

Carol Rees Parrish, M.S., R.D., Series Editor

The Calorie Requirement Conundrum



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Severe overfeeding of critically ill patients results in increased complications without clinical benefits. However, the optimal timing and amount of nutrition to feed critically ill adults has not been established. There are multiple prediction equations for estimating calorie expenditure of critically ill patients, but most studies comparing the accuracy of different prediction equations are inadequate. There is a wide day to day variability of the energy expenditure of critically ill patients, which means that a single indirect calorimetry study does not reflect average calorie expenditure more accurately than prediction equations in the first weeks of critical illness. Although guidelines often promote more complex means of estimating calorie expenditure, critically ill patients receive variable and often incomplete amounts of nutrition that mitigates any possible difference in the accuracy between the smorgasbord of calorie prediction equations.

INTRODUCTION

Nutrition recommendations for adult critically ill patients in the 1970's and 1980's encouraged increased calories to a range of 3000-5000 kcals/day to reduce muscle breakdown or improve nutrition status.¹ It was not uncommon for patients to receive 1.5 to more than 2X their actual calorie expenditure into the mid 1980's.^{2,3} However, case reports of hyperglycemia, hepatic enzyme elevations, respiratory failure and protracted ventilator weaning associated with purposeful overfeeding (hyperalimentation) were reported by the early 1980's.^{3,4} Research also demonstrated that

providing nutrition in excess of calorie expenditure in the early phase of illness or injury did not prevent catabolism and muscle breakdown.^{5,6} In view of the evidence that severe overfeeding of calories in the early stage of critical illness caused negative consequences, without apparent benefits, clinicians searched for a means to guide the provision of nutrition support.

Measurement Versus Estimation of Calorie Expenditure

Indirect calorimetry (IC) estimates 24-hour calorie expenditure via measurement of oxygen consumption and carbon dioxide exhalation. Studies with indirect calorimetry have revealed that the calorie expenditure of most critically ill adults were more modest than had

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Table 1: Commonly Used Calorie Prediction Equations⁹⁻¹⁴

Formula	Equation
ACCP ¹³	25 kcal/kg body weight
Harris Benedict ¹⁰	Men: 13.75(kg wt) + 5(cm ht) – 6.8(age) + 66 Women: 9.6(kg wt) + 1.8(ht) – 4.7(age) + 655
Swinamer Equation ¹⁴	945(BSA) – 64(age) + 108(Tmax) + 24.2(RR) + 817(Vt) – 4349
Mifflin St. Jeor ¹¹	Men: 10(kg wt) + 6.25(ht) – 5(age) + 5 Women: 10(kg wt) + 6.25(ht) – 5(age) – 161
Ireton-Jones ⁹	Version 1992: 1925 – 10(age) + 5(wt) + 281(male) + 292(trauma) + 851(burns) Version 1997: 1784 + 5(wt) – 11(age) + 244(male) + 239(trauma) + 804(burns)
Penn State ^{9,12}	Version 1998: HBE(0.85) + Tmax(175) + Ve(33) – 6344 Version 2003: MSJ(0.96) + Tmax(167) + Ve(31) – 6212
Brandi ¹⁵	0.96(HBE) + 7(HR) + 48(Ve) -702
Faisy ¹⁶	8(wt) + 14(ht) + 42(Ve) + 94(T) - 4834

wt, weight (kg); ht, height (cm) Tmax, maximum temperature in previous 24 hours (degrees C); Ve, expired minute ventilation (L/min); MSJ, BSA, body surface area (m²); RR, respiratory rate (breath/min); Vt, tidal volume (L/breath); T, temperature at time of study (degrees C), HBE, Harris Benedict equation, MSJ, Mifflin-St.Jeor equation.

previously been thought; and early prediction equations with activity and stress factors for estimation of calorie expenditure often led to overfeeding.^{7,8}

IC is frequently not available at many facilities due to the cost of the equipment and its maintenance, as well as the training and time of experienced personnel. In the absence of IC clinicians routinely use one or several of the multitude of prediction equations to estimate a patient's calorie expenditure.⁹⁻¹⁶ These equations are based on physical attributes such as height, weight and age, and/or physiologic variables such as body temperature, respiratory rate, tidal volume, minute ventilation, and/or severity of injury (See table 1). Over the years, a number of "improved" equations have been published and studies have compared the accuracy of

these prediction equations with estimation of 24-hour calorie expenditure via indirect calorimetry.⁹ Although there is a plethora of work regarding energy expenditure and the accuracy of prediction equations, there is very limited research about the amount of nutrition that will optimize the outcome of critically ill people.

Calorie Requirements Versus Calorie Expenditure

In order to understand the best way to estimate calorie needs, it is important to differentiate between the calorie expenditure of critically ill patients and the calorie provision that allows the best possible patient outcome. To date, there are no large randomized trials demonstrating that meeting a critically ill adult

patient's full calorie expenditure results in improved outcomes. Obviously, providing minimal nutrition for an extended period of time will eventually result in serious malnutrition. However, it is possible that providing nutrition to critically ill adults that meets full calorie expenditure may actually have negative consequences, especially in the early, most acute phase of critical illness. Patients may benefit from a period of reduced, or even no nutrition during the early stage of illness, with increased nutrition at a later point. The ideal amount of nutrition support may be different depending on the degree of malnutrition, age, severity of illness or injury, presence and severity of surgical wounds, trauma or burns, requirement for repeated surgical procedures and duration of recovery. The early phase of critical illness is characterized by unavoidable catabolism that is not reversed by meeting full calorie expenditure.^{5,6} Additionally, increased insulin resistance and decreased gastrointestinal motility in the early stage of critical illness or injury have the potential to increase complications related to providing nutrition support.¹⁷ Researchers have postulated that providing full nutrition needs in the early phase of critical illness may impair the normal activation of mechanisms that are needed to remove cellular damage.¹⁸ There is evidence that in some critically ill adult populations, hypocaloric, full protein feeding may actually improve patient outcomes.^{19,20}

A number of *observational* studies have described associations between the amount of nutrition provided to critically ill patients and their outcomes.²¹⁻²³ However, observational studies cannot attribute cause and effect related to the amount of nutrition received because those patients with worse outcomes are more likely to receive less nutrition. It is not possible to statistically control for all variables that affect outcome in observational studies, and it is inappropriate to make practice recommendations based on associations reported in observational studies.

Two randomized studies have purported to describe improvements in selected outcomes in patients who had calorie expenditure measured by IC followed by increased nutrition delivery.^{24,25} However, the amount of calories provided was not the only difference between the experimental groups in these studies. Both studies provided increased calories *and* significantly more protein to the experimental group, primarily by providing increased parenteral nutrition. In both studies there was only a trivial difference between the calculated nutrition

needs and IC measurements, so neither study provides any meaningful data about indirect calorimetry. In one unblinded single center pilot study, patients received a bundle of increased calories and protein as well as individualized attention from the study dietitian to help ensure adequate nutrition delivery.²⁴ Patients who received increased nutrition had significantly more infectious complications, delayed ventilator weaning and increased time in the ICU. There was no significant difference in hospital mortality on intention to treat, but in the smaller per protocol analysis (n=112), mortality was significantly decreased in the experimental group.²⁴ The authors concluded that a much larger multi-center trial would need to be conducted to understand the effect of increased nutrition on mortality.²⁴ The other study did not result in any significant differences in infectious complications over the entire study period, but did report decreased adjusted probability of infections in the group receiving increased calories and protein over a post-hoc selected time period between days 9-28 (after the parenteral nutrition was discontinued).²⁵ In contrast to these 2 studies of reduced calories with very limited protein, a modest sized study (n = 240) of reduced calories with supplemental protein (compared to full calories and protein) in medical-surgical ICU patients reported significantly less mortality in the group receiving reduced calories.²⁶

A much larger multi-center, randomized study of 1000 patients with acute lung injury (ALI) or ARDS found that attempting to provide full feedings did not result in any outcome improvements compared to "trophic feeding" (approximately 25% of calculated needs).¹⁷ The group with planned full feedings received an average of 80% of calculated needs, but had significantly more minor gastrointestinal complaints such as elevated gastric residuals, regurgitation and episodes of emesis, as well as requiring increased prokinetic and anti-diarrheal medications.¹⁷ In this higher quality study, an average difference of 900 kcals/day (56% of estimated needs) in well-nourished patients with ALI/ARDS did not result in any significant difference in patient outcomes.¹⁷

Calorie Prediction Equations

There are a large number of calorie prediction equations, and multiple studies have compared various prediction equations in assorted patient populations with indirect calorimetry.⁹⁻¹⁶ Although many prediction equations

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have reasonable accuracy for groups of patients, the potential error for most prediction equations in individual patients is +/- 500 calories.²⁷ As stated above, the clinical implications of this magnitude of error are unclear.

Early prediction equations such as the Harris-Benedict equation used fixed variables such as weight, height and age. Some recent prediction equations have incorporated clinical variables such as body temperature, respiratory rate, tidal volume, minute ventilation, and/or severity of injury (See table 1 for a summary of several commonly used fixed and complex predictive equations). The American College of Chest Physicians recommended a simple weight-based method of estimating initial calorie goals.²⁸ More complex calorie estimation formulas generally require more time for collection of clinical variables and calculations that can change throughout the day.

Several studies have suggested superior accuracy for more complex prediction equations and some guidelines have favored one or another method for estimating calorie goals.^{9,27,28,29} Unfortunately, weaknesses of the study methods in most of the research with prediction equations severely limit any conclusions relevant to clinical practice. The vast majority of studies with prediction equations used only a single IC study per patient, measured at various points during the hospitalization for each patient. The largest validation study of predictive equations included 202 mechanically ventilated, critically ill patients and compared 17 different equations.²⁹ Accuracy of the prediction equations was arbitrarily defined as prediction within 10% of the IC measurement. However, there was only 1 IC measurement per patient that was completed between *day 2 and day 64* of the admission, *between day 2 and 27 of their ICU stay*, and with a *sepsis-related organ failure score between 1 and 18*.²⁹

Studies of day to day variation in energy expenditure have established that in the early portion of a patient's admission the day to day variation in energy expenditure varies by as much as 46%, with a more recent study demonstrating that mean daily energy expenditure varied by an average of 31.7 (+/-22.6)%.^{30,31} Even in stable patients the daily variation measured by IC varies by an average of 12%.³⁰ Translated, this means that a single IC measure does not accurately represent the average calorie expenditure of a critically ill patient. A single IC does not meet the criteria of

accuracy (+/- 10%) used in most studies of prediction equations. A study of daily calorie expenditure in critically ill adults found that a single IC measurement extrapolated for 1 week has more cumulative error than several prediction equations.³² Although IC is frequently referred to as the "gold standard," it is clear that in critically ill adults, a *single* IC study is not a more accurate predictor of average calorie expenditure than most prediction equations. Due to the potential "error" of a single IC measurement, compared to the average calorie expenditure, it is not appropriate to recommend one method of estimating calorie expenditure over any other based on studies that used a single IC study.

In one study using daily indirect calorimetry, one prediction equation that used maximum body temperature and expired minute ventilation as part of the calculation estimated daily calorie expenditure with acceptable accuracy (compared to the daily indirect calorimetry).³² However, temperature and minute ventilation used for the calculation in the study were collected at the same time as IC was completed, so it is not surprising that the calculation was similar to the indirect calorimetry. Temperature and minute ventilation vary over the course of the day and there are no studies of prediction equations that use clinical variables where the calculations are done in a blinded fashion to the time and results of the indirect calorimetry. Additionally, the investigators did not report the actual amount of nutrition received by the patients, nor discuss how the equation chosen to estimate calorie goals may affect the actual amount of nutrition provided to the patient. A recent observational study demonstrated that patients who were in the ICU > 4 days who had their calorie goals determined with only weight-based equations had a significantly shorter time to discharge alive, than patients who had calorie goals determined with more complex calculations.³³ As stated above, no cause and effect conclusions can be made from observational studies, but this association between complex calculations and worse patient outcomes highlights the need for outcome data before any method of calculating calorie goals can be recommended above another.

A Practical Issue: Calorie Prediction Versus Calorie Delivery

Compounding the inaccuracy of predictive equations, and the daily variability of energy expenditure, is the issue of how much nutrition a critically ill patient

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actually receives each day. There are a number of studies documenting that many critically ill patients receive only a portion of the nutrition support that is ordered, and the amount of nutrition provided can vary greatly from day to day.³¹⁻³⁵ Only a single study has investigated the difference between daily energy expenditure and the amount of nutrition actually received by the patient.³¹ The study established that even when energy expenditure was measured each day, and daily adjustments made to feeding rates, the actual cumulative energy balance ranged from -6702 to + 4791 kcals.³¹ This large day to day variation in the amount of nutrition actually received suggests that the much smaller “statistical” difference in accuracy between different prediction equations is likely clinically irrelevant. There are no adequate data to support that the use of a particular prediction equation results in improved nutrition delivery, or improved patient outcomes.

In recent years, some studies have focused on enhancing the delivery of nutrition rather than the precision of the initial calorie goal. A study that provided intensive nutrition support with increased feeding rates (150% of goal initially) delivered significantly more calories than a cohort fed according to standard protocols.³⁶ However, the intensive nutrition support group had a significantly increased duration of ICU stay, compared to the standard group. Braunschweig et al, in a randomized study of intensive feeding delivery that increased feeding rates to compensate for missed feeding reported significantly increased mortality in patients with acute lung injury that received increased nutrition.³⁷

A cohort type study (cluster randomized) demonstrated that enhanced enteral feeding protocols (early protein supplements, prophylactic prokinetic medications, volume based feeding) combined with a nursing education program significantly increased protein and calorie delivery compared to control facilities.³⁸ The enhanced feeding protocols combined with nursing education (Pep uP protocol) did not significantly improve patient outcomes, which reinforces the notion that modest changes in calorie delivery do not appear to affect patient outcome.³⁸ The results of these studies³⁶⁻³⁸ indicate the need for better quality randomized studies about patient outcomes before wide scale adopting of intensive feeding protocols or enforcing delivery of full nutrition needs in the early phases of critical illness.

Clinical Considerations

Although there are insufficient data to make strong recommendations for any particular method of estimating calorie expenditure, the reality is that there needs to be some method of establishing initial nutrition goals for patients that receive nutrition support. Time efficient weight based calculations, or more complex calculations are sufficient to prevent gross overfeeding. The actual amount of nutrition provided to patients should be monitored, and if patients are not receiving initial calorie and protein goals, the obstacles to providing reasonable amounts of nutrition in a safe manner should be addressed. Feeding schedule, rate, caloric density of the formula, supplemental protein, alterations in position of the tip of the feeding tube, prokinetic medications, and/or alterations to the bowel regimen are some of the considerations that may need to be modified. The difference between the nutrition goals and the amount of nutrition provided, especially with enteral nutrition, often dwarfs any difference in the accuracy of prediction equations.^{31,34,35} After the most acute phase of critical illness has passed, calorie goals may need to be increased to allow positive nutrition balance and improvements in nutrition status, at a time when patients are capable of compensating for the period of catabolism, and are less likely to have complications from overfeeding.

Patients with a very low BMI (<15 kg/m²) may have their calorie expenditure underestimated by many prediction equations, because they have a greater amount of metabolically active mass per kg, compared to normal weight individuals.^{39,40} Patients with a very low BMI may also be more subject to negative consequences if they receive hypocaloric nutrition support for any length of time. After concerns for possible refeeding syndrome have been addressed, and the most acute phase of critical illness has passed, patients with severe malnutrition and/or low BMI may require a calorie level that exceeds their needs to improve nutrition status.

Patients with obesity (BMI > 30 kg/m²) appear to benefit from hypocaloric feedings when full protein is provided.⁴¹ The details of hypocaloric feeding in obese patients are beyond the scope of this paper, but have been addressed elsewhere.⁴² One of the few prospective studies to address outcomes with hypocaloric feeding in obese patients reported improved patient outcomes using weight based calculations (20 kcals/kg of adjusted body weight) as the goal for hypocaloric feeding.⁴¹

CONCLUSIONS

Indirect calorimetry is the most accurate method of estimating resting energy expenditure, but it is misleading to suggest that IC is a “gold standard” for establishing nutrition goals of critically ill adult patients. Currently, there are inadequate outcome data from randomized studies to support the routine use of IC or a particular prediction equation. Available evidence suggests that in the early stages of critical illness, a single IC study is no more accurate than commonly used prediction equations for estimating average calorie expenditure. Based on the best evidence to date, modest calorie deficits within the early stage of critical illness do not appear to influence outcome, and hypocaloric feedings with full protein and micronutrients may be advantageous in some populations. There are some data to suggest that intensive efforts to make up for “missed” feeding may compromise outcome, and large randomized studies are needed before implementing intensive feeding protocols in routine clinical practice.

In patients receiving EN, the difference between nutrition goals and the actual nutrition provided, by far overshadows the small differences between various prediction equations. Simple weight based prediction equations appear safe and adequate to prevent gross under- or overfeeding. Attention to the actual nutrition provided to patients and addressing barriers to meeting basic nutrition goals is helpful to prevent large cumulative nutrition deficits. ■

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