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Cumulative Energy Imbalance in the Pediatric Intensive Care Unit: Role of Targeted Indirect Calorimetry

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Abstract

Introduction—Failure to accurately estimate energy requirements may result in underfeeding or overfeeding. In this study, a dedicated multidisciplinary nutrition team measured energy expenditure in critically ill children.

Methods—Steady-state indirect calorimetry was used to obtain measured resting energy expenditure, which was compared with equation-estimated energy expenditure and the total energy intake for each subject. The children's metabolic status was examined in relation to standard clinical characteristics.

Results—Sixteen measurements were performed in 14 patients admitted to the multidisciplinary pediatric intensive care unit over a period of 12 months. Mean age of subjects in this cohort was 11.2 years (range 1.6 months to 32 years) and included 7 males and 7 postoperative patients. Altered metabolism was detected in 13 of 14 subjects and in 15 of 16 (94%) measurements. There was no correlation between the metabolic status of subjects and their clinical characteristics. Average daily energy balance was 200 kcal/d (range −518 to +859 kcal/d). Agreement between measured resting energy expenditure and equation-estimated energy expenditure was poor, with mean bias of 72.3 ± 446 kcal/d (limits of agreement −801.9 to +946.5 kcal/d).

Conclusions—A disparity was observed between equation-estimated energy expenditure, measured resting energy expenditure, and total energy intake, with a high incidence of underfeeding or overfeeding. A wide range of metabolic alterations were recorded, which could not be accurately predicted using standard clinical characteristics. Targeted indirect calorimetry on high-risk patients selected by a dedicated nutrition team may prevent cumulative excesses and deficits in energy balance.

Keywords

pediatric critical care; nutrition; energy expenditure; indirect calorimetry; energy imbalance; underfeeding; overfeeding; nutrition team

Malnutrition is prevalent among critically ill children^{1–3} and is associated with greater multi-system abnormalities and increased use of intensive care resources.⁴ Children admitted to the pediatric intensive care unit (PICU) exhibit a metabolic response to critical illness of unpredictable nature and severity. Energy expenditure varies during critical illness,

and failure to accurately estimate energy requirements may result in underfeeding or overfeeding of these patients. Therefore, accurate assessment of energy expenditure and optimal provision of nutrition support should be an integral component of pediatric critical care.

Energy expenditure estimates using standard equations are frequently inaccurate in critically ill children.^{5,6} Measurement of resting energy expenditure (MREE) using indirect calorimetry in mechanically ventilated subjects improves the accuracy of nutrition assessment and may reduce the incidence of underfeeding and overfeeding.⁷⁻⁹ However, there are no established standards for obtaining indirect calorimetry measurements in the PICU population, and its use remains sporadic. Indirect calorimetry may have a role in a select cohort of patients in the PICU, where inaccuracy in estimated resting energy expenditure (REE) is anticipated attributable to clinical suspicion of hypermetabolism or hypometabolism. In an era of resource constraints, a model for targeting indirect calorimetry measurements to a select group of patients by a dedicated nutrition team would be feasible for most facilities. This approach could prevent excesses or deficits in energy balance. The efficacy of such a model in preventing energy imbalances has not been examined previously.

Methods

Indirect calorimetry was performed in high-risk critically ill children identified by a dedicated multidisciplinary nutrition team at a tertiary-level PICU over a period of 12 months. After obtaining permission from the institutional review board, we retrospectively reviewed data to examine the efficacy of this practice model. The multidisciplinary nutrition team included a physician nutrition specialist,¹⁰ dietitian, nurse, and pharmacist, who were available for daily consultation. The registered dietitian rounded daily with the intensive care team and was available at all times for expert nutrition support. The multidisciplinary nutrition team rounded at least weekly in the PICU, and there was regular communication between the intensive care and nutrition teams. Nutrition prescriptions for patients admitted to the PICU during this period followed the existing unit guidelines for EN and PN support.¹¹

Subject selection for indirect calorimetry was based on 1 or more of the following criteria: (a) children with known nutrition deficits, that is, underweight (body mass index [BMI] <5th percentile for age), at risk of overweight (BMI >85th percentile for age), or overweight (BMI >95th percentile for age); (b) unexpected (>10%) weight loss or gain during the PICU course; (c) clinical suspicion for underfeeding or overfeeding; (d) persistent inflammatory state (eg, oncologic diagnoses or severe systemic inflammatory response syndrome); (e) any known condition associated with altered metabolism (including status epilepticus, hyperthyroidism, hypothyroidism, dysautonomic storms); (f) PICU length of stay (LOS) >4 weeks; or (h) unexplained failure to wean or unexpected escalation of respiratory support. The presence of 1 or a combination of the above factors may skew predictions by available equations.¹² Patients were excluded from this study if they met any of the following criteria: (a) presence of an uncuffed endotracheal tube; (b) presence of large leak in the ventilator circuit, defined as difference of >20% between measured inspiratory and expiratory tidal volumes; (c) presence of a chest tube for air leak or bronchopleural fistula; (d) fraction of inspired oxygen ($F_{I}O_2$) >0.6; (e) need for extracorporeal membrane oxygenator support; (f) metabolic instability attributable to progressive deterioration requiring ongoing resuscitation or procedures at bedside; and (g) failure to achieve steady state during indirect calorimetry.

Indirect calorimetry was performed with the portable Vmax Encore® indirect calorimetry cart (Viasys, Loma Linda, CA). Flow sensor calibration and gas calibration were performed

prior to each measurement, as per the manufacturer's instructions. In spontaneously breathing subjects, a clear plastic canopy was placed around the head and neck. In mechanically ventilated subjects, the flow sensor adaptor was connected to the expiratory outlet (exhaust) of the ventilator with an adaptor. Subjects were enterally fasted for 4 hours, and the indirect calorimetry measurement was performed at least 2 hours after any interventions, such as changes in mechanical ventilatory support, suctioning, or painful procedures. After equilibration, measurements were continued for 30 minutes until a steady state was attained. Steady state was defined as a period of at least 5 minutes with <10% fluctuation in oxygen consumption and carbon dioxide production and <5% fluctuation in respiratory quotient (RQ).¹³ MREE was calculated by the device software using a modified Weir equation.¹⁴ Estimated energy expenditure (EEE) was calculated for each subject using age-appropriate equations (Schofield, Harris-Benedict, or World Health Organization).^{15–17} In subjects whose weight and height were available at the time of the study, the Schofield equation was used for children <15 years old and the Harris-Benedict equation was used in those 15 years of age or older. The World Health Organization equation for energy expenditure was used when a recent height was not available. Estimated energy expenditure was used to guide energy prescription in our patients until indirect calorimetry measurement. Stress factors ranging from 1.0 to 1.5 were incorporated by the nutrition team.¹⁸ The stage of illness, fever, inflammation, and hypermetabolic features such as autonomic storms, seizures, and increased work of breathing are some of the factors that influenced the application of stress factors.

Demographic and clinical data, including Pediatric Risk of Mortality score (PRISM 3),¹⁹ FIO_2 requirements, and LOS in the PICU at the time of the study were recorded. Based on their metabolic status, patients were classified into 2 groups: hypermetabolic (MREE: EEE ratio >1.1) and hypometabolic (MREE: EEE ratio <0.9). Clinical characteristics and other variables from the 2 groups of patients were analyzed to examine their correlation with metabolic status. Nutrition data were collected by the dietitian to obtain the total daily energy intake (EI), accounting for both parenteral and or enteral nutrients, in the 48 hours preceding the calorimetric measurement. Twenty-four-hour energy balance was calculated as the difference between total EI and MREE. This value was used to calculate a projected weekly energy balance, in an attempt to hypothesize the cumulative effect of any imbalance between measured energy expenditure and intake. EI:MREE ratio was calculated to examine the tendency to overfeed or underfeed. Finally, the total daily EI was compared with the EEE. Because EEE was used to determine caloric goal prior to indirect calorimetry study, the EI:EEE ratio represented the extent to which caloric goal was reached at the time of this study. Quantitative data were expressed as mean $\pm$ standard deviation (SD). The level of agreement between the MREE and EEE was assessed using the Bland-Altman method.²⁰ The distribution of the difference between MREE and EEE was approximately normal. Accordingly, ± 2 SD of the difference was used for limits of agreement.

Results

Sixteen measurements were performed in 14 patients admitted to the multidisciplinary PICU over a period of 12 months. The demographic, clinical, nutrition, and metabolic characteristics of the subjects are presented in Table 1. Mean age of subjects in this cohort was 11.2 years (range 1.6 months to 32 years), and they included 7 males and 7 postoperative patients. Twelve indirect calorimetry measurements were performed in mechanically ventilated subjects and 4 measurements using a canopy in spontaneously breathing subjects. The duration of the studies ranged from 20–65 minutes (mean 34 minutes), and a steady state was achieved in each case. Measurements were repeated in 2 subjects during this study, but the intervals between studies in each case were >2 weeks. For the purpose of analyses, these repeat measurements were considered as distinct data points.

There was no correlation between the metabolic status of subjects (ie, hypometabolism vs hypermetabolism) and their severity of illness scores (PRISM 3), initial diagnosis, age, or BMI. The clinical, anthropometric, and nutrition parameters of the hypometabolic and hypermetabolic subjects are shown in Table 2. There were no significant differences in $F_{I}O_2$, PRISM 3 scores, anthropometry (weight, height, and BMI), length of PICU stay, and age between the 2 groups. The hypermetabolic group tended to consist of a higher number of postoperative surgical patients (5/7, 71.4%) compared with the hypometabolic group (2/6, 33%). LOS in the PICU at the time of indirect calorimetry testing tended to be lower in the hypometabolic group (44.5 ± 35 days) vs the hypermetabolic group (68.7 ± 68 days); neither of these comparisons reached statistical significance.

The total daily EI recorded for patients in our study was 132% (± 68) of the MREE. Average daily energy balance was 200 kcal/d (range -518 to $+859$ kcal/d; Figure 1). Weekly energy balances ranged from $+7310$ to -8580 kcal (mean 732.6 kcal). Energy balance between the 2 groups of patients was not significantly different. On the other hand, EI:EEE ratio, which reflects the actual intake vs estimated goal intake based on EEE prior to indirect calorimetry testing, was significantly higher in hypermetabolic patients (2.1 ± 1.0) compared with hypometabolic patients (0.94 ± 0.5 ; $P < .0039$). Mean RQ of $0.94 (\pm 0.07)$ in the hypometabolic group tended to be higher than that in the hypermetabolic group (0.85 ± 0.07 , $P = .17$). There was no correlation between RQ and energy balance.

The Bland-Altman plot of agreement between the EEE and MREE values is shown in Figure 2. Agreement between the 2 methods was poor, with mean bias of 72.3 ± 446 kcal/d (limits of agreement -801.9 to 946.5). Mean MREE:EEE ratio was 0.94 with a range of 0.43–1.53. Altered metabolism was detected in 13 of 14 subjects and in 15 of 16 (94%) measurements.

Discussion

Energy expenditures and, consequentially, energy requirements in critically ill and postoperative subjects are highly variable.²¹ Estimates of energy expenditure from standard equations adjusted for illness severity and activity (using stress factors) have been used traditionally to calculate nutrition needs.²² However, such estimates are frequently inaccurate and may result in underfeeding or overfeeding, which may affect patient outcomes.^{6,23} We were unable to predict the measured energy expenditure in a group of critically ill children selected by a multidisciplinary nutrition team. The use of equations to estimate energy expenditure in this cohort resulted in underfeeding or overfeeding of the majority of subjects. The mean bias and limits of agreement between measured and equation-estimated energy expenditure in our study were large, suggesting that estimates cannot be relied upon when planning energy intake in critically ill children.

The accurate assessment of energy expenditure in select critically ill children can be achieved using indirect calorimetry when steady-state conditions are met.²⁴ However, multiple factors have limited the application of this testing in everyday clinical practice, and indirect calorimetry is only sporadically used in the PICU.^{25,26} In a review of PICU practice across 111 centers in Europe, only 17% of centers reported the regular use of indirect calorimetry to measure energy expenditure.²⁶ In the current resource-limited environment, where indirect calorimetry testing is applied sporadically, we have demonstrated the ability of a nutrition team to select patients with metabolic alterations who would benefit from indirect calorimetry.

Dedicated nutrition teams are increasingly becoming a standard component of the multidisciplinary intensive care unit (ICU) team. Availability of a dedicated nutrition team in ICU is variable, ranging from 25% to 73% of units in recent surveys.^{26,27} In a survey of

nutrition practices across Canada, a direct correlation was observed between the presence of a funded dietitian assigned to the ICU and successful provision of nutrition support.²⁷ Similarly, implementation of a nutrition support team has been shown to increase enteral nutrition and reduce the reliance on parenteral nutrition with improved patient outcomes.²⁸ A nutrition team that participates daily in bedside rounds with the ICU team may be able to target a cohort in which accurate measurements of energy expenditure may prevent underfeeding and overfeeding. Our study has shown that a nutrition team was able to identify a subset of patients, using selection criteria outlined in the methods section, whose actual metabolic status was significantly different from that predicted by standard equations. The application of indirect calorimetry testing in this cohort helped prevent large excesses and deficits in energy balance.

The heterogeneity of subjects in this study, in terms of age, diagnoses, and severity of illness, is typical of a PICU with a mixed population. We observed a wide range of metabolic alterations in our subjects, with the ratio of measured to predicted energy expenditure ranging from 0.44–1.53. Previous studies in critically ill adults have shown similar wide ranges in ratios of MREE to EEE, suggesting a heterogeneous population in which multiple factors influence energy needs.^{8,29,30} A majority of patients (75%) selected for calorimetry in our study were receiving mechanical ventilatory support. However, in our small study sample, we did not find a predilection for hypermetabolism or hypometabolism. An average tendency toward hypermetabolism has been reported in mechanically ventilated children in the PICU.²⁹ Similar to our observation, severity of illness scores were unable to predict the nature or degree of altered metabolism in this pediatric study. Studies in adult critical care patients have shown variable correlation between MREE and severity scores, probably attributable to the timing of the measurement. Our study differs from most in that we selected a cohort of patients with a longer stay in the PICU. Because of dynamic alterations during the illness course, the metabolic status of patients in such a cohort is likely to be heterogeneous and unrelated to admission severity scores. In children with severe burn injury with extreme hypermetabolism in the early stages of injury, standard equations have been shown to underestimate the MREE.³¹ Stress or activity correction factors traditionally have been factored into basal energy requirement estimates to adjust for the nature of illness, its severity, and the activity level of hospitalized subjects.^{32,33} On the other hand, critically ill children who are sedated and mechanically ventilated may have significant reduction in true energy expenditure, attributable to multiple factors including decreased activity, sedation, mechanical ventilatory support, and transient absence of growth during the acute illness.³⁴ These patients may be at a risk of overfeeding when estimates of energy requirements are based on age-appropriate equations developed for healthy children, especially if stress factors are incorporated. Thus, the application of predetermined values of correction factor based on broad diagnostic groups of patients in the ICU is likely to be inaccurate and may increase the risk of overfeeding or underfeeding. Stress or correction factors should only be applied after careful consideration of metabolic status in individual cases. To prevent unintended overfeeding, clinicians should revisit the need for stress factor incorporation during the illness course, especially in patients with long stays in the PICU.

Following indirect calorimetry testing, we compared the MREE with EI in our patients. The mean EI:MREE ratio (1.6 ± 0.8) and EI:MREE difference in our study are suggestive of an overall tendency to overfeed this cohort. However, the wide range of values in such a small cohort warns against any uniform assumptions of this trend. The degree of overfeeding, although more pronounced for the hypermetabolic patients than for the hypometabolic group, was not statistically significant in our study. We also estimated negative energy balance in 5 subjects, attributable to the failure to anticipate severe hypermetabolism. One subject in our study suffered anoxic brain insult manifesting in severe dysautonomia.³⁵ Rapid and severe weight loss in this patient prompted calorimetric testing that detected

energy expenditure >150% predicted by standard equation. Hypermetabolism in this patient abated when dysautonomia was managed with pharmacotherapy.

Negative caloric balance in the critically ill child may be further compounded by the failure to meet prescribed caloric goals in an ICU because of multiple factors such as fluid restriction, feed interruption attributable to diagnostic or surgical procedures, and feed intolerance.^{3,36} The EI:EEE ratio indicates the amount of EI in relation to the goal requirement based on EEE. EI:EEE ratio was reportedly lower in a hypermetabolic group compared with a hypometabolic group of mechanically ventilated children in a previous study.²⁹ In contrast, we recorded a significantly higher ratio in hypermetabolic patients in our study. This could be related to the incorporation of correction factors into the energy expenditure estimates. Overall, the energy balance calculations performed in this cohort, using actual energy intake and MREE by indirect calorimetry, demonstrated the potential for a wide range of cumulative energy deficits and excesses, with risk of both underfeeding and overfeeding in the absence of accurate measurement of energy expenditure.

The role of RQ as an isolated measure of underfeeding or overfeeding in individual patients is debatable. Despite the theoretical relationship between RQ and substrate use, RQ has not been helpful as a marker of substrate utilization in individual cases.³⁷ Although RQ values in the hypometabolic group were higher than those in the hypermetabolic group in our study, this was not statistically significant, and the study was underpowered to detect such differences. Furthermore, there was no correlation between the RQ and the EI:MREE ratios or energy balance.

Our study is limited by the small number of subjects, failure to study all eligible patients attributable to exclusion criteria, and the lack of comparison with a control group. Although the results suggest that we were able to select patients at high risk of metabolic alteration, we did not attempt to record the metabolic state of all patients in the PICU. There is an inherent selection bias for patients with either hypermetabolism or hypometabolism in our study. It is likely that some degree of hypermetabolism and hypometabolism may be prevalent among those patients who did not undergo indirect calorimetry testing because of the exclusion criteria. A total of 2079 patients were admitted to the PICU during the 12-month period of the study. Fifty patients had a PICU LOS >4 weeks, and indirect calorimetry was performed on 14 subjects (28%) who did not have any of the exclusion criteria and whose steady-state data were recorded. Our cohort included 2 subjects with LOS <4 weeks. We did not routinely perform serial calorimetric measurements in our cohort. Daily variations in energy expenditure may necessitate multiple indirect calorimetric measurements in some critically ill subjects.³⁸

Refining and expanding the criteria for selection may improve the identification of patients at risk of underfeeding and overfeeding. Given the high incidence of hypermetabolism or hypometabolism in patients selected by the criteria used for the study and based on some of the study results, we have suggested criteria that might allow selection of high-risk patients in the PICU for indirect calorimetry (Appendix 1). Furthermore, a single measurement may not necessarily reflect 24-hour energy expenditure in some subjects with rapid variations in metabolism. Future studies directing indirect calorimetry at selected groups could include more postoperative patients, children with increased LOS in the ICU, and those who have failed to meet caloric goals based on careful serial measurements of EI. In the near future, continuous measurement of REE may be feasible with recent advances in continuous gas exchange measurement technology. Compact and portable indirect calorimetry devices have the ability to measure gas fractions integrated with flow signal and to use complex software to provide REE with reasonable accuracy and agreement with standard indirect calorimetry machines.³⁹ These technological advances could potentially make indirect calorimetry more

feasible for daily bedside application. Until then, a dedicated nutrition team could efficiently select patients for indirect calorimetry testing using clinical criteria such as those outlined in Appendix 1. Indirect calorimetry in these patients enables intensivists to monitor energy balance and prevent cumulative energy deficits or excesses, both of which are associated with significant anthropometric changes.⁴⁰

In summary, children admitted to the PICU demonstrate a metabolic response to stress, infection, and injury and have varying caloric needs. We observed a disparity between EEE, actual delivered energy intake, and MREE in these children. This is attributable to the wide range of metabolic alterations in a subset of patients in a multidisciplinary PICU with extremes of hypermetabolism and hypometabolism. The metabolic state did not correlate with age, diagnosis, or severity of illness and therefore could not be accurately predicted by standard clinical characteristics. Nutrient intake guided by equation-assisted estimations results in underfeeding or overfeeding in a majority of these children. Our study reiterates the role of bedside indirect calorimetry measurements for planning nutrient intake in select critically ill children and preventing cumulative excesses and deficits in energy balance. Currently, resource and technical restraints seem to preclude regular indirect calorimetry testing in most units. In such an era, a dedicated nutrition team can identify a subset of patients who are at risk of altered metabolism and who should undergo indirect calorimetry testing. Studies aimed at refining the criteria for selecting patients for indirect calorimetry are needed to examine the cost-effectiveness of a model of nutrition team-directed indirect calorimetry and its impact on patient outcomes. The advent of continuous indirect calorimetry is exciting and may allow a closer examination of the temporal relationship between energy expenditure and the course of critical illness. Finally, these advances should translate to the application of indirect calorimetry at the bedside to provide nutrition intake that is tailored to individual patients and adjusts dynamically to their illness course.

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Figure 1.
Daily and projected weekly energy balance for subjects (n = 14).

Figure 2.

Bland-Altman representation of the difference between estimated energy expenditures EE by standard equations and resting energy expenditure measured by indirect calorimetry vs the mean of estimated energy expenditure and measured resting energy expenditure. Mean bias (72.3 kcal/d) and the limits of agreement (−801.9 to 946.5 kcal/d) are represented by dashed lines.

Table 1
Clinical and Demographic Data of Pediatric Intensive Care Unit Patients Undergoing Indirect Calorimetry

Study No.	Age, y	Weight, kg	Sex	Height, cm	BMI	BMI, z Score	Weight/Height, z Score	Diagnosis	Length of Stay Prior to Indirect Calorimetry, d	Type of Study	PRISM 3
1	14.5	58	F	168	20.6	0.38		Myocarditis	31	Vent	NA
2	0.18	3.5	M	52	NA		-0.9	Congenital diaphragmatic hernia, repaired	65	Canopy	0.90%
3	32.6	185	M	188	52.34	3.15		Congenital lymphatic malformation	9	Vent	0.60%
4	1.32	6.7	M	65.5	NA		-1.13	Acute renal failure	238	Canopy	20%
5	0.13	3.03	M	45	NA		2.32	Congenital heart disease	49	Vent	NA
6	11.6	37	F	146	17.36	-0.18		Brain abscess	20	Vent	3.80%
7	14.5	59	F	157	23.94	1.09		Asthma with hypoxic brain injury	69	Vent	36%
8	20.7	55.8	M	152.4	24.03	0.31		Pancreatic insufficiency, recent Islet cell transplant	146	Canopy	0.4%
9	24.4	60	F	144	28.9	1.37		Developmental delay with seizure disorder	19	Vent	4.90%
10	24.5	59	F	144	28.4	1.31		Developmental delay with seizure disorder	1	Canopy	NA
11	1.29	8.95	F	72	NA		0.25	Aspiration pneumonia in a patient with lung hypoplasia	68	Vent	2.70%
12	1.27	11.16	F	79	NA		0.89	Near drowning	18	Canopy	26%
13	5.7	12.5	M	93.5	14.3	-1.01		Acute lymphocytic leukemia requiring bone marrow transplant	48	Vent	18%
14	5.8	13.7	M	93.5	15.67	0.23		Acute lymphocytic leukemia requiring bone marrow transplant	77	Vent	18%
15	27.6	182	F	135	99.86	3.76		Spina bifida with ventriculoperitoneal	24	Vent	0.30%
16	0.36	8.5	M	69	NA		0.46	Omphalocele with pulmonary hypertension	102	Vent	4.90%

BMI, body mass index; PRISM 3, Pediatric Risk of Mortality; F, female; M, male; NA, not available.

Table 2

Comparative Characteristics of Hypermetabolic and Hypometabolic Subjects

	Hypermetabolic Group, MREE:EEE >110%, n = 7 (7 Indirect Calorimetry Measurements)	Hypometabolic Group, MREE:EEE <90%, n = 6 (8 Indirect Calorimetry Measurements)	P Value
Age, y	10.69 ± 11.7	11.36 ± 11.9	.91
Weight, kg	50.3 ± 64.2	44.5 ± 59	.86
Height, cm	115.5 ± 59.5	104.8 ± 31	.66
BMI, kg/m ²	29.7 ± 15.8	37.4 ± 35.5	.60
BMI z score	1.11 ± 1.4	1.13 ± 1.7	.98
Medical-surgical patients, n	2:5	3:1	
EEE, kcal/d	937.4 ± 714	1128.8 ± 789	.63
MREE, kcal/d	1257 ± 970	707.5 ± 620	.21
EI, kcal/d	1464 ± 1008	935 ± 559	.22
MREE:EEE	1.3 ± 0.1	0.61 ± 0.1	< .0001
EI:MREE	1.6 ± 0.8	1.6 ± 0.8	.49
EI:EEE	2.1 ± 1.0	0.94 ± 0.5	.039
Protein intake, g/kg/d	1.97 ± 0.9	1.4 ± 0.8	.39
RQ	0.85 ± 0.03	0.94 ± 0.06	.17
PRISM score (%)	12.26 ± 15	11.6 ± 10	.94
F _I O ₂ , %	34.1 ± 8.8	31.8 ± 8.8	.63
Days in ICU before indirect calorimetry study	68.7 ± 78	44.5 ± 35	.44
Total ICU LOS, d	112 ± 104	117.5 ± 159	.94

MREE, measured resting energy expenditure; EEE, estimated energy expenditure; BMI, body mass index; EI, energy intake; RQ, respiratory quotient; PRISM, Pediatric Risk of Mortality; F_IO₂, fraction of inspired oxygen; ICU, intensive care unit; LOS, length of stay.

Appendix 1

Suggested Criteria for Selecting Patients for Indirect Calorimetry in the Pediatric Intensive Care Unit

Underweight (body mass index [BMI] <5th percentile for age), at risk of overweight (BMI >85th percentile for age), or overweight (BMI >95th percentile for age)
Greater than 10% weight gain or loss during medical-surgical intensive care unit stay
Failure to consistently meet prescribed caloric goals
Failure to wean or escalation in respiratory support
Need for muscle relaxants for >7 days
Neurologic trauma (traumatic, hypoxic, and/or ischemic) with evidence of dysautonomia
Oncologic diagnoses (including stem cell or bone marrow transplantation)
Need for mechanical ventilatory support >7 days
Suspicion of severe hypermetabolism (status epilepticus, hyperthermia, systemic inflammatory response syndrome, dysautonomic storms) or hypometabolism (hypothermia, hypothyroidism, pentobarbital or midazolam coma)
Intensive care unit length of stay >4 weeks