benedict equation (kcal/d)
Boys: $66.4730 + (5.0033 \times \text{height}) + (13.7516 \times \text{weight}) - (6.7550 \times \text{age})$
Girls: $655.0955 + (1.8496 \times \text{height}) + (9.5634 \times \text{weight}) - (4.6756 \times \text{age})$

Schofield-W 3–10 y Girls: $22.5 \times \text{weight} + 99$
Boys: $22.7 \times \text{weight} + 495$
11–18 y Girls: $17.5 \times \text{weight} + 651$
Males: $12.5 \times \text{weight} + 746$

Schofield-HW 3–10 y Girls: $16.97 \times \text{weight} + 1.618 \times \text{height} + 371.2$
Boys: $19.6 \times \text{weight} + 1.033 \times \text{height} + 414.9$
11–18 y Girls: $8.365 \times \text{weight} + 4.65 \times \text{height} + 200$
Boys: $16.25 \times \text{weight} + 1.372 \times \text{height} + 515.5$

Schofield equations (kj/d) (1 kcal = 4.186 kj)
< 3 y Boys: $(0.0007 \times \text{weight}) + (6.349 \times \text{height}) - 2.584$
Girls: $(0.068 \times \text{weight}) + (4.281 \times \text{height}) - 1.730$
3–10 y Boys: $(0.082 \times \text{weight}) + (0.545 \times \text{height}) + 1.736$
Girls: $(0.071 \times \text{weight}) + (0.677 \times \text{height}) + 1.553$
10–18 y Boys: $(0.068 \times \text{weight}) + (0.574 \times \text{height}) + 2.157$
Girls: $(0.035 \times \text{weight}) + (1.948 \times \text{height}) + 0.837$

White (kJ/d) $17 \times \text{age [mo]} + (48 \times \text{weight [kg]}) + (292 \times \text{body temp }^{\circ}\text{C}) - 9677$

FAO/WHO/UNU equations
< 3 y Boys: (kcal/d): $(60.9 \times \text{weight}) - 54$
Girls: (kcal/d): $(61 \times \text{weight}) - 51$
3–10 y old (1 kcal = 4.186 kJ)
Boys: (kJ/g): $(95 \times \text{weight}) + 2071$
Girls: (kJ/d): $(94 \times \text{weight}) + 2088$
10–18 y Boys: (kcal/d): $(16.6 \times \text{weight}) + (77 \times \text{height}) + 572$
Girls (kcal/d): $(7.4 \times \text{weight}) + (482 \times \text{height}) + 217$

Maffeis equations (kJ/d) (1 kcal = 4.186 kJ)
Boys: $(28.6 \times \text{weight}) + (23.6 \times \text{height}) - (69.1 \times \text{age}) + 1287$
Girls: $(35.8 \times \text{weight}) + (15.6 \times \text{height}) - (36.3 \times \text{age}) + 1552$

Fleisch equation (kcal/d)
Boys: 1–12 y: $24 \times \text{BSA} \times (54 - 0.885 \times \text{age})$
13–19 y: $24 \times \text{BSA} \times (42.5 - [0.64 \times \{\text{age} - 13\}])$
Girls: 1–10 y: $24 \times \text{BSA} \times (54 - 1.045 \times \text{age})$
11–19 y: $24 \times \text{BSA} \times (42.5 - [0.778 \times \{\text{age} - 11\}])$

Kleiber equations (kcal/d) $\text{PEE} = 70 \times \text{weight}^{0.75}$

Dreyer equation (kcal/d) Boys: $\text{weight}^{1/2} / (0.1015 \times \text{age}^{0.1333})$
Girls: $\text{weight}^{1/2} / (0.1127 \times \text{age}^{0.1333})$

Caldwell-Kennedy equation (kcal/d): $22 + (31.05 \times \text{weight}) + (1.16 \times \text{age})$

Hunter equation (kcal/d) $\text{PEE} = 22 \times \text{weight}$

BSA, body surface area; FAO/WHO/UNU, Food and Agriculture Organization/ World Health Organization/United Nations University; PEE, predictive energy expenditure