

Throwing darts in ICU: how close are we in estimating energy requirements?

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ABSTRACT

Background Indirect calorimetry (IC) is the gold standard for determining energy requirement. Due to lack of availability in many institutions, predictive equations are used to estimate energy requirements. The purpose of this study is to determine the accuracy of predictive equations (ie, Harris-Benedict equation (HBE), Mifflin-St Jeor equation (MSJ), and Penn State University equation (PSU)) used to determine energy needs for critically ill, ventilated patients compared with measured resting energy expenditure (mREE).

Methods The researchers examined data routinely collected as part of clinical care for patients within intensive care units (ICUs). The final sample consisted of 68 patients. All studies were recorded during a single inpatient stay within an ICU.

Results Patients, on average, had an mREE of 33.9 kcal/kg using IC. The estimated energy requirement when using predictive equations was 24.8 kcal/kg (HBE \times 1.25), 24.0 kcal/kg (MSJ \times 1.25), and 26.8 kcal/kg (PSU).

Discussion This study identified significant differences between mREE and commonly used predictive equations in the ICU.

Level of evidence III.

INTRODUCTION

Especially among those who work closely with nutrition for critically ill or acutely injured patients, it is well known that indirect calorimetry (IC) is the gold standard for measuring resting energy expenditure (mREE). However, its use in daily clinical application is not common because indirect calorimeters are not widely available.¹ As a result, several predictive equations have been developed to estimate energy requirements, such as the Harris-Benedict equation (HBE), the Mifflin-St Jeor equation (MSJ), the Penn State University equation (PSU), and the American Society for Parenteral and Enteral Nutrition-Society of Critical Care Medicine (ASPEN-SCCM) Guidelines weight-based equation (WBE)²⁻⁸ (table 1).

Because the use of these equations is widespread due to the paucity of indirect calorimeters, it is often thought that these equations are accurate estimations of resting energy expenditure (REE). However, the accuracy rates of these equations are variable at best since overestimation or underestimation of caloric needs may be off by 40%, leading to overfeeding or underfeeding.⁸

The purpose of this study is to determine the accuracy of predictive equations (ie, HBE, MSJ, PSU, and WBE) that are commonly used for calculating energy needs for critically ill, ventilated patients as

compared with the mREE that is measured through IC, to demonstrate the unpredictable inaccuracy of predictive equations for those who may be less familiar with the use of indirect calorimeters. This study is unique in that it compares IC directly with the HBE as well as MSJ, PSU, and WBE formulae. These selected predictive equations are arguably the most common and reflect the ASPEN-SCCM Guidelines, which recommend using a “published predictive equation” or a weight-based method of 25 to 30 kcal/kg.²

PATIENTS AND METHODS

This observational retrospective study examined data collected prospectively from February 2016 to August 2017 as part of routine clinical care for patients within the intensive care units (ICUs) of a 500-bed American College of Surgeons verified level 1 trauma center and public safety net hospital, including the medical, trauma/surgical, and coronary care ICUs.

The study sample consisted of 68 unique consecutive intubated, mechanically ventilated, hemodynamically stable patients for whom IC was requested by the clinical treatment teams of the respective ICUs. All patients were receiving enteral nutrition consistent with the “Enhanced Protein-Energy Provision via the Enteral Route in Critically Ill Patients” or the PEP uP protocol developed by Heyland *et al.*⁹ All studies were recorded during a single inpatient stay within an ICU. The IC studies are normally performed during the mid-day, after morning rounds had been completed. The first IC measure completed was used in the study. Patients were excluded if they had previous ICU admissions during the particular inpatient admission, were hemodynamically unstable, in shock, or on inotropic or vasopressor support. Metabolic cart studies performed using the canopy or facemask method were also excluded. Tests were not performed on patients who were identified with a system air leak (ie, chest tube), patients receiving continuous renal replacement therapy, or those patients found with a fractional inspired oxygen >60%. These patients cannot undergo IC as these variables may cause inaccuracies in the measurements.⁸

The clinical information used in this study originated from patients’ electronic medical record (EMR) and consisted of age (years), gender (female, male), height, weight, body mass index (BMI), minute ventilation, temperature (in °C), and heart rate (beats per minute). The patient’s height used in the study was either recumbent length or reported height. The weight used was usual body weight if available or what was deemed as the patient’s dry

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Table 1 Resting energy expenditure predictive equations

Name	REE equation
ASPEN-SCCM Guidelines ² weight-based equation	25–30 kcal/kg/day
Harris-Benedict equation ⁴	
Female	$655.0 + [9.6 \times \text{weight (kg)}] + [1.7 \times \text{height (cm)}] - [4.7 \times \text{age (years)}]$
Male	$66.0 + [13.7 \times \text{weight (kg)}] + [5.0 \times \text{height (cm)}] - [6.8 \times \text{age (years)}]$
Mifflin-St Jeor equation ⁵	
Female	$[9.99 \times \text{weight (kg)}] + [6.25 \times \text{height (cm)}] - [4.92 \times \text{age (years)}] - 161.00$
Male	$[9.99 \times \text{weight (kg)}] + [6.25 \times \text{height (cm)}] - [4.92 \times \text{age (years)}] + 5.00$
Penn State University equation ^{6,7}	$(\text{MSJ} \times 0.96) + (\text{Ve} \times 31) + (\text{Tmax} \times 167) - 6212$

ASPEN, American Society for Parenteral and Enteral Nutrition; MSJ, Mifflin-St Jeor equation; REE, resting energy expenditure; SCCM, Society of Critical Care Medicine; Tmax, maximum temperature in °C; Ve, maximum ventilation in L/min.

body weight or lowest documented weight available in the EMR. The mREE was obtained using the COSMED Quark RMR.¹⁰ Predictive equations used in this study were MSJ, HBE, PSE, and WBE. A stress factor of 1.25 was applied to MSJ, HBE, and PSU energy expenditure estimates to create consistent comparison. This stress factor was selected as it was used in other similar research studies.^{1,8,11} The use of a static stress factor also made statistical sense for comparison purposes. Otherwise, stress factor selection is subjective and based on the clinician's perception of the degree of hypermetabolism. The WBE was calculated at 25 and at 30 kcal/kg/day.

The IC measures in this study were performed by registered dietitian nutritionists (RDNs). Two RDNs who work in the critical care areas were trained by the COSMED staff in using the Quark RMR in the ICU.¹⁰ Training was held in two separate sessions for a total of 8 hours. Prior to initiation of testing, the machine was calibrated. The duration of IC testing is typically 30 to 40 min, which includes the set-up, dismantling, and sanitization of the machine.

Statistical analysis

Summary statistics were estimated for the variables of interest (ie, age, gender, heart rate, ICU type, mREE, predictive equations). Bland-Altman plots were used to depict the relative percent difference between energy estimate equations and the measurement from metabolic cart for the patients. The y-axis shows the relative percent difference between the predictive equations and the reference energy expenditure measurement from metabolic cart. The x-axis shows the energy expenditure using the metabolic cart, the reference method. Dotted lines represent the 95% limits of agreement. The solid line represents the mean difference. The upper limit of agreement indicates the most likely maximum increase in percent difference of the energy estimate equation from the energy estimate using metabolic cart, and the lower limit of agreement indicates the percent decrease in value.^{12–14} All statistical analyses were performed using SAS V.9.4.

RESULTS

The average age of the patients included in the sample was 61.7 ± 17.4 years and 60.3% were male. Across the sample, 44.1% were from trauma/surgical ICU, 48.5% were from

Table 2 Characteristics of the study sample

Variable	Study sample (N=68)
Age (years)	61.7 ± 17.4
Gender	
Female	27 (39.7%)
Male	41 (60.3%)
Body mass index	27.2 ± 8.5
ICU type	
Coronary care unit	5 (7.4%)
Medical ICU	33 (48.5%)
Trauma/surgical ICU	30 (44.1%)

ICU, intensive care unit.

medical ICU, and 7.4% from coronary care unit. The average BMI was 27.2 ± 8.5 (table 2).

Energy expenditure values predicted by equations as well as using metabolic cart are shown in table 3. As illustrated in table 3, patients, on average, had an mREE of 33.9 kcal/kg using IC. The estimated energy requirement when using predictive equations was 24.8 kcal/kg (HBE \times 1.25), 24.0 kcal/kg (MSJ \times 1.25), and 26.8 kcal/kg (PSU). The average heart rate was 104.6 beats per minute.

The energy expenditure values predicted using HBE \times 1.25, MSJ \times 1.25, and PSU were compared against mREE in Bland-Altman plots (figure 1). Relative to the metabolic cart, HBE \times 1.25 underestimated the energy expenditure on average by 21%, MSJ \times 1.25 underestimated by 23.6%, and PSU underestimated by 16.2%. The limits of agreement between energy expenditure predicted using equations relative to measurement by metabolic cart were the widest for HBE \times 1.25 (37.3% and -79.3%) (figure 1A) and narrowest for PSU (29.4% and -61.8%) (figure 1C). The weight-based formula underestimated by 17.3% when calculated at 25 kcal/kg and by 11.5% when calculated at 30 kcal/kg (figure 2).

DISCUSSION

Most clinicians, primarily RDNs, use weight-based formulae or predictive equations as part of nutrition assessment to determine estimated REE to help guide nutrition prescription. When using equations, one must be cognizant regarding the inaccuracies of much of the anthropometric data used in the calculation. It has been practiced in this facility to obtain recumbent length measures. The most reliable weight available should be used: the admission weight (usually the lowest documented weight) or the usual body weight or documented dry weight. As discussed, it

Table 3 Predictive equations and measured values in the study sample

Measurement	Mean \pm SD
Tmax (°C)	38.3 ± 0.84
Max Ve	13.8 ± 3.7
Heart rate (beats per minute)	104.6 ± 18.4
HBE \times 1.25 (kcal/kg)	24.8 ± 4.0
MSJ \times 1.25 (kcal/kg)	24.0 ± 3.4
PSU (kcal/kg)	26.8 ± 4.9
REE using metabolic cart (kcal/kg)	33.9 ± 9.5

HBE, Harris-Benedict equation; Max Ve, maximum ventilation; MSJ, Mifflin-St Jeor equation; PSU, Penn State University equation; REE, resting energy equation; Tmax, maximum temperature.

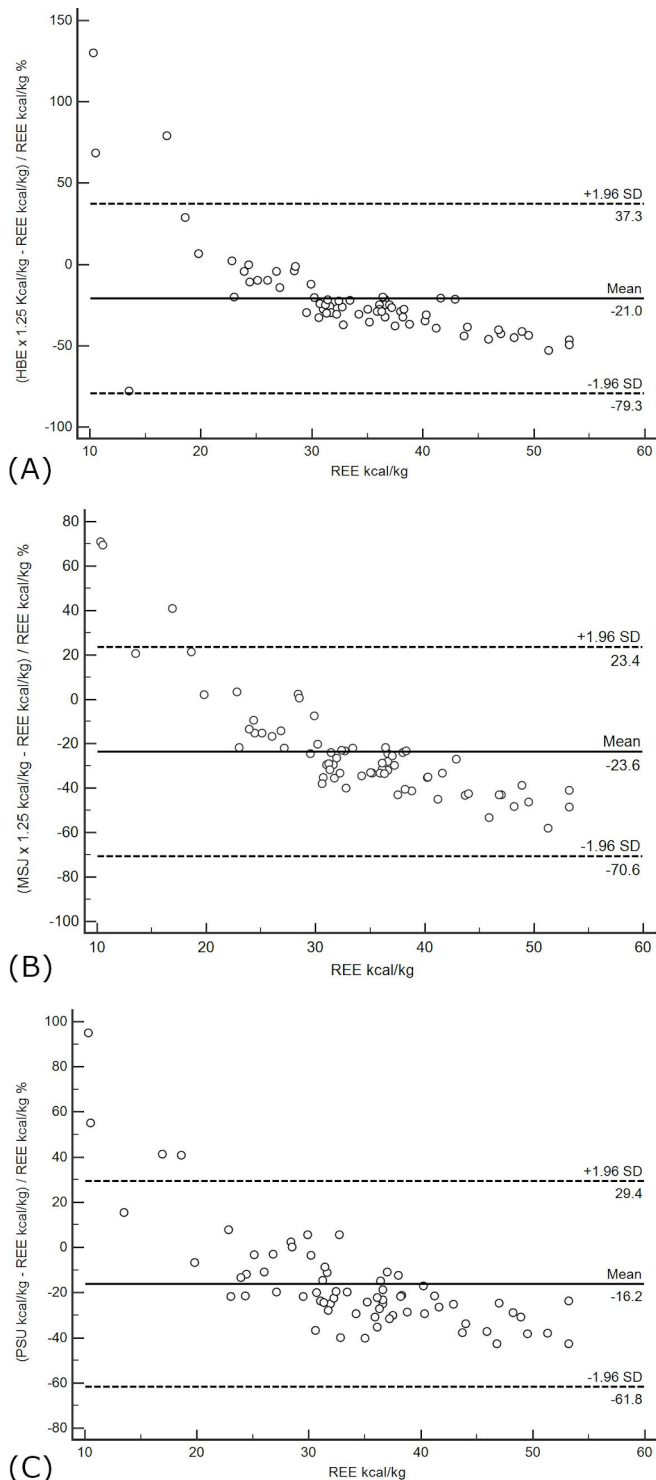


Figure 1 Bland-Altman plots comparing the predictive equations with metabolic cart measurements. (A) HBE, Harris-Benedict equation; (B) MSJ, Mifflin-St Jeor equation; (C) PSU, Penn State University equation; REE, resting energy expenditure.

remains disputed in the literature as to whether or not predictive equations are accurate enough in day-to-day determination of energy requirement. IC is uncommon, and even rare, outside of academic centers, due in part to the high cost of acquiring the indirect calorimeter and the need for skilled and trained personnel to conduct studies.¹¹ Poor reimbursement by insurance for tests performed has also been considered a barrier to using

IC.⁸ As a result, predictive equations have been recommended as surrogates for IC, despite accuracies which range from 0% to 77%.¹⁵ Unfortunately, those healthcare professionals who do not receive a strong education in nutrition or are not familiar with critical care medicine do not recognize these formulae were created based on healthy individuals. So although the predictive formulae are reasonably accurate for reasonably healthy individuals, it is often incorrectly assumed these equations are also accurate in patients with significant medical illness.¹⁶ This misconception is further reinforced by the ASPEN-SCCM Guidelines, which recommend a weight-based formula due to its simplicity over more complicated predictive equations, when IC is not available.² The Bland-Altman plots of the predictive equations and weight-based formulae illustrate that although across a group of patients these calculations may be reasonable estimates collectively, for an individual patient it is not possible to know the direction or magnitude of the error (figures 1 and 2).

IC studies are reimbursable and have specific assigned Current Procedural Terminology (CPT) codes and reimbursements (ie, Medicare reimbursement CPT code 94690 “Exhaled Air Analysis”) which can offset the costs associated with its purchase and necessary disposables (ie, tubing, filters, gas).¹⁷ As determined in the study by Heyland *et al*,¹⁸ caloric adequacy may contribute to prolonged ICU survival. Underfed patients are also likely to experience poor wound healing and increased risk of nosocomial infections.¹⁹ Overfeeding, although arguably a less common occurrence in ICU, is also detrimental as it is associated with prolonged ventilation weaning, increased risk of infection, and hyperglycemic events.⁸ Therefore, it is imperative to provide the optimum energy dose for the critically ill patients to ensure the best outcomes. The usefulness of IC continues to be debated as prediction equations are seen as easier and less costly to use. IC calculates REE by measuring gas exchange between whole-body oxygen and carbon dioxide.¹⁹ The mean level of hypermetabolism in trauma patients has been reported to be as high as 116% to 158%.²⁰ Factors that may influence REE include injury (ie, burn, trauma, surgery), temperature (presence or absence of fever), diet-induced thermogenesis, sepsis or infection, sedation, agitation, and potentially when family or friends visit the patient at bedside.⁸ Patients on extreme ends of the BMI scale, those with significant fluid accumulation, or those with amputations provide a challenge when using predictive equations as most equations use body weight as a variable.¹⁹ BMI does not consistently correlate with body composition, which is an important determinant of energy expenditure due to variations in the metabolic activities of tissues, such as the skeletal muscle as compared with adipose.^{21 22} Findings by Janssen *et al*²³ indicate that men have more skeletal muscle than women (38.4% vs. 30.6%) and that these gender differences are greater in the upper body. Independent of gender, aging has been found to be associated with a decrease in skeletal muscle mass that is explained, in large measure, by a decrease in the lower body occurring after the fifth decade of life. Equations attempt to take these differences into account; however, body composition is highly variable, directly affecting mREE.²³

The patients that were included in this study had an average core temperature slightly above the normal range ($38.3^{\circ}\text{C} \pm 0.84^{\circ}\text{C}$), which may explain why the average kcal/kg for mREE was higher than HBE and MSJ, but more closely related to PSU. PSU incorporates temperature as part of the equation. Disease severity may play a role in increased mREE, but diagnoses or disease severity data were not collected in this study. Estimation formulae cannot factor in other issues such as metabolic conditions and effects of medications (ie, paralytics,

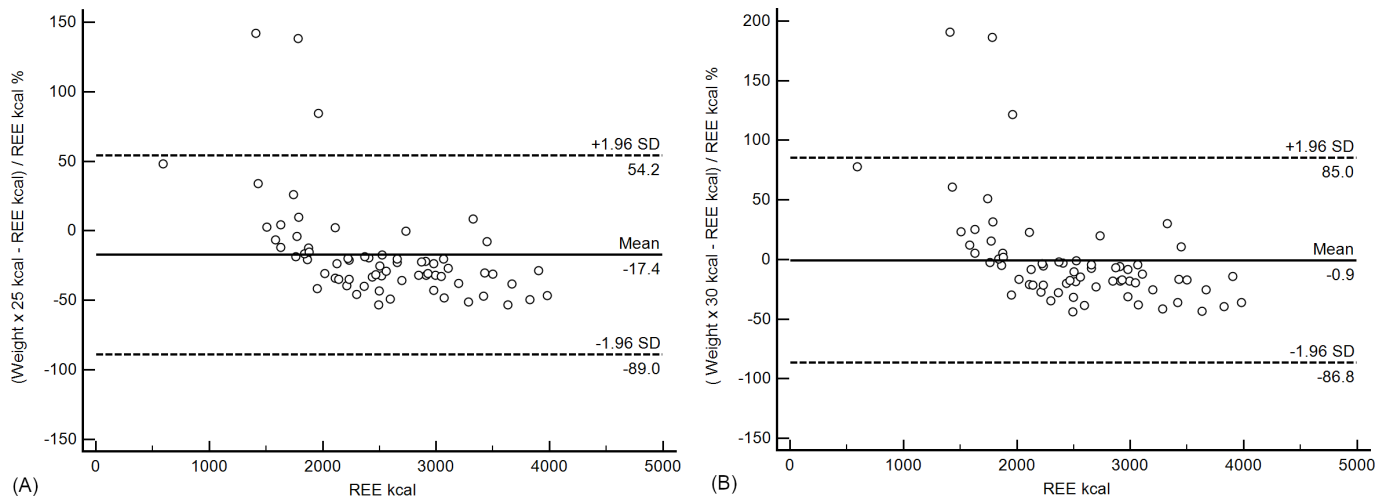


Figure 2 Bland-Altman plots comparing weight-based formulae with metabolic cart measurements. REE, resting energy expenditure.

steroids, beta blockers). This makes the choice of a stress factor less of an educated guess and more of a random multiplier that gives a false sense of accuracy.

Clinicians may not fully realize the importance of accurate dosing of nutrition support.²⁴ A retrospective analysis of prospective study data from an international sample of ICUs examined the relationship between caloric provision and mortality in critically ill patients requiring long-term ventilation. It was found that only 0.8% of approximately 8000 cases used IC.¹⁸ A total of 475 patients out of 1223 study participants met the criteria for further analysis. Of these 475 patients, 36% died. Patients who received less than estimated/measured caloric requirements had a significantly shortened survival time than those who were considered to be adequately fed. In this study, nutritional adequacy was categorized as low (<50%), moderate (≥50% and <80%), and high (≥80%). This study shed light on the importance of appropriate dosing of calories. However, Heyland *et al* admitted there was no standardized method used between study participants' determination of energy requirements (IC vs. numerous predictive equations).¹⁸ The researchers detailed this as a major limitation of the study.

The strengths of this study include that IC testing was limited to two skilled RDNs, performed by the same Quark RMR metabolic cart that was regularly calibrated. The limitations include measurements obtained from a single center with a fairly low number of patients, in a retrospective fashion, and that all patients were intubated and mechanically ventilated. As the number of ICU patients assessed increases, it will be possible to repeat the process of this study in specific conditions, such as traumatic brain injury, acute decompensated congestive heart failure, or acute sepsis and septic shock. Future studies will consider the acuity of the patients studied based on diagnoses and the Acute Physiology and Chronic Health Evaluation II scoring to determine disease severity. Using these data, a multivariate regression analysis might be able to determine if severity of illness condition affects the comparison of IC with commonly used predictive equations. Serial studies may allow assessment of how mREE changes throughout different phases of illness/injury. Finally, the use of the IC canopy would allow expansion of the use of IC to patients who are not mechanically ventilated.

CONCLUSION

This study identified significant differences between the mREE and commonly used predictive equations for mechanically

ventilated patients in the ICU. The variances between them can be large and may affect patient clinical outcomes due to an inappropriate nutrition prescription. It is essential that physicians who are not familiar with IC understand the unpredictable nature of the errors inherent to the predictive equations and that it is worthwhile for facilities to invest in an IC device and to train personnel to conduct regular tests. Accuracy in determining nutrition prescription will improve clinical outcomes by helping to avoid the pitfalls associated with both undernutrition and overnutrition.

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Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information. Deidentified participant data are available with permission from the corresponding author.

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