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Energy imbalance and the risk of overfeeding in critically ill children*

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Abstract

Objective—To examine the role of targeted indirect calorimetry in detecting the adequacy of energy intake and the risk of cumulative energy imbalance in a subgroup of critically ill children suspected to have alterations in resting energy expenditure. We examined the accuracy of standard equations used for estimating resting energy expenditure in relation to measured resting energy expenditure in relation to measured resting energy expenditure and cumulative energy balance over 1 week in this cohort.

Design—A prospective cohort study.

Setting—Pediatric intensive care unit in a tertiary academic center.

Interventions—A subgroup of critically ill children in the pediatric intensive care unit was selected using a set of criteria for targeted indirect calorimetry.

Measurements—Measured resting energy expenditure from indirect calorimetry and estimated resting energy expenditure from standard equations were obtained. The metabolic state of each patient was assigned as hypermetabolic (measured resting energy expenditure/estimated resting energy expenditure >110%), hypometabolic (measured resting energy expenditure/estimated resting energy expenditure <90%), or normal (measured resting energy expenditure/estimated resting energy expenditure = 90–110%). Clinical variables associated with metabolic state and factors influencing the adequacy of energy intake were examined.

Main Results—Children identified by criteria for targeted indirect calorimetry, had a median length of stay of 44 days, a high incidence (72%) of metabolic instability and alterations in resting energy expenditure with a predominance of hypometabolism in those admitted to the medical service. Physicians failed to accurately predict the true metabolic state in a majority (62%) of patients. Standard equations overestimated the energy expenditure and a high incidence of overfeeding (83%) with cumulative energy excess of up to 8000 kcal/week was observed,

*See also p. 470.

especially in children <1 yr of age. We did not find a correlation between energy balance and respiratory quotient (RQ) in our study.

Conclusions—We detected a high incidence of overfeeding in a subgroup of critically ill children using targeted indirect calorimetry. The predominance of hypometabolism, failure of physicians to correctly predict metabolic state, use of stress factors, and inaccuracy of standard equations all contributed to overfeeding in this cohort. Critically ill children, especially those with a longer stay in the PICU, are at a risk of unintended overfeeding with cumulative energy excess.

Keywords

pediatric; critical care; nutrition; overfeeding; metabolism

The high prevalence of malnutrition in children admitted to the pediatric intensive care unit (PICU) has persisted over the past 3 decades (1–3). Furthermore, the nutritional status of critically ill children deteriorates further during the course of their illness and may have a negative impact on clinical outcomes (2, 4, 5). Thus, careful screening for existing malnutrition and the development of a formal nutrition prescription are important goals of pediatric critical care (6).

Failure to accurately estimate energy requirements during critical illness may predispose patients to underfeeding or overfeeding. The resultant cumulative deficit or excess of energy may remain undetected (7). The recently revised national guidelines for adult and pediatric critical care have emphasized the importance of accurately measured energy expenditure in patients admitted to the intensive care unit (ICU) (6, 8). Indirect calorimetry (IC) testing provides an accurate measurement of resting energy expenditure and may be used as a guide to prescribe optimal energy allowance in critically ill children. However, the application of IC in the PICU has remained sporadic, likely as a result of limitations of resources and expertise. Children with existing malnutrition on admission, prolonged stay in the ICU, and those who are unable to wean from mechanical ventilatory support are at a high risk of an altered metabolic state and may be appropriate candidates for IC (9).

Our aim was therefore to evaluate the role of a targeted IC approach in detecting the adequacy of energy intake and the risk of cumulative energy imbalance in a subgroup of critically ill children suspected to have alterations in resting energy expenditure (REE). We also examined factors such as the ability of clinicians in the PICU to accurately estimate the metabolic state and the accuracy of standard equations for estimating REE that might influence energy prescription in this group of patients.

METHODS

We selected children admitted to the multidisciplinary PICU at Children's Hospital Boston over a period of 12 months for REE measurement by IC if they met criteria for targeted calorimetry (Table 1) (6, 9). Patients were excluded from this study if they met any of the following criteria: 1) uncuffed endotracheal tube; 2) large leak in the ventilator circuit, defined as a difference of <10% between measured inspiratory and expiratory tidal volumes; 3) presence of a chest tube for air leak or bronchopleural fistula; 4) fractional inspired

oxygen concentration <60%; 5) need for high-frequency oscillatory ventilator or extracorporeal membrane oxygenator support; 6) clinical deterioration requiring ongoing resuscitation or procedures at the bedside; and 7) failure to achieve steady state during IC.

IC was performed using a portable metabolic cart (Vmax Encore; Viasys Healthcare, Loma Linda, CA) for a period of at least 30 mins after an initial 5-min period to allow for equilibration. Details of the calorimetric procedure have been described earlier (7). In brief, flow sensor calibration and gas calibration were performed before each measurement as per the manufacturer's instructions. In subjects spontaneously breathing room air, a clear, plastic canopy was placed around the head and neck. In mechanically ventilated subjects, the flow sensor was connected to the expiratory outlet (exhaust) of the ventilator with an adaptor. Subjects were enterally fasted for a minimum of 4 hrs if they received bolus intermittent feeds. IC measurement was performed at least 2 hrs after any interventions such as changes in mechanical ventilatory support, suctioning, or painful procedures. Measurements were continued for a period of 30 mins or until a steady state was attained. Steady state was defined as a period of at least 5 mins with <10% fluctuation in oxygen consumption, carbon dioxide production, and <5% fluctuation in respiratory quotient (RQ, which is the ratio of carbon dioxide production:oxygen consumption) (10). Measured resting energy expenditure (MREE) was calculated by the device software using a modified Weir equation (11). The REE measurements were extrapolated to 24-hr values as previously validated in critically ill subjects (12). Studies that failed to meet steady-state conditions and those with RQ values <1.3 despite repeat testing were excluded from analysis.

Daily nutrition goal was determined for each patient by the PICU dietitian. Standard age-appropriate equations (Schofield, Harris-Benedict, or World Health Organization) were used to derive daily estimated energy expenditure (EEE) to which a stress factor, based on Pediatric Risk of Mortality III illness severity (13) score calculated within 24 hrs of admission, and the pretest estimate of the metabolic state was added where applicable by the dietitian (14). In subjects whose weight and height were available at the time of admission, the Schofield equation was used for children <15 yrs of age and the Harris-Benedict equation was used in subjects ≥ 15 yrs of age. The World Health Organization equation for energy expenditure was used when a height was not available within the past 4 wks. The dietitian recorded actual daily energy intake for each patient from enteral and parenteral sources using volume administered and manufacturer's description/labels for nutrient content. Baseline nutritional parameters such as weight and length were recorded and the National Center for Health Statistics reference data set was used to calculate z-score for weight for age, weight for height, and body mass index.

MREE obtained by IC was compared to the EEE calculated by standard predictive equations. The patients were classified as hyper-metabolic (MREE/EEE >110%), hypometabolic (MREE/EEE <90%), or normal (MREE/EEE = 90–110%). Before IC testing, the PICU physicians responsible for prescribing parenteral nutrition were asked to record their pre-test clinical estimate of the metabolic state for each patient (hypermetabolic, hypometabolic, normal, or unknown). This estimate was compared with the measured metabolic state. Based on actual energy intake (EI) recorded before IC, feeding status of patients was determined as: overfed (EI:MREE >1.2), underfed (EI:MREE <0.8), or

appropriately fed (EI: MREE was between 0.8 and 1.2). We recorded patient characteristics such as age, sex, diagnosis, illness severity (Pediatric Index of Mortality 2 scores) (15), duration of PICU stay at the time of IC, total PICU and hospital length of stay, and survival to hospital discharge. Twenty-four-hr energy balance was calculated (kcal/day) as the difference between total EI and MREE on the day of the IC testing. The MREE value was then used with daily energy intake to calculate a cumulative energy balance over 7 days. Because providing excessive energy intake should in theory increase carbon dioxide production and in turn increase the RQ, we evaluated the relationship between RQ and energy balance. The protocol was approved by the Children's Hospital, Boston Institutional Review Board.

Statistical Methods

Descriptive analyses of patient characteristics were conducted. Categorical outcomes were summarized using count (percentage) and continuous outcomes were summarized using medians (range). Bland-Altman analysis was used to evaluate the agreement between MREE and estimated REE. Clinical characteristics, nutritional state, feeding status, and RQ were compared among patients with normal metabolism, hypermetabolism, and hypometabolism. Chi square test was used to study relationships between two categorical variables and the Kruskal-Wallis test was used to compare continuous outcomes among multiple groups.

RESULTS

We measured REE using IC in 33 consecutive patients (12 females) admitted to the PICU who met criteria for targeted calorimetry. Steady state was achieved in 29 (88%) cases. Data from four subjects who failed to reach steady state were excluded from the analysis. The median age of the cohort was 2 yrs (range, 0.1–25.8 yrs). The median length of stay in the PICU at the time of IC testing was 44 days (range, 3–216 days). The mean body temperature of patients during the measurements was $37.6 \pm 0.7^{\circ}\text{C}$. Two patients had body temperatures 36.7°C and one patient had body temperature $>38.5^{\circ}\text{C}$. Body temperature was not statistically correlated to the metabolic state in our study. Patients were admitted to the surgical service ($n = 12$ [41%]) including those after cardiac surgery ($n = 5$) and other surgical procedures ($n = 7$), or the medical service ($n = 17$ [59%]). Parenteral nutrition was used either exclusively or in combination with enteral nutrition in 24% of the patients. Table 2 shows the baseline clinical and nutritional characteristics of this cohort. This cohort of selected patients represented 3% of the total PICU admissions that year and 16% of children with >48 hrs stay in the PICU. Overall mortality in this cohort was high at 34% compared with the average mortality of 2.4% for the PICU population in the same year.

The average MEE:EEE ratio for the cohort was 95% (range, 46–188%). Based on the IC measurements, five (17%) patients were hypermetabolic, 16 (55%) were hypometabolic, and eight (28%) had normal metabolism. The Bland-Altman analysis for agreement between MREE and EEE showed a mean bias of -90 kcal/day and the limits of agreements were -470.4 to 301.9 kcal/day (Fig. 1).

Table 3 shows patient characteristics in relation to their metabolic status. Patients admitted to the medical ICU service were more likely to have IC measurements consistent with

hypometabolism compared with those on the surgery service (81% vs. 19%, Fisher's exact test, $p = .02$). Hypermetabolism was significantly associated with age <1 yr (80%, $p = .01$). Overall ICU length of stay was significantly higher for patients with hypermetabolism (median 142 days, $p = .04$) as compared with those with normal (median 33 days) or hypometabolism (median 50 days). Other demographic and nutritional factors such as sex, nutritional status on admission, and PICU length of stay at the time of study were not significantly related to metabolic status. There was no association between the metabolic state of patients and mortality.

PICU physicians incorrectly estimated the metabolic status in 18 (62%) cases. Physicians tended to overestimate the metabolic status in patients with normal or hypometabolism compared with hypermetabolic patients (50% vs. 20%, $p = .05$). Average energy intake:MEE ratio was 164% (range, 90–250%). Energy goal was prescribed after adding an average stress factor of 1.54 (range, 0.79–1.95) to the estimates of energy expenditure. Based on the difference between measured REE and energy intake, we detected overfeeding in 24 (83%) cases. Figure 2 shows the daily and projected weekly cumulative energy balance in this cohort. Projected weekly energy imbalance was on average positive 2166 kcal (range, –1512 to +8827 kcal). Children <1 yr of age were at a higher risk of overfeeding with median (interquartile range) for intake:MREE of 187% (153–217) vs. 147% (130–150) in the rest of the group ($p = .05$). Diagnoses, medical/ surgical team, and metabolic status were not predictive of the degree of overfeeding in this cohort. IC results were available to the healthcare team at the bedside. Based on the results of IC testing, nutrient (energy) intake was altered in 15 of 29 (52%) patients. Cumulative weekly change in energy intake in these 15 patients, after IC results were available to the team, was an average of +491 kcal (range, –3360 to +1260 kcal).

Mean RQ for the cohort was 0.94 (range, 0.79–1.28). Figure 3 shows the poor correlation between the adequacy of energy intake (as measured by the energy intake:MREE ratio) and RQ ($r = 0.03$, $p = .88$). This suggests that RQ was not an accurate indicator of adequacy or excess of energy intake in this group of patients.

DISCUSSION

The recently published critical care nutrition guidelines recommend that energy prescription in adults and children admitted to the ICU should be guided by accurate measurement of energy expenditure using indirect calorimetry when feasible (6, 8). Targeted calorimetry has been proposed as a means to select critically ill children at risk of metabolic instability who are likely to benefit from accurate REE measurement (9). This is the first report of validation of the criteria for targeted calorimetry recommended in the national guidelines. The cohort identified in our study using these criteria included patients with a broad age range, both medical and surgical illnesses, with altered metabolism (either hyper- or hypometabolism) in 72% of patients.

The metabolic response to stress from injury, surgery, or illness is variable and the degree of hypermetabolism is unpredictable and unlikely to be sustained during a prolonged course in the PICU (16, 17). Critically ill children cannot be presumed to be hypermetabolic after

acute illness or injury and energy expenditure may actually be decreased in some groups of patients (18, 19). Although sustained increase in metabolism has been reported for weeks after burn injury, REE peak returns to baseline within 12 hrs after some surgical procedures (20, 21). We found a predominance of hypometabolism in this cohort, especially in patients admitted to the medical service. We did not find any correlation between the illness severities of subjects, as measured by the Pediatric Risk of Mortality III score, and their measured energy expenditure. Our observation is similar to previous studies in critically ill children in whom severity of illness failed to predict the energy expenditure (22, 23). Furthermore, there was no significant difference in mortality between children in these metabolic groups, although the study was not powered to detect this difference. Although we aimed to identify the degree of underfeeding or overfeeding risk and potential of energy imbalance in a cohort of selected patients in the PICU, our study was not designed to examine outcomes associated with cumulative energy imbalance. The results of IC in our study were available to the healthcare team and energy prescription was modified at their discretion. More than half of the patients had interventions in the form of decrease or increase in energy intake after the IC test. Future randomized studies comparing routine practice with a strategy in which targeted IC is used to optimize energy intake are desirable.

Metabolic state after injury may influence patient outcomes and indeed hyper-metabolism was associated with increased total PICU length of stay in our study. The clinical variables that predict the metabolic states of critically ill children need to be described but remain elusive. Acute phase reactants such as C-reactive protein have been used as a marker of metabolic state (24). C-reactive protein is not routinely measured in critically ill children. Furthermore, use of these variables to define metabolic state during illness is probably too simplistic. We used the ratio of the measured to the estimated energy expenditure (MREE: EEE) as a marker of the metabolic state. This ratio, also termed the metabolic index, has been used to stratify patients into hypermetabolic or hypometabolic states and has been described in previous studies (22, 25). Children aged <1 yr represented the large majority of patients with hypermetabolism. Aside from admission to the medical service and age <1 yr, no other clinical variables were able to predict metabolic state in our study.

As a result of the variable nature of metabolic stress and the inability to accurately predict its severity, estimation of energy expenditure during critical illness is challenging. Predictive equations are commonly used to estimate the REE of hospitalized patients so as to allow prescription of optimal calories. These standard predictive equations fail to allow for the variability of stress response during critical illness (19, 26) and do not account for effects of the underlying medical condition and interventions responsible for the variable course and severity of the same illness over time in individual patients (24, 27). Therapeutic interventions that are typical for the PICU setting (eg, mechanical ventilation, administration of vasoactive or sedative agents) can have various metabolic effects that are superimposed on illness-related factors. For example, the use of neuromuscular-blocking agents in severe head trauma markedly decreases energy expenditure in patients who typically react with an increase in REE, resulting in a lower than predicted total energy expenditure (28, 29). The use of standard predictive equations to assess energy requirements in ventilated, critically ill children is questionable. Previous studies have shown significantly poor agreement between MREE and energy expenditure predicted by the Schofield equation, Food and Agriculture

Organization/World Health Organization/United Nations University equation, and Harris-Benedict equation (19, 30). Most standard age-based equations do not incorporate measurements of body composition (31) and were derived from a healthy population, with few young children, and represent reference data from several years ago (32). The variables included in these equations are static and do not account for the heterogeneity of critical illness. The White equation for predicting energy expenditure in mechanically ventilated critically ill children was reported to be more accurate in this group of patients when compared with previous equations (19). However, the authors discuss the weakness of this equation, including their use of estimated weights in their study. Fluid shifts inherent to acute illness commonly confound measured body weight and thus might introduce significant error in the use of predictive equations (because these rely on weight to calculate REE). In the absence of available height measurement, the use of weight for age z-score as a variable for the White equation may not be an accurate indicator of nutritional status. The equation does not accurately predict energy expenditure in patients with burn injury, postcardiac surgery, or those <2 months of age.

Previous studies examining the correlation between EEE and MREE in critically ill children were focused on the initial days in the PICU after injury or illness. Vasquez Martinez et al (33) reported that equation estimates of energy expenditure had poor agreement with measured REE in children within the first 6 hrs after admission to the PICU. The mean bias for predictive equations such as those used in our study was high and could result in significant errors in estimating REE. Oosterveld et al (34) reported no significant difference between measured and estimated energy expenditure in critically ill children. In their longitudinal study of energy balance in 46 patients during the first 7 days of critical illness, patients were underfed on 60% of days and overfed on approximately 30%. Although underfeeding was predominant, patients with sepsis were reported to have positive cumulative balance at the end of 1 week and were more likely to be over-fed. Taylor et al (16) reported serial IC measurements in critically ill children during the first week of illness. The broad limits of agreement between measured and estimated REE varied between -484 and + 854 kcal/day, depending on the equation used for estimating REE. Framson et al (35) reported the inaccuracy of equations in estimating energy expenditure in critically ill children. They observed little variation in energy expenditure measured at three different time points during critical illness and noted a lack of hypermetabolic response. Seventeen patients had IC measurement at the third time point (median length of stay 192 hrs) and were hypometabolic ($n = 6$ [35%]), and the rest were either hyper-metabolic or had normal metabolic state. These studies have shown that children do not experience the degree of hyper-metabolic response seen in adults after injury or illness and the use of predictive equations for REE may introduce significant errors. Adult studies have also shown that during the acute phase of stress, most patients are not hypermetabolic (36). Our study's novel findings of a high prevalence of hypometabolism, among a heterogeneous group of ICU patients with a high mortality rate and prolonged ICU stay, add significantly to the literature. To our knowledge, this is the first study describing the metabolic state and feeding status of children with prolonged illness and longer stay in the PICU and examining the accuracy of predictive equations in this group. As a result of the restrictive inclusion criteria, the median duration of PICU stay at the time of IC was 44 days in our cohort. Although the

equation estimated REE and the measured REE were significantly correlated, Bland-Altman analysis showed very broad limits of agreement, suggesting a lack of reliability and validity for individual patients. Standard equation-derived estimates of energy expenditure must be used with caution in this group of critically ill children and, when feasible, energy intake should be guided by accurate measurement of REE. Our study demonstrates the effect of inaccurate estimation of REE on energy prescription and the consequential increase in the risk of over-feeding in the PICU.

An important observation in our study was that clinicians were unable to accurately estimate the degree of metabolic effects of illness in a majority of cases, overestimating it particularly in hypo-metabolic patients. To our knowledge, this degree of inaccuracy of physician estimates of metabolic state has not been previously described. The overestimation of the severity of metabolic stress may have led to the application of higher stress factors to energy prescription in our cohort. A wide range of stress factors are incorporated into the estimates of energy requirements in an attempt to account for the increased energy burden of hypermetabolic states (37). However, these factors are applied inconsistently in clinical practice and the reasons for choosing a particular stress factor in individual cases are not clear. The empiric use of stress factors for presumed hyper-metabolism in the absence of accurately measured metabolic state during critical illness is probably unwarranted and may have contributed to overfeeding patients in our study.

The variability of metabolic stress, the inaccuracy of standard equations used to estimate REE, the inability of physicians to accurately predict the metabolic state, and the consequential application of stress factors to energy prescription may all have contributed to the prevalence of overfeeding in our study. This degree of overfeeding has not been reported before in critically ill children. Overfeeding in critically ill children is underrecognized (38) and may have many deleterious effects (39, 40). Carbohydrate overfeeding increases ventilatory work by increasing carbon dioxide production and can potentially prolong the need for mechanical ventilation (41). Overfeeding may also impair liver function by inducing steatosis and cholestasis and increase the risk of infection secondary to hyperglycemia. The incidence of obesity in children admitted to the PICU is rising and is increasingly recognized as a premorbid condition, which worsens outcomes from a variety of illnesses (42–44). In the adult critical care population, especially those with pre-existing obesity, there is increasing evidence of the beneficial role of hypocaloric feeding (8). Although the role of hypocaloric feeding in children has not been examined, prevention of overfeeding during critical illness is desirable. Despite the desirable benefits of accurately measured REE, the application of IC in the critically ill population remains sporadic, probably as a result of cost, need for expertise, absence of ideal testing conditions, and the time commitment associated with this procedure. In a review of PICU practice across 111 centers in Europe, only 17% of centers reported the regular use of IC and therefore, a majority of centers rely on estimations from equations when prescribing daily energy goals (45). The modern metabolic cart is portable and it provides reproducible data that can be useful for directing nutrition intervention at the bedside. Newer compact metabolic monitors may allow easier calibration, portability, and ability to use in patients requiring frequent respiratory interventions or different ventilator modes (46, 47). In an era of resource constraints, IC may be targeted to patients who are at risk of metabolic instability, in which

equation estimates are often unreliable and likelihood of energy imbalance is high (6). We were able to target high-risk patients using a set of clinical criteria, thus limiting the application of IC to those at risk of unintended energy imbalance. We identified a high prevalence (72%) of altered metabolic state in children selected by these criteria. With strict adherence to quality control measures, we obtained steady-state measurements in all but four patients. Although the cost-benefit ratio of such a strategy needs to be further examined, its ability to detect and potentially prevent energy imbalances during critical illness may have implications for patient outcomes.

Cumulative negative energy balances, accrued as a result of underfeeding, have been correlated with higher mortality and increasing number of infectious complications in critically ill adults (48, 49). Significant anthropometric changes, especially loss of lean body mass, have been shown in infants after critical illness (4). Although negative balance has been studied in the past, the degree and incidence of cumulative energy excess in critically ill children has not been explored. A majority of patients in our study were receiving calories far in excess of their requirements at the time of their IC measurement. In some patients, the projected cumulative positive balance reached up to 8000 kcal over 1 week if nutrient in-take had been continued based on estimated energy requirements. Future studies will need to examine the impact of large energy excess on patient outcomes.

The interpretation of RQ as a marker of substrate use in adult studies has been inconsistent. $RQ > 1.0$ was not a specific marker of excessive caloric intake in adults on parental nutrition (50). RQ is affected by factors such as body habitus, acid-base disturbances, or underlying metabolic conditions such as diabetes mellitus. In addition, critical illness may alter the ability to metabolize substrate. McClave et al (51) reported $RQ > 1.0$ in <30% of all adults who were overfed in their study. In critically ill children, a single measurement of RQ had poor sensitivity (21% for overfeeding) when a specific cutoff of $RQ > 1.0$ was used to classify the degree of overfeeding (52). We did not find a correlation between energy provision in relation to measured REE and RQ in our study. The best indicator of overfeeding is the difference between energy intake and energy expenditure measured by IC.

Our study was limited by its cross-sectional design and hence the lack of serial metabolic data. The variable nature of metabolic stress over the course of critical illness makes it difficult to rely on a single measurement of REE. We selected patients for IC and the metabolic and feeding data from this study may not represent the general PICU population. However, if IC is not feasible in all patients, we have demonstrated the effectiveness of a set of criteria in targeting those with high risk of metabolic instability. Patients requiring extracorporeal membrane oxygenation, air leak, and high-frequency oscillatory ventilation were not included as a result of limitations of the IC technique. The exclusion of these critically ill technology-dependent children may have resulted in underestimating the metabolic state in our cohort. However, severely stressed neonates on extracorporeal membrane oxygenation therapy did not demonstrate the hypermetabolic response in a previous study using stable isotope methods (20). Our study was not designed to examine the role of IC on titrating energy intake in critically ill children. Future studies must examine the impact of targeted IC on patient outcomes.

Improved understanding of the metabolic response to injury and illness in children will help optimize nutritional support in the PICU population. With the advent of newer technology, continuous and accurate metabolic monitoring in critically ill children may be possible at the bedside. Studies evaluating the accuracy of devices providing continuous metabolic monitoring, the relationship between inflammatory state and metabolic state, and the application of this technology in the PICU are needed (46, 47).

In summary, we selected critically ill children for IC by using a previously described set of clinical criteria. A high incidence of metabolic alterations, with a predominance of hypometabolism, was detected in this group. Standard equations overestimated the energy requirements and physicians overestimated the degree of metabolic stress in a majority of these patients. These factors contributed to a high degree of overfeeding in patients in our study, especially children <1 yr of age, who were at risk of significant cumulative energy excesses during their PICU course. This degree of unintended overfeeding in critically ill children is concerning and may influence clinical outcomes. Targeted IC allows detection of energy imbalance from over-feeding in a subset of metabolically unstable critically ill children and may have a role in optimizing energy intake in the PICU.

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Figure 1.

Bland-Altman plot of the difference between predicted energy expenditure (*EE*) by equation and measured resting *EE* (*REE*) vs. the mean of measured *REE* and predicted *EE*.

Figure 2.
Projected weekly cumulative energy balance (kcal) in critically ill children.

Figure 3.

Correlation between respiratory quotient (RQ) and adequacy of energy intake (intake: requirement ratio). $r = 0.03$ ($p = .8$). IC , indirect calorimetry; $MREE$, measured resting energy expenditure.

Table 1**Criteria for selecting patients for IC testing in the PICU (6)**

Underweight (BMI <5th percentile for age), risk of overweight (BMI >85th percentile for age), or overweight (BMI >95th percentile for age)
Unexpected weight loss or gain of >10% of admission body during the current illness
Clinical suspicion for underfeeding or overfeeding
Clinical suspicion of persistent inflammatory state (eg, oncologic diagnoses, systemic inflammatory response syndrome)
Other condition associated with significantly altered metabolic rate (eg, status epilepticus, hyperthyroidism, or dysautonomia)
PICU length of stay >4 weeks
Unexplained failure to wean from or escalation of respiratory support

IC, indirect calorimetry; PICU, pediatric intensive care unit; BMI, body mass index.

Table 2

Clinical characteristics of the children (n = 29) selected for targeted indirect calorimetry (IC)

Characteristic	No. (%) or Median (Range)
Male sex	18 (62%)
Age, yrs	2 (0.1–28)
Age <12 months	13 (45%)
Medical	17 (59%)
Surgical	12 (41%)
Diagnoses	
Pneumonia/ARDS	6
Congenital heart disease	5
Congenital diaphragmatic hernia	3
Chronic lung disease	7
Traumatic brain injury/intracranial bleed	5
Others	3
Days in PICU at time of IC test	44 (3–216)
Total PICU length of stay, days	33 (7–246)
Total length of hospital stay, days	51 (7–246)
PRISM III score (n = 22)	7.5 (0–28)
Mortality	10 (34%)

ARDS, acute respiratory distress syndrome; PICU, pediatric intensive care unit; PRISM, Pediatric Risk of Mortality.

Table 3

Patient characteristics of critically ill children targeted for IC in relation to their metabolic status

	Normometabolic	Hypometabolic	Hypermetabolic	<i>p</i>
Medical	2	13	2	.04 ^a
Surgical	6	3	3	
Age in months	17.5 (1.4 to 184)	40 (7.7 to 98.8)	0.13 (0.03 to 6.6)	.09
Age <12 months	4/8 (50%)	4/16 (25%)	4/5 (80%)	.01 ^a
WAZ	−0.25 (−2.9 to 1.05)	−0.15 (−1.8 to 0.27)	−1.63 (−1.7 to −1.3)	.3
WFH/BMI-Z	−0.28 (−1.37 to 1.4)	0.5 (−0.25 to 1.53)	−0.49 (−0.9 to 0.14)	.5
LOS in days at the time of IC	21 (17 to 27)	29 (13.5 to 45)	98 (39 to 134)	.1
LOS total in days	33 (25 to 51)	50 (32 to 67)	142 (132 to 173)	.04
Overfeeding	5/8 (62.5%)	15/16 (93.7%)	4/5 (80%)	.15 ^a
Percent energy excess (intake:REE)	144 (112 to 174)	171 (109 to 250)	140 (90 to 238)	.22
Incorrect pretest estimate	7/8 (87.5%)	10/16 (62%)	1/5 (20%)	.05 ^a
Mortality	4/8 (50%)	3/16 (19%)	4/9 (45%)	.19 ^a

IC, indirect calorimetry; WAZ, weight for age z-score; WFH, weight for height; BMI, body mass index; LOS, length of stay; REE, resting energy expenditure.

^a *p* values from Wilcoxon test or Fisher's exact test. Values are median (ranges) or no. (%).