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**Invited Review**

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**Best Practices for Determining Resting Energy Expenditure in Critically Ill Adults**

Kirsten Martine Schlein, MS, RD, LD⁠¹; and Sarah Peskoe Coulter, MS, RD, LD⁠²

**Abstract**

Indirect calorimetry (IC) is the gold standard for measuring resting energy expenditure (REE) in the critically ill patient. The use of predictive equations to develop nutrition regimens can be problematic in the critical care setting, because the effects that disease, injury, and stress have on REE are often varied and unpredictable. IC testing ensures that the specific conditions of the critically ill patient are taken into account, thereby preventing potential complications from over- and underfeeding. The clinical indications for and appropriate applications of IC testing are discussed. In addition, 3 case studies are presented that highlight the application of IC. The clinician can face numerous obstacles in implementing IC testing, including lack of equipment, staff shortages, and lack of knowledge regarding application and interpretation of the IC study. Recommendations for addressing these challenges are discussed. In addition, guidelines on ordering and interpreting the IC study are provided. Best practices for predictive equations in critically and acutely ill patients are also presented, since IC testing is not feasible in certain situations. Given the importance of predicting REE in the critically ill patient, it is paramount that more healthcare professionals incorporate IC testing into practice. A multidisciplinary approach is helpful in developing a well-established clinical practice. Nutrition support clinicians can promote optimal nutrition management by being well-informed and able to provide evidence-based recommendations for the use of IC. (Nutr Clin Pract. 2014;29:44-55)

**Keywords**

indirect calorimetry; metabolic cart; resting energy expenditure; energy metabolism; nutritional support; critical care

Indirect calorimetry (IC) is the gold standard for measuring resting energy expenditure (REE) in the critically ill patient.¹⁻⁵ IC calculates REE by measuring whole-body oxygen (VO₂) and carbon dioxide (VCO₂) gas exchange. This concept is based on the strong correlation between intake of oxygen and release of carbon dioxide with energy production. It is estimated that approximately 80% of energy expenditure is due to oxygen consumption, and the remaining 20% of energy expenditure is due to carbon dioxide production.⁶⁻⁸

The VO₂ and VCO₂ values are applied to the abbreviated Weir equation, where energy expenditure equals \(3.94 \times VO₂ + (1.11 \times VCO₂)\).⁶⁻⁹ While the full equation contains a component to assess urinary nitrogen excretion, this factor is often excluded. Urinary nitrogen excretion is not essential to determine REE, as it accounts for <4% of energy expenditure in the critically ill patient.¹⁰

The human body uses its total energy expenditure (TEE) in the form of 3 components: basal energy expenditure (BEE), the thermic effect of food, and activity-induced energy expenditure.¹¹⁻¹² For practical reasons, BEE is rarely measured, and REE is most often applied. Energy expenditure measured by IC testing correlates best with REE, which is approximately 10% above BEE¹³ and 0% to 30% below TEE.⁴⁻⁷ REE includes activities needed to sustain life, such as respiration, circulation, and body temperature. Approximately 60%–70% of REE is attributed to the relatively constant metabolism in the liver, brain, heart, and kidneys.⁵,¹⁴⁻¹⁶ While REE does not account for all of the energy expenditure of the critically ill patient, the remainder is potentially negligible in this population.¹³,¹⁶,¹⁷

REE is affected by several basic, distinguishing factors among individuals, such as overall size and body composition.⁶⁻¹⁷⁻¹⁹ As height and weight increase, so does REE. Sex and age are associated with REE in that females and the elderly have decreased estimations. Even females of similar size to males have decreased REE, because males generally have less body fat and greater fat-free lean body mass.⁶,¹⁴,¹⁷,¹⁹,²⁰ For this reason, many predictive equations include some component of height, weight, sex, and age in the estimation of REE, but the struggle of accurate energy assessment extends far beyond these basic calculations in the face of critically ill patients.

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Adequate nutrition provision is imperative when considering the prevalence of malnutrition in the hospitalized patient. It is estimated that at least one-third of patients are malnourished when admitted to the hospital, and two-thirds of these patients will have a decline in nutrition status if left untreated. With regard to patients who are well nourished at admission, it is estimated that one-third may become malnourished during their stay. Malnutrition is associated with numerous adverse outcomes, including immune suppression, higher rates of infection, longer hospital length of stay, higher readmission rates, higher hospital costs, and increased mortality.

Preventing over- and underfeeding with the use of IC testing and the subsequent design of appropriate nutrition support regimens can have potential cost savings. For example, using IC testing as opposed to predictive equations can translate into improvement in the precision of parenteral nutrition (PN) prescription. One study compared predictive formulas vs measured REE in 100 patients receiving PN and found that the support for respiratory distress, and high-risk status with multiple comorbidities.

Patients who fail to respond to a previously prescribed nutrition support regimen may benefit from IC studies. Biweekly IC testing in patients may ensure that the nutrition support is indeed meeting the prescribed REE and may assist in eliminating a prescribed nutrition regimen as a contributing factor to under- or overfeeding, poor wound healing, or longer than anticipated days on the ventilator.

The basis of nutrition support is to preserve lean body mass, preserve immune function, and prevent complications related to under- and overfeeding. As patients become more critically ill, the variability of REE becomes greater. For this population, uncertainty in REE should be minimized whenever possible to avoid the negative effects of under- or overfeeding (see Table 1). Patients who have a disease state or clinical condition that dramatically alters their REE merit IC testing (see Table 2). These patient populations include those with burns, multiple or large wounds, multiple trauma, neurologic trauma or severe closed head injury, multisystem organ failure, sepsis or systemic inflammatory response syndrome (SIRS), acute respiratory distress syndrome (ARDS), and postoperative solid organ transplantation. Patients with a significantly altered body composition, such as those who are either morbidly obese or underweight or have limb amputation(s), peripheral edema, and/or severe ascites, present a challenge with regard to estimation of caloric needs.

Even the same patient in a single hospital stay may be subject to a variety of factors that not only affect his or her REE but may also reduce the accuracy of predictive equations. Present in many critically ill patients, these factors include the management of wound care, sedation source, ventilator...
results of predictive formulas exceeded measured REE by an average of 1076 calories, which would translate into the administration of 6947 excess liters of PN per year. Another study estimated that predictive equations resulted in an estimation of 500–2000 calories per day above measured REE, and using the metabolic cart over 1 year reduced the quantity of PN administered from 33,000 to 26,000 L.

Underfeeding patients can also potentially translate into increased costs for an institution, given the high cost of malnutrition. For example, 1 study found that patients at risk of malnutrition had a 6-day longer length of stay than those not at nutrition risk, resulting in an additional $1633 increase per patient per hospital stay. Another financial consequence of malnutrition is the development and exacerbation of pressure ulcers in the acute care setting. There is a significant relationship between malnutrition and pressure ulcers, and adequate nutrition provision plays a key role in addressing this issue. One study found that the average hospital treatment cost associated with stage IV pressure ulcers and related complications was $129,248 for hospital-acquired ulcers during 1 admission and $124,327 for community-acquired ulcers over an average of 4 admissions. Therefore, adequate nutrition provision is crucial to prevent the development of malnutrition and not to exacerbate the condition of preexisting malnutrition.

While predictive equations may initially be used in determining caloric requirements, the application of IC testing can be helpful if patients do not respond well to the prescribed nutrition regimen based on predictive methods. The correlation between a nutrition regimen and patient response may be difficult to directly correlate; however, examples of potential poor outcomes may include failure to wean from mechanical ventilation and poor wound healing. IC testing can also be a valuable tool when evaluating whether under- or overfeeding is contributing to respiratory and metabolic issues in patients.

Since IC testing is often not practical and equipment may be unavailable, standardized equations are frequently used to estimate metabolic rate. Hundreds of equations are available to estimate needs. Often, uncertainty surrounds how to best calculate metabolic rate in a given patient population. Many equations have been shown to be inaccurate in a range of settings and may be significantly different from measured REE. However, current research does provide some guidance for best practice with regard to predictive equations.

Calculating REE in overweight and obese patients presents a particular challenge. Predictive equations are less consistent and accurate in this population, and IC testing should be used whenever possible. The tendency to overfeed patients is greater when using predictive equations. Obese, critically ill patients are just one patient population at high risk.

The demographics of Americans are changing, and, in turn, the demographics of hospitalized patients are different than in decades past. The epidemic of overweight and obesity affects 69% of adult Americans, translating into 78 million adults who are considered obese. These data translate into a growing population of hospitalized overweight and obese patients, which has complicated healthcare delivery. It is estimated that 25%–30% of patients admitted to the intensive care unit (ICU) have a body mass index (BMI) ≥30. The accuracy of predictive equations is questioned in patients who are obese, especially those with morbid obesity (BMI ≥40). Increasing numbers of overweight and obese individuals contribute to the chronic health status of patients, the presence of comorbidities, and the increased complexity of patients being managed. Yet, predictive equations established for patients who are healthy continue to be used.

Additional key findings of the most recent National Health and Nutrition Examination Survey are that more than 35% of older adults 65 years and older were obese in 2007–2010, representing approximately 13 million Americans. The forecast continues to grow for the older adult demographic—especially those who are obese. These growing numbers not only compound healthcare spending but pose challenges for nutrition support clinicians in the field who are providing medical management for individuals with declining metabolisms and lean muscle mass who may be at risk for malnutrition. These obese patients have greater risk for complications, including organ failure, infection, increased duration of mechanical ventilation, higher aspiration risk, and longer hospital and ICU length of stay. Research is not clear as to the best method for assessing these patient populations, as data are limited on elderly, obese patients. In patients who are at high risk of nutrition decline and malnutrition, it is crucial to develop appropriate nutrition support regimens that optimize nutrition. The best answer at present is through IC testing.

**IC Equipment**

It is possible to measure REE using IC in both mechanically ventilated and spontaneously breathing patients. In either case, the use of a device for IC testing requires a physician order for application. Various devices exist for spontaneously breathing patients, including ventilated canopy, masks, and mouthpieces with nose clips. Recent design improvements in face masks and mouthpieces have been developed to safeguard against air leaks because nose clips may increase REE artificially.

One of the oldest methods of measuring REE is an open-circuit Douglas bag, where the participant breathes ambient air into an airtight container through a 1-way valve. Relative concentrations of oxygen and carbon dioxide are measured in sampled expired gas by electronic gas analyzers. VO₂ and VCO₂ are then determined by comparing the composition of inspired and expired air. Technical expertise is required for this method.

Measuring energy expenditure via IC testing with a metabolic cart is preferred over the use of estimations by predictive equations. Metabolic carts may be used in the mechanically ventilated population where gas samples are continuously
obtained and analyzed from a mixing chamber. The patient breathes either through a mouthpiece or into a mask connected to the metabolic cart. Most models interface well with mechanical ventilators and connect through the exhalation port. The cost of a metabolic cart is approximately $25,000. The metabolic cart employs breath-by-breath analysis, is accurate, and is well-accepted in clinical settings; however, this device requires technical expertise to maintain. Indirect calorimeters require regularly scheduled maintenance—namely, calibration. Calibration is one of the most important aspects of maintenance, because a small change in calibration can affect REE outcomes.

As technology advances, the cost of metabolic carts reduces, machines become more portable, and accuracy improves. The latest technological advances in ventilators include airway modules capable of continuous respiratory monitoring and gas exchange measurement (GE Healthcare, Golden, CO). This technology provides the opportunity to extract recent data from periods when IC testing is most precise.

One of the newer machines suited for spontaneously breathing patients is the handheld indirect calorimeter, a validated and reliable handheld device using a mouthpiece and nose clip to capture gas exchange. However, I study demonstrated bias with increasing REE values for the MedGem (Healthtec, Golden, CO). The machine itself is portable, and the device conveniently self-calibrates. Like the metabolic carts, it employs breath-by-breath technology, but this device is not indicated for use in mechanically ventilated patients. By directly measuring VO2, the handheld indirect calorimeter determines REE by the modified Weir equation. In comparison to the expense of a metabolic cart, the cost of a handheld indirect calorimeter is approximately $2500 (Viasys Healthcare, Yorba Linda, CA; Datex Ohmeda, Andover, MA). In addition, it is not required that a respiratory therapist (RT) be present, as nutrition support clinicians are capable of performing these tests at a patient’s bedside.

How to Accurately Perform IC

A variety of factors must be assessed prior to administering IC testing to ensure accuracy. These factors include mechanical, environmental, and metabolic. Being cognizant of the factors referenced in Tables 3 and 4, the nutrition support clinician can attempt to limit those conditions that affect accuracy.

To determine if IC testing is accurate, consider if the metabolic cart was appropriately calibrated. Regardless of the equipment, REE measurements should be taken when patients are undisturbed. The environment itself should be as consistent and uniform as possible, including a quiet, thermoneutral setting. Routine nursing care, activities, visitors, interruptions, and encounters with any other clinicians should be avoided. Medications frequently used in the clinical settings can also affect REE. Sedatives and paralytic drugs are commonly administered in the critical care setting to facilitate mechanical ventilation by decreasing VO2. Paralytic drugs or a continuous infusion of sedatives, a common practice in managing those who are critically ill, decrease respiratory drive and central blood flow. Examples of medications that can increase REE include catecholamines and pressor agents, while medications that may decrease REE include sedatives, analgesics, neuromuscular blocking agents, barbiturates, and general anesthesia.

Delay IC testing for at least 1 hour after a painful procedure, if possible. If a chest tube is present, it is recommended to avoid IC testing due to an inability to collect all expiratory flow. Air leaks may increase or decrease results of the IC study depending on the location of the leak and its effect on inspiratory vs expiratory air. If medically able, sources of supplemental oxygen such as nasal cannulas, continuous positive airway pressure (CPAP)/bilevel positive airway pressure (BiPAP) masks, and tracheostomy collars are turned off during the routine room air measurement.

For practical purposes, early morning IC testing also may be preferred for spontaneously breathing patients, since patients are often fasting at this time. To obtain an accurate result with IC testing, the patient should be in a resting state. A resting state requires a minimum of 5 hours of fasting, no physical activity, and no consumption of stimulants such as caffeine or nicotine. In the critical care setting, patients often receive continuous enteral feeds and are not fasting; however, the metabolic rate change related to diet-induced thermogenesis is minimal. Continuous enteral nutrition (EN) or PN, if present, should be at the same rate of infusion, and the composition of tube feeds should be consistent for 12 hours prior to initiation and throughout the duration of IC testing. In the event of bolus feedings or cyclic nutrition support (either EN or PN), a 1-hour wait after feeding is recommended if thermogenesis is to be considered in the IC study, and a 4-hour wait after feeding is recommended if it is to be excluded from the study.

General anesthesia should not be administered within 6–8 hours prior to the IC study. Analgesics or sedatives for those patients in pain should be administered at least 30 minutes before the start of the IC study when feasible, and, if given, the REE measurement taken will be specific to this sedated state. Patients who have recently received hemodialysis or any procedure that affects gas exchange are not appropriate candidates for IC testing. Although data are limited, the current recommendation is to allow 4 hours after the end of the hemodialysis session before conducting an IC study. Continuous renal replacement therapy (CRRT) affects the accuracy of IC testing, although to what extent remains unclear. CRRT may increase CO2 elimination from the plasma. It is suggested that IC testing be repeated once CRRT is discontinued. This subject warrants further research.
Table 3. Recommendations for Improving Accuracy of Indirect Calorimetry.

- Patients have rested in a supine position (in bed or a recliner) for more than 30 minutes before the study to avoid the effects of voluntary activity on resting energy expenditure (REE).6,9,39
- Patients receiving intermittent feedings (ie, bolus enteral feeding, cyclic enteral or parenteral nutrition, or meals) are studied approximately 1 hour after the feeding if thermogenesis is to be included in the REE or 4 hours after the feeding if it is not.6,39
- The rate and composition of nutrients being infused on a continuous basis are stable for at least 12 hours before and throughout the study.6,39
- Measurements are made in a quiet, thermoneutral environment.6,9,23,39
- All sources of supplemental oxygen (ie, nasal cannulas, masks, or tracheostomy collars) are turned off during routine room air measurements, if medically feasible.6,9,39
- The fraction of inspired oxygen (FiO2) remains constant during the measurement.6,9
- The study will be delayed for 90 minutes if changes are required in ventilatory settings.6,9,23,39
- The patient has usual patterns of voluntary skeletal muscle activity (movement of the extremities) during the study.6,9,23,39
- No leaks are present in the sampling system.6,9,23,39
- All data used to derive REE and respiratory quotient (RQ) are taken from a period of equilibrium or steady state that has been identified according to statistically defined guidelines.6,9,23,39
- The patient has not received general anesthesia 6–8 hours before the study.5
- If the patient is in pain or agitated, analgesics or sedatives will be given at least 30 minutes before the study when clinically possible, and this information will be documented for consideration during the interpretation of the study.6,23,39,66
- The study will be delayed for 3–4 hours after hemodialysis.6,9,74
- The study will be delayed 1 hour after painful procedures have been performed.6
- Routine nursing care or activities involving other healthcare professionals should be avoided during the study.6,23


Table 4. Technical Factors That Decrease Indirect Calorimetry Accuracy.

- Mechanical ventilation with fraction of inspired oxygen (FiO2) ≥60
- Mechanical ventilation with positive end expiratory pressure (PEEP) >12 cm H2O
- Hyper/hypoventilation (acute changes altering body CO2 stores)
- Leak in the sampling system
- Moisture in the system can affect the oxygen analyzer
- Continuous flow through the system >0 L/min during exhalation
- Inability to collect all expiratory flow
- Unstable inspiratory FIO (T ≥±0.01)
- Leaking chest tube (inability to collect all expired gases)
- Bronchopleural fistula (inability to collect all expired gases)
- Supplemental oxygen in spontaneously breathing patients
- Hemodialysis, peritoneal dialysis, or continuous renal replacement therapy in progress
- Errors in calibration of indirect calorimeter


No changes to the ventilator settings for a minimum of 90 minutes prior to IC testing are desirable. Once the IC study is initiated, the fraction of inspired oxygen (FiO2) should remain constant, and the patient should not exhibit any unusual activity or movement of extremities during IC testing.6,9,11,23,39

Ventilator-related factors can cause artifactual changes in REE. For example, acute hyperventilation can result in increased VCO2 from the work of breathing, which would cause a rise in REE.72 A painful procedure could cause temporary increases in VCO2, increasing REE.73 Hypoventilation would have the opposite effect. Any air leaks would also cause artifactual decreases in REE through loss of both VO2 and VCO2. In addition, an inaccurate increase in REE would be seen with a pressure surge from the ventilator, which would cause an increase in FiO2. This surge would occur in the open-circuit indirect calorimeter, which measures partial pressure of oxygen in the blood (PO2).9

Accurate IC testing requires that all respiratory gases are captured and remain stable.75-77 The volume-controlled ventilator mode has been considered the ideal setting, because it results in less variation in minute ventilation (Ve), which alters gas balance.77,78 Spontaneous breath settings such as CPAP cause instability and, therefore, may not appropriate for IC testing.78 While often assumed that a control mode is the only ventilatory setting appropriate for an IC study, other settings may be considered as well. A mixed-mode setting such as synchronized intermittent mandatory ventilation (SIMV) may be considered for IC testing, although used with caution.

In addition, while a volume-controlled ventilator mode is typically used for IC testing, a study examining volume vs pressure-controlled ventilator modes for use in IC studies found that both groups yielded similar and satisfactory results. The pressure-controlled group was comparable to the volume-controlled group in that both were sedated without any muscular activity or spontaneous breathing.79 The effect of ventilatory settings on measured REE is an area in need of additional study.

Changing a patient’s ventilatory setting solely for the purpose of conducting an IC study is not ideal. While a change may in fact help to achieve steady state, the vent setting change...
alone can have an impact on the measured REE. A change in ventilatory setting may not be representative of the patient’s respiratory status and, therefore, will not truly reflect the patient’s metabolic condition.

**Obtaining an Accurate IC Measurement**

Steady state is a period of metabolic equilibrium where VO\(_2\) and VCO\(_2\) change by <10% during 5 consecutive minutes or whereby the mean coefficient of variation (CV) for these 2 values is less than 5%.\(^7,11,24,35,39,79\) The concept of steady state was developed to improve the degree to which a short-term measurement study would accurately represent 24-hour REE. It does so by minimizing the chances that a short-term respiratory artifact will affect the REE measurement.\(^85,86\) Obtaining steady state during IC testing is recommended to reduce error and ensure validity,\(^4,13,39,87,88\) and it has been suggested that strict guidelines are needed.\(^35\)

Due to the variability of REE in the critically ill patient population, errors can result when a measurement over a short period is used to represent 24-hour REE.\(^35,79,87\) For example, 1 study found that REE can range from 10% below to 23% above a measurement obtained from a brief IC study,\(^87\) while another study found that during the initial phase of a hospital course, critically ill patients can have variability in REE ranging from 37%–56%.\(^90\)

Achieving steady state in the critically ill patient population can be challenging.\(^6,13,79\) Metabolic carts typically require a 30-minute testing period to achieve a steady state, where the initial 5 minutes of testing are discarded.\(^7,11\) If an interruption does occur, it is acceptable to use a shorter interval period. Several studies have found that 5-minute measurements with less than 5% CV are equivalent to 30-minute measurements with less than 10% CV in critically ill, ventilated patients.\(^40,79,80,83,85\) In the event of equipment and staff shortages, this protocol should be used whenever possible. Minimally sedated or agitated patients will be less likely to achieve the 5-minute protocol.\(^85\) Such practice in the critically ill, ventilated patient has been assigned a Grade 1, meaning studies of strong design have demonstrated the results are generalizable, without bias and flaws in research design.\(^58\)

If steady state cannot be achieved, 1 recommendation is to prolong the study period and/or take additional measurements at a separate time.\(^79,85\) This practice should be exercised within reason, so as to not delay care, occupy the metabolic cart unnecessarily, and/or accrue excessive costs. If using a metabolic cart, 2 or 3 nonconsecutive measures may improve accuracy.\(^58\) One of the advantages of using an IC module integrated into the ventilator is that readings can simply be compared over time.

It has been proposed that failure to obtain steady state should imply that the IC study results are likely not valid and the data should not be used.\(^4,35,39,79\) While failure to achieve steady state may not necessarily mean that the IC study is invalid, lessening the rigidity for defining steady state does lead to less accuracy in representing 24-hour REE.\(^79\) While IC testing without achievement of steady state can be considered to extrapolate 24-hour REE, there is no current evidence to support this practice.

In addition to REE, IC testing calculates a respiratory quotient (RQ), defined by the ratio between VO\(_2\) and VCO\(_2\). The RQ has traditionally been of interest as a marker of substrate use; however, the use of RQ for this purpose is not recommended. The RQ has low sensitivity and specificity, limiting its use as an indicator of over- or underfeeding.\(^11,86\) The physiological range of the RQ is 0.67–1.3; a value outside of this range may indicate an invalid IC study.\(^17,23\) In a systematic review, the use of RQ to suggest protocol violations or inaccurate gas measurement when measuring <0.7 or >1 was assigned a Grade II. This grading reflects “fair” design quality, indicating the evidence consists of results from studies of strong design, although inconsistencies exist among results.\(^58\) Therefore, the best use of the RQ is as a marker of test validity.\(^7,11,17,86\)

**Key Points**

- Control-mode ventilator settings such as assist control are ideal for an IC study and are the most likely to yield accurate results.
- Stable FIO\(_2\) is required to achieve steady state.
- Steady state is reached after the first 5 minutes of data are discarded and a 5-minute period is achieved with a CV <5%. An alternative method is to conduct a 25-minute study where a CV <10% is achieved.
- The RQ value of 0.67–1.3 can be used to confirm test validity.

**Interpreting IC Results**

Once measured, the REE should be the caloric goal for the patient, because it most closely reflects 24-hour REE. No stress or activity factor is needed.\(^11,79\) If a patient is receiving continuous feedings, then a thermogenesis factor is unnecessary. However, if the feeds were intermittent or the patient was fasting, then an 8%–10% increase in the REE should be added to account for thermogenesis.\(^6\)

**Alternative Methods for REE When IC Is Not Available: Predictive Equations**

When IC testing is not feasible, cautious use of predictive methods along with clinical judgment should always be employed. Clinicians often use adjusted body weight in equations for patients who are obese or underweight; however, this adjustment is not evidence based. Therefore, actual body
weight should always be used in equations when predicting REE.  

The Penn State University equation has been validated as the most accurate and precise predictor of REE in the critically ill patient, with an accuracy rate of 70%–75%. The Academy of Nutrition and Dietetics (the Academy) currently recommends this equation be used in critically ill patients when IC testing is not feasible. A modified Penn State University equation (2010) was developed and validated for use in the obese, older adult population and is currently recommended by the Academy. However, a recent study indicates that there is uncertainty as to whether there is a need for the modified Penn State University equation (2010). The original Penn State University equation (2003) may be just as accurate in obese, older adults. The most recent study examining the Penn State University equation (2003) found that while the equation has been validated for use in a wide range of body mass indexes, accuracy is lower in underweight patients, with a tendency to underestimate energy needs.  

The Ireton-Jones 1992 equation is a commonly used equation for predicting REE in critically ill patients. However, several validation studies have shown that this equation may not be sufficiently accurate.  

Estimating REE in acutely ill, spontaneously breathing patients is a challenging area for energy expenditure estimation. Information on this population is contradictory, and additional research is warranted. Equations commonly used are derived from healthy, nonobese, nonhospitalized individuals. 

An evidence analysis reviewing the research conducted by the Academy indicates that the Mifflin–St Jeor equation has the highest accuracy rate compared with the Harris-Benedict equation in healthy adults. The accuracy of the Mifflin–St Jeor equation decreases when used in obese patients. It is a useful reference equation, and consideration for use should be given to both obese and nonobese patients. Several validation studies have found that when using the Mifflin–St Jeor equation, REE can be accurately predicted in 80% of nonobese people and 70% of obese people.  

The Mifflin–St Jeor equation multiplication by 1.25 is a common modification in the clinical setting and accounts for illness hypermetabolism. This multiplication improves bias, precision, and accuracy, and may be useful in acutely ill, spontaneously breathing patients. In addition, the Mifflin–St Jeor equation is more accurate without a stress factor in obese patients.  

The Harris-Benedict equation is one of the oldest and most commonly used predictive equations. However, this equation is not currently recommended in critically ill patients and is less accurate than the Mifflin–St Jeor equation in healthy adults. The use of calories per kilogram of body weight (kcal/kg) is also a common practice for estimating REE. The American Society for Parenteral and Enteral Nutrition (A.S.P.E.N.) guidelines recommend the use of 20–35 kcal/kg/d for adults. In the critically ill, obese patient, 11–14 kcal/kg actual body weight per day or 22–25 kcal/kg ideal body weight (IBW) per day is recommended. Hypocaloric feeds are recommended in the critically ill, obese patient to avoid overfeeding. Once REE has been determined, caloric provision should be between 60% and 70% of this estimation. The recommendation for hypocaloric feedings is currently assigned a Grade D and is an area in need of additional research to more fully understand the impact on patient outcomes. The American College of Chest Physicians recommendation of 25 kcal/kg/d was designed for critically ill patients. This strategy is based solely on body weight and has a high tendency toward inaccuracy; therefore, it is not recommended in the critical care setting.  

**Key Points for Predictive Equations**  

- The Penn State University equation is the most accurate and precise predictor of REE in the critically ill patient and should be used on all ventilated patients when IC testing is not feasible.  
- The Mifflin–St Jeor equation is the most accurate predictor of REE in healthy adults.  
- There are currently no recommendations for predicting REE in acutely ill, spontaneously breathing patients. The Mifflin–St Jeor equation may be used as a reference equation; multiplication by a stress factor (1.2–1.3) may improve accuracy in this population.  
- Predictive equations can be used in conjunction with the A.S.P.E.N. guidelines of 20–35 kcal/kg/d in adults. In the obese patient, 11–14 kcal/kg actual body weight per day or 22–25 kcal/kg IBW is recommended.  

**Practical Issues**  

At the crux of any nutrition support regimen is the registered dietitian’s or nutrition support clinician’s challenge to obtain a patient’s true REE. Without question, IC testing is considered the gold standard. However, IC testing may not be practical for clinicians, because of associated time, costs, resources, personnel, and technical training. Even the ideal candidate may not be appropriate in view of air leaks or other technical factors that affect IC testing accuracy. Performing a measurement is only the first step in ensuring that patients are receiving the correct nutrition regimen. In the critical care setting, EN may be held for procedures or the administration of medications. Achieving goals even once an REE is established can remain a challenge. If this goal is inaccurate, it will be difficult to obtain improved outcomes, because physiological needs will not be met.  

**Application of the Metabolic Cart**  

**Case Study 1**  

A 76-year-old obese woman presented with an incarcerated ventral hernia with small bowel perforation and extensive
necrosis. The patient underwent emergent exploratory laparotomy, hernia repair, small bowel resection with primary anastomosis, debridement of necrotic tissue, and negative pressure wound therapy to the abdomen. The patient was sedated and intubated postoperatively, requiring pressor support and CRRT. The patient transitioned to hemodialysis within the first week of admission. EN was initiated on postoperative day 3. Several pressure ulcers existed on admission, including stage II to coccyx and stage III to right leg. No additional past medical history was available.

This patient was an appropriate candidate for IC testing due to the presence of sepsis, organ dysfunction, prolonged mechanical ventilation, obesity, and wounds. These factors made it challenging to determine REE, and an IC study was ordered once the patient transitioned from CRRT to intermittent hemodialysis.

When using a metabolic cart as opposed to reviewing data from a built-in airway module ventilator, it is challenging to collect data that reflect true REE. Specifically, this IC study was conducted at least 4 hours after hemodialysis, at a time when ventilatory settings remained unchanged for at least 90 minutes, and once EN was consistent for at least 12 hours.

This IC study contributed to the development of the most appropriate nutrition regimen. It could be argued that the nutrition support regimen was meeting 100% of REE needs at 1575 calories, which is a 525-calorie difference from what the IC testing demonstrated (Table 5). Since the patient was dependent on tube feeds for 16 days, the cumulative total deficit would have been 8400 calories had the feeding regimen met the lower end of predicted needs.

In this example, as in all situations that require interdisciplinary care, coordination between departments presented challenges. Nutrition support clinicians may deem a patient to be a good candidate for IC testing based on his or her ventilatory settings, pulmonary laboratory results, nutrition regimen, and current clinical state. However, delays in IC testing can result from any number of factors. Given the nature of critical illness, this window of opportunity for IC testing may be narrow; therefore, good communication between all health professionals involved is crucial to ensure IC testing is conducted at appropriate times.

**Case Study 2**

A 37-year-old man had end-stage liver disease secondary to Wilson disease. He had 2 orthotopic liver transplants with initial transplant failure, complications, and prolonged hospital stay. The patient was sedated and intubated postoperatively with an open abdomen that required multiple abdominal washouts, in addition to a bile leak repair. CRRT was initiated for aggressive fluid removal. Small bowel feeding was delayed until postoperative day 2. Additional past medical history included diabetes mellitus.

IC testing was required to obtain accurate REE because severe edema precluded accurate REE prediction. Fluid overload altered the patient’s BMI and made it impractical to use actual body weight. Furthermore, REE predictions are problematic in patients who undergo solid organ transplantation. CRRT, multiple trips to the operating room, and intermittent EN affected the timing of the IC study.

IC testing indicated that REE was lower than initially predicted, and caloric provision was reduced to match the measured results. The highest initial estimation would have overfed the patient with 500 calories per day (Table 5).

**Case Study 3**

A 31-year-old morbidly obese man was admitted with multiple gunshot wounds to the flank, pelvis, and arm. He underwent a rectosigmoidectomy with end colostomy as well as ligation of external and internal iliac arteries and veins. A left hip wound resulted in lower extremity compartment syndrome, resulting in 4 compartment fasciotomies and negative pressure wound therapy with skin grafts. Past medical history was unknown. After 3 days of EN while intubated, the patient transferred out of the ICU with signs of improvement. Soon thereafter, the patient developed severe complications secondary to a large bleeding gastric ulcer. Upon returning to the ICU, he was sedated and intubated requiring pressor support. Once the patient reached the goal rate of EN, IC testing was ordered.

The presence of multiple traumatic injuries, nonhealing wounds, multisystem organ failure, and morbid obesity made estimating REE problematic. Hypocaloric feeding was not deemed necessary despite a BMI of 47, due to the patient’s length of stay at the time that EN was reinitiated. Achieving steady state was difficult, and data collection continued for approximately 1 hour to obtain periods of equilibrium. Environmental conditions of the trauma ICU while sedation was being weaned warranted consideration, because these are factors that could also affect REE.

A.S.P.E.N. recommendations for hypocaloric feeding of morbidly obese patients would have substantially underfed this patient. Conversely, the Penn State University equation overestimated REE, although more reflective of the IC study results. The feeding regimen was adjusted to match the measured REE (Table 5).

**Recommendations**

To provide the most optimal nutrition support regimen that is truly patient specific, clinicians should employ IC testing whenever feasible. Nutrition support clinicians can play a key role in educating other disciplines about IC testing. Staying current on research to understand best practices is one way nutrition support clinicians working in the clinical setting can play a leading role in the use of IC testing in their institutions. Collaboration...
and communication with physicians, nurses, and RTs are a necessary component. Discussing IC study initiation with nurses can ensure that the patient meets criteria for accurate IC testing. RTs can provide education for nutrition support clinicians on the fundamentals of interpreting pulmonary laboratory results and ventilator settings.

While IC equipment may be available at an institution, it may be underused or misused due to a lack of education and training. Ideally, registered dietitians or other nutrition support clinicians would take more initiative in addressing the issue of staff shortages that may prevent the use of IC. For instance, the department that owns and operates the metabolic cart may be facility specific; therefore, nutrition support team members’ involvement in IC testing would vary. Understanding appropriate applications, contraindications, and interpretation of IC test results is essential. Evaluation and interpretation of REE in critically ill patients using IC testing should be the expertise of the registered dietitian or nutrition support clinician.

The Academy has an evidence-based protocol for how to perform IC testing, with separate guidelines for healthy adults and critically ill patients. Developing and adhering to protocols based on the most current research is necessary to perform successful IC studies. Continuous research and data collection through IC testing could be beneficial to improve protocols and practices. This information could be useful in improving hospital protocols and justifying funding.

To date, limited data support that IC testing actually improves patient outcomes. This issue has contributed to the lack of funding available for IC equipment. A metabolic cart or ventilator with integrated IC capability simply may not be available due to funding issues. Collaborating with other disciplines may be helpful in developing a well-established clinical practice to pool funding. Presenting data regarding the importance of accurate nutrition provision and the key role that IC plays in the process could be a persuasive approach in justifying the need for IC testing equipment.

The protocols for performing studies are poorly standardized. This is an area that warrants further research. In personal correspondence (2013) with David C. Frankenfield, MS, RD, CNSC, “The calorimetry project of the EAL [Evidence Analysis Library] is being updated right now and also upgraded to a guideline.” Furthermore, accurately identifying caloric goals is only part of the picture; IC can only improve patient outcomes if there is adequate delivery of nutrition provision. This area remains in need of additional study.

### Key Points for Involvement of Nutrition Support Clinicians in IC Testing

- Collaborating with other disciplines such as respiratory therapy is helpful in developing a well-established clinical practice.
- Evaluation and interpretation of REE in critically ill patients using IC testing should be the expertise of the nutrition support clinician.
- Clinicians should engage in continuous research and data collection on IC testing to improve protocols and practices. Developing and adhering to protocols based

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### Table 5. Nutrition Characteristics and Comparison of Estimated and Measured Energy Needs in 3 Critically Ill Patients.

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Anthropometrics</th>
<th>Estimated energy needs</th>
<th>Estimated protein needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Height: 68 in.</td>
<td>15–20 kcal/kg: 1575–100 kcal</td>
<td>118–160 g protein</td>
</tr>
<tr>
<td></td>
<td>Actual body weight: 105 kg</td>
<td>Penn State equation: 1890 kcal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ideal body weight: 64 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Body mass index: 35 kg/m²</td>
<td>Measured energy needs using metabolic cart: 2102 kcal (RQ 0.84)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case Study 2</th>
<th>Anthropometrics</th>
<th>Estimated energy needs</th>
<th>Estimated protein needs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Height: 76 in.</td>
<td>22–27 kcal/kg: 2178–2673 kcal</td>
<td>129–149 g protein</td>
</tr>
<tr>
<td></td>
<td>Actual body weight: 99 kg</td>
<td>Penn State equation: 2440 kcal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ideal body weight: 76 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Body mass index: 26.4 kg/m²</td>
<td>Measured energy needs using metabolic cart: 2217 kcal (RQ 0.77)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case Study 3</th>
<th>Anthropometrics</th>
<th>Estimated energy needs</th>
<th>Estimated protein needs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Height: 64 in.</td>
<td>11–14 kcal/kg: 1400–1900 kcal</td>
<td>118–148 g protein</td>
</tr>
<tr>
<td></td>
<td>Actual body weight: 125 kg</td>
<td>Penn State equation: 2433 kcal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ideal body weight: 59 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Body mass index: 47 kg/m²</td>
<td>Measured energy needs using metabolic cart: 2388 kcal (RQ 0.87)</td>
<td></td>
</tr>
</tbody>
</table>

A.S.P.E.N., American Society for Parenteral and Enteral Nutrition; IBW, ideal body weight; RQ, respiratory quotient.
on the most current research is necessary to perform successful IC testing.

- Grants and funding may be available for IC equipment. It may be helpful to collaborate with other disciplines in this effort.
- Nutrition support clinicians can play a key role in educating other disciplines about IC testing.

IC testing remains the gold standard for measuring REE in the critically ill adult; however, the reality is that it is greatly underused in many facilities. Given the importance of predicting REE in the critically ill patient, it is paramount that more clinicians incorporate IC testing into practice. As forerunners of nutrition, a primary role of dietitians and other nutrition support clinicians in the clinical setting is to implement best practice for determining REE. While initial monetary investments may be necessary to acquire IC testing equipment, the benefits will be reflected in improved patient outcomes and, therefore, reduced hospital costs. Just as registered dietitians and other nutrition support clinicians now have order-writing privileges and are placing small bowel feeding tubes, the measurement of REE through IC testing is an area where scope of practice has room to expand.

References


