Universal Journal of Clinical Medicine 1(3): 39-43, 2013 http://www.hrpub.org
DOI: 10.13189/ujcm.2013.010302

# Energy Estimation in the Critically Ill:A Literature Review

**Kristopher R. Maday**

School of Health Professions, Physician Assistant Program, University of Alabama at Birmingham, Birmingham, Alabama, 35294, United States
*Corresponding Author: maday@uab.edu



**Abstract** Critically ill patients have higher energy expenditure and increased nutritional needs compared to non-critically patients. This can lead to medical malnutrition if nutritional interventions are not implemented quickly and accurately in the disease course. Obtaining an accurate estimation of nutritional needs is paramount in establishing nutritional support. The literature review was designed to look at the numerous predictive equations and determine the accuracy among different critically ill patient populations. Data Sources: Using keywords *energy estimation*, *nutritional predictive equations*, and *critical illness*, systematic reviews, meta-analyses, and validation studies were identified through electronic database searches and citation tracking. Study Selection: Articles were selected that evaluated individual predictive equations in critically ill patients, their accuracy compared to indirect calorimetry, and their use in special patient populations. Data Extraction and Synthesis: A total of 12 articles were selected using the inclusion and exclusion criteria. Accuracy of the predictive equations was separated into overall accuracy among all patients, all ages, non-obese, young obese and non-obese, and elderly obese and non-obese. Conclusions: There are several validated predictive equations for estimating energy expenditure in critical illness. The most accurate equations are the 2003 Penn State equation, for obese and non-obese adult patients, and the 2010 Penn State equation, for elderly obese patients. Given the trend of obesity in the United States, further validated studies are needed to look at the individual classes of obesity and the accuracy with this specific patient population.

**Keywords** Nutrition; Nutritional Support; Critical Care; Malnutrition; Energy Estimation; Predictive Equations

## 1. Introduction

Patients who require intensive care unit (ICU) admission due to critical illness are at an increased risk for malnutrition.[1]The disease state itself increases energy demands and places the body in a hypermetabolic state.If this new energy requirement is not met or if adequate nutritional reserves are absent, lean body mass is lost very quickly in order to support the patient through the illness.This loss of lean body mass in critically ill patients has been shown to reduce the overall chance of survival during the course of the illness.[2]Failing to provide adequate nutrition during critical illness also increases complications while in the hospital and includes increased risk for all infections, increased hospital length of stay, and increased risk for organ failure.[1]Overfeeding a critical care patient can be just as detrimental and complications can include hyperglycemia, azotemia, and hypercapnia.[3] It is imperative to not only identify critically ill patients in the hospital that are at risk for malnutrition, but to also provide optimal nutrition to limit or prevent potential complications.

Estimating energy requirements in humans has been an interesting field of study for decades within nutrition research. There are several modalities available now to measure energy expenditure, but, unfortunately, not all are applicable to medical patients and even fewer still can be used in patients with critical illnesses. The most readily available means to estimate energy expenditure in the hospital setting has been with predictive equations. These formulas use measureable data, which range for simple anthropometric measurements to minute ventilation, to calculate an estimate of energy expenditure for an individual. Several of the current predictive equations available for critical care patients are the Ireton-Jones, Penn State, Swinamer, Brandi, and Faisy equations.

## 2. Materials and Methods

An online search was conducted using Pubmed (1960-July 2012), Cochrane (1960-July 2012), and Medline (1960-July 2012).Search terms used were energy estimation, nutritional predictive equations, and critical illness. For the purpose of this review, critical illness was defined as requiring admission to an intensive care unit for management. Inclusion criteria included original publication of predictive equations and validation studies. Exclusion criteria included non-critically ill patients and not using indirect calorimetry as the control.

### 2.1. Ireton-Jones Equations

The Ireton-Jones equation is one of the most well known predictive equations for energy estimation in ventilated patients. It was first developed in 1992 and was created by multivariate regression analysis with respect to age, gender, weight, and whether the patient suffered from any traumatic or burn injuries.[4]The study had 200 patients, 33% were ventilator-dependant, and predominately male with a mean age of 43 years.[4] It was found to have no significant difference on paired *t* test ($P$>0.25), though 2of the better known validation studies have found overall accuracy of the equation to be 28%[5] and 60%[6].

Due to this discrepancy, Ireton-Jones re-analyzed the data in 1997 to try to minimize the mean prediction error.99 ventilator-dependant patients were studied and found that the 1992 equation tended to overestimate energy requirements.[7]This equation was then adjusted and the rate of overestimation in ventilated patients improved from 65% to 52%.[7]However, in a validation study by Frankenfield, it still only showed an overall accuracy of 36%.[6]

After analyzing numerous validations studies from both the 1992 and 1997 equations, underestimation is more prevalent when using the 1997 equation, where the 1992 is statistically unbiased due to both over- and underestimation across all patient populations.[8]If the Ireton-Jones equations are to be used for energy calculations, the 1992 equation is preferred as it is unbiased and is more accurate across all critically ill patients. Both of these equations use data that is simple to measure or obtain in a critical care setting and do not requirement specific ventilator measurements that can be confounded due to illness, instrumentation, or sedative medications.

### 2.2. Penn State Equations

The original Penn State equation was first developed in 1998 using 169 mixed (medical and surgical) ICU patients and utilized the Harris Benedict equation for resting energy expenditure with minute ventilation and maximum temperature over 24 hours as adjusting variables.[9]By using the approach, body size and inflammatory state can be taken into consideration and can be adjusted over time as the patient resolves their illness. The original formula used actual body weight for non-obese patients and adjusted body weight for patients with > 125% of ideal body weight.[9]Validation studies found overall accuracy of the 1998 Penn State equation at 68%[6] and 29%[5].

In 2003, the authors compared several different anthropometric equations with their original formula and found that accuracy improved with using the Mifflin-St.Jeor equation and actual body weight instead of adjusted body weight.[10]In the same validation studies performed by Frankenfield and MacDonald in the 1998 Penn State equation, the authors found improved accuracy to 72%[6] and 39%[5].

Frankenfield again modified the 2003 equation to attempt to improve the predictive ability in elderly, obese patients. The author used data from 50 new patients and 75 patients from previous studies that were not used to develop either of the 1998 or 2003 Penn State equations and found improved accuracy for new patients (68%) and the previous patients (66%).[11]This modification in 2010 improved the overall accuracy in patients > 60 years of age and > 30 kg/m$^2$ body mass index (BMI) to 74%.[11]

The Penn State equations were the first equations studied that used variables that fluctuate over the course of a patient's hospitalization and take into account the inflammatory state of the patient to adjust energy estimates. This allows practitioners to trend the energy requirements of a patient over time and adjust nutritional support to prevent both under- and overfeeding complications.

### 2.3. Swinamer Equation

The Swinamer equation was developed in 1990 in Canada using 112 surgical, medical, and trauma patients on mechanical ventilation in various intensive care settings.[12]The premise behind this equation is using measured variables that have the greatest effect on energy expenditure. Where previous formulas used simple anthropometric measurements to calculate estimated energy expenditure, this formula uses body surface area, maximum temperature over 24 hours, respiratory rate, and tidal volume.[12]These factors use body surface area as a surrogate for obesity and weight, whereas temperature, tidal volume, and respiratory rate are used to assess the current inflammatory state of the patient. By using these variables, a patient's energy estimate can be changed as often as needed in order to provide optimal nutritional support. The author found that using this new equation, only 15 of the 112 patients had a > 15% deviation of predicted energy expenditure as compared to measured energy expenditure.[12]

Only two validations studies have been performed to date comparing the Swinamer equation to indirect calorimetry.In these studies, the authors found accuracy rates 45% in 141 patients[5] and 55% in 76 patients[13].The paucity of data surrounding this equation can be due to difficulty in obtaining all of the measurable data variables, specifically having an accurate body surface area measurement. This is the most important limiting factor in using this equation routinely for energy estimation in a critically ill patient.

### 2.4. Brandi Equation

The Brandi equation was created in Italy in 1999 using 26 adult trauma patients requiring mechanical ventilation and intensive care unit admission.[14]This equation uses the Harris Benedict formula and inflammatory variables of heart rate and minute ventilation to adjust energy estimates.[14] This is the first study that demonstrated a significant lack of correlation between injury severity and energy expenditure and challenges commonly used stress factors with predictive equations.[14]To date, there is only one validation study on the Brandi equation and it showed the formula to be precise and unbiased in the non-obese population but less accurate in the obese groups.[15]This review also found an accuracy of 67%, when compared to the trauma group, and accuracy of 51% when compared to the non-trauma group.[15]Further studies need to be performed with a larger patient population, as well as additional validation studies, before this equation can be critically evaluated and recommended. Although this equation can be useful for traumatic injuries, it is not as accurate when used for non-traumatic injuries and should be used with caution for general critically ill patients.

### 2.5. Faisy Equation

The Faisy equation was developed in 2003 and used data from 70 adult patients that required mechanical ventilation for more than 24 hours.[16]This study was performed in France and the patients included in the study were slightly older with a mean age of 61 and had primarily medical problems, excluding surgery or trauma.[16]This formula looked at the effects of height, weight, temperature, and minute ventilation on energy expenditure when compared to measured indirect calorimetry.[16]There is only one published validation study that compares the Faisy equation across age groups and obesity spectrum. This study found that the Faisy equation was inaccurate in the older population and tended to overestimate energy needs, but was accurate and unbiased in younger patients.[15]Frankenfield found an overall accuracy of 53% among all patients, but only 37% with elderly non-obese patients and 39% with elderly obese patients.[15]This is the first equation that has been studied that specifically excluded surgery and trauma patients and focused primarily on medical patients. This can be significant as different illness and injuries can have different stress responses and therefore, have different caloric needs. Previous formulas used mixed ICU patient populations that included medical, surgical, and trauma patients to generalize the predictive equations to all critical illnesses.

### 2.6. Indirect Calorimetry

Indirect calorimetry is the gold standard of energy measurement and is used as the control in every study that has developed a predictive equation for energy expenditure in the critically ill patient.[15]By using specialized equipment, a trained respiratory therapist can measure oxygen consumption ($V_{O2}$) and carbon dioxide excretion ($V_{CO2}$) to calculate two very important nutritional variables: respiratory quotient (RQ) and energy expenditure.[17]

RQ can be used to indirectly extrapolate substrate utilization of a patient. A respiratory quotient of < 0.7 suggests primary fat breakdown, 0.8-1.0 suggests protein or mixed substrate breakdown, and > 1.0 suggests primary carbohydrate utilization.[18]There are several causes of a RQ > 1.0, but can indicate overfeeding and need for adjustment of nutritional intake when looked at from a nutritional support viewpoint.Caloric requirements can then be calculated by taking the measured oxygen consumption and carbon dioxide excretion and, using the Weir equation, determine resting energy expenditure over the course of the measurement.[19]

The procedure itself can be performed continuously, though most institutions perform intermittent measurements due to machine and staff availability.The study should continued for 20-30 minutes or until steady-state is attained, as this is considered an accurate estimation of 24 hour energy expenditure.[8,20]In order to limit error before or during the procedure, no ventilator changes should be 90 minutes before the exam, no general anesthesia should be given 6-8 hours before the study, sedation or analgesia should be given no sooner than 30 minutes before the start of the measurement, and routine activities of other healthcare personnel should be avoided during the study.[18]

There are several factors that can render the data obtained during the study as invalid and should be assessed prior to ordering the study to limit inappropriate use of the machine and resources.The most common reasons in critical illness are due to ventilator settings and include > 60% fractional inspired oxygen ($FiO_2$), > 12 $cmH_2O$ positive end expiratory pressure (PEEP), or a system leak.[18]Other patient specific variables include thoracostomy tubes, bronchopleural fistula, hemodialysis, or inadequate sedation/patient agitation.[18]

## 3. Results

A summary of the results is included in Table 1.Of the eight variations of predictive equations for energy estimation in the critically ill, the 2003 Penn State equation had the highest overall accuracy (67%[15]) and the highest accuracy in young obese (69%[15]) patients and in elderly non-obese (77%[15]) patients.The Faisy equation had the highest accuracy in young obese (72%[15])patients.The 2010 Penn State equation had the highest accuracy for elderly obese (74%[11]) patients.

## 4. Conclusion

Providing nutritional support is an important part of the medical management in the intensive care unit and should be assessed daily on all patients with critical illness to limit mortality and malnutrition.[1]It is not enough to simply provide calories to these patients, but to supply adequate and optimal nutrition to meet the physiologic demands as a consequence of the critical illness. Often this is a difficult and daunting task as both underfeeding and overfeeding critically ill patients can result in complications.This review shows that indirect calorimetry is still the gold standard of measuring energy expenditure in mechanically ventilated patients, but it not only has procedural limitations, but also institutional limitations.Several predictive equations are available to estimate a patient's energy requirement using anthropometric measurements, ventilator measurements, and vital signs to determine the patient's body size and inflammatory state.These equations are often easier to use and can be used if indirect calorimetry is not available, or if the patient's medical status precludes its use.Of all the equations reviewed, the most accurate by validations studies were the 2003 Penn State equation for adult, non-obese patients and the 2010 Penn State equation for obese, elderly patients and both are recommended in the 2012 Executive Summary of Recommendations for Critical Illness by the Academy of Nutrition and Dietetics.[21]

**Table 1.** Predictive equation and accuracy profiles

| | % Accuracy* | | | | | |
|---|---|---|---|---|---|---|
| | Overall | All ages, Non-Obese | Young | | Elderly | |
| | | | Non-Obese | Obese | Non-Obese | Obese |
| **Ireton-Jones (1992)[4]**<br>1925 – 10(age) + 5(wt) + 281(male) + 292(trauma) + 851(burns) | 28[5],60[6],46[15] | 23[5] | 33[15] | 49[15] | 50[15] | 51[15] |
| **Ireton-Jones (1997)[7]**<br>1784 + 5(wt) – 11(age) + 244(male) + 239(trauma) + 804(burns) | 36[6] | - | 48[6] | | 15[6] | |
| **Penn State (1998)[9]**<br>1.1(HBE) + 140($T_{max}$) + 32($V_e$) – 5340 | 68[6], 62[15] | 63[5] | 58[15] | 70[15] | 62[15] | 59[15] |
| **Penn State (2003)[10]**<br>0.96(MSJ) + 167($T_{max}$) + 31($V_e$) - 6212 | 57[6], 67[15] | - | 69[15] | 70[15] | 77[15] | 53[15] |
| **Penn State (2010)[11]**<br>0.71(MSJ) + 85($T_{max}$) + 64($V_e$) - 3085 | - | - | - | - | - | 74[11] |
| **Swinamer (1990)[12]**<br>945(BSA) – 64(age) + 108($T_{max}$) + 24.2(RR) + 817($V_t$) – 4349 | 55[13], 54[15] | 62[5] | 61[15] | 51[15] | 60[15] | 43[15] |
| **Brandi (1999)[14]**<br>0.96(HBE) + 7(HR) + 48($V_e$) -702 | 55[15] | - | 61[15] | 55[15] | 61[15] | 41[15] |
| **Faisy (2003)[16]**<br>8(wt) + 14(ht) + 42($V_e$) + 94(T) - 4834 | 53[15] | - | 65[15] | 72[15] | 37[15] | 39[15] |
| **Harris Benedict**<br>Men: 13.75(ht) + 5(ht) – 6.8(age) + 66<br>Women: 1.8(ht) + 9.6(wt) – 4.7(age) + 655<br>*Use actual body weight unless patient is > 125% of ideal, then use:*<br>*0.25(actual weight – ideal weight) + ideal weight*<br>*Ideal Weight Calculation[22]*<br>*Men: 106lb + 6lb for every inch over 60*<br>*Women: 100lb + 5lb for every inch over 60* | 18[15] | 52[5] | 31[15] | 0[15] | 27[15] | 12[15] |
| **Mifflin-St.Jeor (1990)[23]**<br>Men: 10(wt) + 6.25(ht) – 5(age) + 5<br>Women: 10(wt) + 6.25(ht) – 5(age) - 161 | 25[15] | - | 23[15] | 21[15] | 21[15] | 35[15] |

*within 10% of measured energy expenditure

Non-Obese, BMI < 30; Obese, BMI > 30; Young, < 60 years; Elderly, > 60 years; wt, weight (kg); HBE, Harris Benedict Equation; $T_{max}$, maximum temperature in previous 24 hours (°C); $V_e$, expired minute ventilation at the time of collection (L/min); MSJ, Mifflin-St.Jeor Equation; BSA, body surface area ($m^2$); RR, respiratory rate (breath/min); $V_t$, tidal volume (L/breath); T, temperature at time of study (°C); ht, height (cm)

# REFERENCES


[1] Giner M, Laviano A, Meguid MM, Gleason JR. In 1995 a correlation between malnutrition and poor outcome in critically patients still exists. Nutrition. 1996;12:23-29.

[2] Ali NA, O'Brien JM Jr, Hoffman SP, et al. Acquired weakness, handgrip strength, and mortality in critically ill patients.Am J RespirCrit Care Med. 2008;178:261-268.

[3] Klein CJ, Stanek GS, Wiles III CE. Overfeeding macronutrients to critically ill adults: metabolic complications. J Am Diet Assoc. 1998;98;795-806.

[4] Ireton-Jones CS, Turner WW, Liepa GU, Baxter CR. Equations for estimation of energy expenditure of patients with burns with special reference to ventilator status.J Burn Care Rehabil. 1992;13:330-333.

[5] Macdonald A, Hildebrandt L. Comparison of formulaic equations to determine energy expenditure in the critically ill patient.Nutrition. 2003;19(3):233-239.

[6] Frankenfield D, Smith S, Cooney RN. Validation of 2 approaches to predicting resting metabolic in critically ill patients.JPEN. 2004;28(4):259.264.

[7] Ireton-Jones CS, Jones JD. Why use predictive equations for energy expenditure assessment? J Am Diet Assoc. 1997;97(9) Supplement:A44.

[8] Walker RN, Heuberger RA. Predictive Equations for Energy Needs for the Critically Ill.Respir Care. 2009;54(4):509-521.

[9] Frankenfeld DC. Energy dynamics. In: Matarese LE, Gottschlich MM, eds. Contemporary Nutrition Support Practice: A Clinical Guide. Philadelphia, PA: WB Saunders; 1998:79-98.

[10] Frankenfeild DC, Rowe WA, Smith JS, Cooney RN. Validation of several established equations for resting metabolic rate in obese and non-obese people. J Am Diet Assoc. 2003;103(9):1152-1159.

[11] Frankenfeld DC. Validation of an equation for resting metabolic rate in older obese, critically ill patients. JPEN. 2011;35(2):264-269.

[12] Swinamer DL, Grace MG, Hamilton SM, Jones RL, Roberts P, King G. Predictive equation for assessing energy expenditure in mechanically ventilated critically ill patients.Crit Care Med. 1990;18(6):657-661.

[13] Boulatta J, Williams J, Cotrell F, Hudson L, Compher C. Accurate determination of energy needs in hospitalized patients. J Am Diet Assoc. 2007;107(3):393-401.

[14] Brandi LS, Santini L, Bertolini R, Malacarne P, Casagli S, Baraglia AM. Energy expenditure and severity of injury and illness indices in multiple trauma patients.Crit Care Med. 1999;27:2784-2689.

[15] Frankenfield DC, Coleman A, Alam S, Cooney RN. Analysis of estimation methods for resting metabolic rate in critically ill adults.JPEN. 2009;33(1):27-36.

[16] Faisy C, Guerot E, Diehl JL, Labrousse J, Fagom JY. Assessment of resting energy expenditure in mechanically ventilated patients.Am J ClinNutr. 2003;78:241-249.

[17] McClave S, Snider HL. Use of indirect calorimetry in clinical nutrition.NutrClinPract. 1992;7:207-221.

[18] Wooley JA, Sax HC. Indirect calorimetry: Application to Practice. NutrClinPract. 2003;18:434-439.

[19] Weir JB de V. New methods for calculating metabolic rate with special reference to protein metabolism.J Physiol. 1949;109:1-9.

[20] Fung EB. Estimating energy expenditure in critically ill adults and children.AACNClin Issues. 2000;11(4):480-497.

[21] Executive Summary of Recommendations, Critical Illness Guidelines 2012. Website. Available at: http://www.adaevidencelibrary.com/topic.cfm?cat=4840. Accessed on 07/19/2012.

[22] Hamwi GL. Therapy: changing dietary concepts. In: Danowski TS, ed. Diabetes Mellitus: Diagnosis and Treatment. New York, NY: American Diabetes Association; 1964.

[23] Mifflin MD, St Jeor ST, Hill LA, Scott BJ, Daugherty SA, Koh YO. A new predictive equation for resting energy expenditure in healthy individuals.Am J ClinNutr. 1990;51:241-247.