Clinical Critical Care
Clinical Critical Care
Volume 30, Article ID e0019, 7 pages
https://doi.org/10.54205/ccc.v30.259272
REVIEW
eISSN 2774-0048

Energy expenditure in critically ill patient

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OPEN ACCESS
Citation:
Chittawatanarat K. Energy expenditure in critically ill patient. Clin Crit Care 2022; 30: e0019.

Received: September 11, 2022
Revised: October 18, 2022
Accepted: November 1, 2022

Data Availability Statement:
The data and code were available upon reasonable request (Kaweesak Chittawatanarat, email address: kaweesak.chittaw@cmu.ac.th).

Funding:
This was an unfunded study.

Competing interests:
All authors report no financial or other relationships that represent actual or potential conflicts of interest relevant to the content of this study.

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ABSTRACT:

There are a variety of terms for energy expenditure. In severely ill patients, resting energy expenditure should be measured through indirect calorimetry or estimated using an equation or body weight. Although indirect calorimetry provides a more precise method of estimate, the measuring instrument has significant limitations and is not generally accessible in Thailand. Consequently, weight-based estimate is widespread, and it is currently the method that many societies suggest. For optimal results, energy supply should neither be excessive nor insufficient. The average energy delivery should account for between 70 and 85 percent of energy expenditures during the acute phase of critical illness or the first week of intensive care unit admission.

Keywords: Indirect calorimetry, Energy expenditure, Weight-based estimation, Energy delivery.

INTRODUCTION

The amount of vital energy that must be maintained in order to survive is referred to as "energy expenditure." The words "basal energy expenditure" (BEE), "resting energy expenditure" (REE), and "total energy expenditure (TEE)" are some of the terminologies pertaining to energy expenditure that may cause confusion. In addition to the patient's existing nutritional condition in critically ill situations, patients who are receiving less or more nutrition than the amount of basic energy required will have a higher risk of developing complications than patients who receive the appropriate number of calories [1-4].

DEFINITION

The term "basal energy expenditure" (BEE) refers to the process of determining the amount of energy that is required by the body while it is at rest and free from stress, both physically and mentally. This measurement is performed in an environment that is between 27 and 29 degrees Celsius, a temperature at which the body does not require energy to generate heat, and while the individual is in a fasting state, meaning that they have not consumed any oral food for more than 10 hours prior to the measurement for prevention of the "diet induced thermogenesis (DIT) [5]. In addition to this, there can be no confounding factors that exist in the body, including inflammation, some medications, and metabolic effect of treatment during hospital admission.

With such constraints in evaluating energy demands in general, a more flexible criteria is utilized: resting energy expenditure (REE), which is assessed at least four hours after a meal or in the case of intensive care unit (ICU) patients. However, it should be measured at least 2 hours after drinking alcohol or smoking, or 4 hours after consuming coffee. During measurement, the patient is laid down in a flat position with no additional physical stress, is conscious and free of mental stress or restlessness, and is in a temperature-controlled, comfortable environment (Figure 1). In average, REE is 10 to 15% more than BEE; but, in circumstances of physical stress or a pre-existing illness termed stress energy expenditure (SEE), the quantity of such energy may be higher.

The energy expenditure levels, on the other hand, are dependent on activities such as physical therapy, exercise, walking, climbing and descending stairs, and others. The sum of the energy required to carry out a variety of activities is referred to as "activity energy expenditure (AEE)". "Total energy expenditure (TEE)" is the combination of REE and AEE (Table 1).

HOW TO DETERMINE THE ENERGY EXPENDITURE

This is based on the fact that it is not feasible to assess actual energy requirements directly in each individual. As a result, the energy requirements can be estimated by several methods[6]. Currently, there are two main methods that can be used to determine it: (1) Estimation by measurement tool (indirect calorimetry): prediction energy expenditure derived from measurements of oxygen consumption and carbon dioxide production, in conjunction with the amount of excreted nitrogen in the urine. Because it is an indirect measurement of energy expenditure using oxygen consumption and carbon dioxide production, it is referred to as "indirect calorimetry"[7]. Some people call this apparatus as "metabolic cart" or "metabolic gas analysis" which refers to the equipment that perform breath gas analysis to estimate the body's metabolism. At present, this method is generally accepted as the reference standard for determining how much energy the body requires. However, in order for patients to eligible for the test, they need to be able to rest for approximately 20 minutes, the value being measured is affected by a number of variables that can lead to inaccurate results, and the equipment and materials are only available at some hospitals in Thailand. A study was conducted in 2012 in Thailand, which included 155 intensive care units (ICU). In the ICU, such a device was not available [8]. As a result, this measuring technique is reserved mostly for use in research rather than in the provision of patient routine care in the ICU. (2) Estimation by predictive equations or body weight: according to the equation-based estimation method, the equations are derived from a particular demography and different illness. These may result in estimation errors when applied to other populations. Nevertheless, body weight estimation is a convenient method. Therefore, weight-based estimation continues to be the most widely used method of practice in Thailand [9].

KEY MESSAGES:

- Although indirect calorimetry is recommended for measuring of energy expenditure in current recommendations, its use is limited by the availability of measurement devices. Weight-based estimate is an alternation and widely utilized. It is important to avoid under- or overfeeding and to encourage enteral nutrition.

1. Determination of energy requirements by indirect calorimetry measurement.

Patients who spontaneously breathe and those who use a mechanical ventilator are able to use this method (Figure 1). This approach evaluates the energy need based on the quantity of oxygen consumed (VO_2, liters per minute), the quantity of carbon dioxide produced (VCO_2, liters per minute) and the amount of protein metabolism are measured by urine urea nitrogen (UUN, grams per day) [7]. The Weir equation is the equation being used to calculate the needed energy as following equations (Equation 1 and 2).

(Equation 1) : Metabolic energy expenditure (kcal/min) = $(3.94 \times VO_2) + (1.11 \times VCO_2) - (2.17 \times UUN)$

(Equation 2) : Resting energy expenditure (REE) (kcal/day) = Metabolic energy expenditure x 1440

Table 1. Definition of various term in energy expenditure.

Term	Briefly definition	Type of population
Basal energy expenditure (BEE)	The amount of energy for organ survives and functions	Healthy
Diet – induced thermogenesis (DIT)	The amount of energy generated by receiving food.	Healthy or patients
Stress – induced energy expenditure (SEE)	The amount of energy consumed from physical stress.	Patients
Activity energy expenditure (AEE)	The amount of energy used for various activities.	Healthy or patients
Resting energy expenditure (REE)*	REE = BEE + DIT + SEE	Healthy or patients
Total energy expenditure (TEE)	TEE = REE + AEE	Healthy or patients

Note: *In healthy individual SEE=0

Figure 1. Indirect caloric measurement in spontaneous breathing and measurement profile.

The Weir's equation is appropriate for those who have been fasting for at least four hours. Because the energy error utilized by about 1 percent of the energy needed from protein rises every 12.5 percent of the total energy [7], it is possible that low-stress situations do not need to undergo UUN testing. This would make the measuring process simpler. Regarding this assumption, UUN is expressed in around 8% of total energy expenditure of situations in which proteins are used at the greatest ratio and urinary nitrogen excretion accounts for less than 4% of energy expenditure in the critically ill patient, it is often excluded. Some papers used the term "adjusted or modified Weir's equation ; hence, a calculation that does not include UUN value is as follows (Equation 3 and 4).

(Equation 3) : REE (kcal/day) = 1440 x [(3.94 x VO_2) + (1.11 x VCO_2)]
(When the unit of VO_2 and CO_2 is l/min)

(Equation 4) : REE (kcal/day) = 1.44 x [(3.94 x VO_2) + (1.11 x VCO_2)]
(When the unit of VO_2 and CO_2 is ml/min)

In addition, the measured values can be derived from the respiratory quotient (RQ = VCO_2 / VO_2), which provides an estimate of the proportion of energy received from each food, with the RQ of fat oxidation = 0.7, RQ protein oxidation = 0.85, and RQ glucose oxidation = 1.0 [6]. In the case of overfeeding and fat accumulation, the RQ value can exceed 8.79. However, this method has some limitation, previous studies showed that RQ had low sensitivity and specificity for predicting under- or overfeeding. It should be noted that the physiologic range of RQ is 0.67-1.3 according to the oxidation of macronutrients, therefore it can be used as a marker of the measurement adequacy. If the RQ is outside this range, the test may be invalid [10]. On the normal dietary pattern, the composition of protein, carbohydrate, and fat are 16%, 49% and 35% respectively. Therefore, the simple formula could be estimated by VCO_2 as the following equation (Equation 5-10). These equations are applied in mechanical ventilators to estimate energy consumption based on only the VCO_2 value (Equation 9 and10).

(Equation 5) : Simple Weir equation: EE = 1440 x [(3.94 x VO_2) + (1.11 x VCO_2)]

(Equation 6) : Estimated VO_2 = VCO_2/RQ

As the assumption of normal food composition delivery: Protein 16%, Carbohydrate 49%, Fat 35%.

(Equation 7) : Estimated RQ = (0.16 x 0.8) + (0.46 x 1) + (0.35 x 0.7) = 0.86

(Equation 8) : Simple Weir equation: EE = ([VCO_2/0.86 × 3.94] + [VCO_2 × 1.11]) ×1440

(Equation 9) : Simple Weir equation: EE = 8193 x VCO_2 (L/min)

(Equation 10): Simple Weir equation: EE = 8.19 x VCO_2 (mL/min)

Regarding the limitation of indirect calorimetry, this is caused by the fact that indirect calorimetry measurements include just a short sampling time period for evaluation of oxygen consumption and carbon dioxide production in order to estimate the quantity of energy required during the whole day while the subject is at rest. Therefore, several precautions are taken to ensure the accuracy of the measurements. Furthermore, as indicated in Table 2, some patients' features may result in inaccurate measurements [6,7].

2. Determination of energy requirements by calculation methods

It is the most widely used approach in clinical practice since it is the more convenient and does not need instrumental testing, unlike indirect calorimetry. The evaluation techniques are classified into two categories: (1) estimation based on body weight and (2) estimation based on equations. In circumstances in which indirect calorimetry measurements are unable to be carried out, it is recommended to use an estimation based on body weight as the preferred technique [11].

1. The body weight estimating approach is the most practical method. Nevertheless, for individuals in critical care who have various systemic problems, the estimation based on body weight may be inaccurate. In situations like these, the supply of energy needs to be modified in accordance with indirect calorimetry. In addition, the energy requirements in each patient are distinct. Table 3 provides a summary of suggestions made in the past as well as conditions that are related with individuals who are critically ill.

Table 2. Recommendations and technological elements to enhance the accuracy of indirect calorimetry measurements.

Recommendations to improve measurement accuracy	**Technical factors that contribute to the measurement inaccuracy**
- Rest for a minimum of 30 mins before measuring. - During measurement, extremities may be moved normally. - (In case of intermittent feeding) stop feeding at least 4 hours. - (In the case of continuous feeding) the feeding rate should remain constant for at least 12 hours before and during examination. - The examining room must be calm and at a comfortable temperature, neither too hot nor too cold. - Utilized constant oxygen concentration (FiO_2) - In the case that the ventilation level is altered, evaluation must wait at least 90 minutes before measuring. - No leakage of the gas system - The valid measurement value must be at the constant state. - No general anesthetic is administered 6 to 8 hours before to the examination. - Give analgesics and adequate sedatives. If provide treatment, wait at least 30 minutes before measuring. - After utilizing renal replacement treatment, wait a minimum of 3 - 4 hours. - It is recommended to wait at least 1 hour after a procedure that causes discomfort to the patient. - During measurements, nurses should avoid from providing care.	- High oxygen concentration ($FiO_2 \geq 0.6$) - PEEP > 12 cm water - Breathing faster or slower than normal (hypo- / hyperventilation) - There is a leak in the gas system - High humidity in the ventilator system - Contaminated air while exhaling - Unstable level of FiO_2 - Bronchopleural fistula. - Supplemental oxygenation in spontaneous breathing patient - During renal replacement therapy - Error of machine calibration

Table 3. Estimation of energy requirements based on body weight based on various guidelines and disease situations.

Source	**Level ***	**The amount of energy provided.**
ACCP (1997) [12]	Not mentioned.	25 kcal/kg/day
EAST (2004) [13]	Level II – III	Moderate – severe injury (ISS 25 – 30): 25 – 30 kcal/kg/day or 120 – 140% of basic requirements (BEE from Harris-Benedict equation) Severe head injury (GCS < 8) - In case of not providing muscle relaxants, the requirement is 30 kcal/kg/day or about 140% of the rest requirement (MREE). - In the case of muscle relaxants, the need is 25 kcal/kg/day or about 100% of the resting requirement (MREE). Spinal cord injury (feeding until the energy required within 2 weeks) - Quadriplegia 20 – 22 kcal/kg/day or 55 – 90% of BEE - Leg paraplegia 22 – 24 kcal/kg/day or 80 – 90% of BEE Burns, scalding water. - More than 20% of the total body surface area (TBSA) Curreri equation = (25 x weight) + (40 x percentage of surface area of burns, scalding water) (Try to feed through the enteral feeding as much as possible and avoid parenteral nutrition.) - Less than 20 percent of TBSA 25 – 30 kcal/kg/day or 120 – 140% of BEE
ESPEN (2006) [14] (Enteral nutrition)	Grade C	Acute phase: 20 – 25 kcal/kg/day Anabolic flow phase: 25 – 30 kcal/kg/day
ESPEN (2009) [15] (Parenteral nutrition)	Grade C	25 kcal/kg/day Increase energy levels to achieve the target in 2-3 days.
ASPEN (2009) [16]	Grade C	Typical patients in ICU: equation-based estimation Patients with a BMI ≥ 30 kg/m^2 : 60 – 70% of target energy, or 11 – 14 kcal/kg (actual weight)/day, or 22 – 25 kcal/kg (ideal weight)/day
ASPEN (2016) [11]	Very low	Typical patients in the ICU: 25 – 30 kcal/kg/day Obese patients: 65 – 70 percent of target energy (measured by indirect calorimetry). - Body Mass Index 30 – 50 kg/m^2: 11 – 14 kcal/kg (actual weight)/day - Body Mass Index > 50 kg/m^2: 22 – 25 kcal/kg (ideal weight)/day
ESPEN (2017) [17] (Perioperative)	Good practice point	25 -30 kcal/kg (ideal weight)/day should start perioperative nutrition therapy When it is estimated that you cannot eat for more than 5 days or orally intake less than 50% for more than 7 days.
ASPEN (2022)[18]	Moderate	12 – 25 kcal/kg in the first 7 – 10 days of ICU stay

Note:* The level of recommendations has different rules in place in each practice.
Abbreviation: ACCP, American College of Chest Physician; EAST, Eastern Association for the Surgery of Trauma; ESPEN, European Society of Parenteral and Enteral Nutrition; BEE, basal energy expenditure; MREE, measure basal energy expenditure (Modified with permission from Kaweesak Chittawatanarat. Nutrition support in surgical ICU., in: Kaweesak Chittawatanarat, Editor. Surgical critical care in practice. 1st edition. Chiang Mai: Faculty of Medicine, Chiang Mai University; 2017:323-72.)

2. Estimation based on the use of equations: from the EAST guideline (Table 3), the recommendation of the amount of energy that patients should receive is used based on the Harris Benedict equation (HBE) to calculate the basal energy expenditure and to calculate the total required energy level by multiplying the stress factor. This is accomplished in patients who have been associated with injuries of moderate to severe. HBE is the equation for calculating basal energy expenditure (BEE), which takes into account body weight, height, age, and gender as its variables. The equation's specific details are presented in the form of a formula below (Equation 11 and 12).

(Equation 11) Men: BEE = 66 + (13.7 x body weight in kg) + (5 x Height in cm) – (6.8 x Age in years)

(Equation 12) Women: BEE = 665 + (9.6 x body weight in kg) + (1.9 x Height in cm) – (4.7 x Age in years)

And then assign the BEE value of each individual patient to calculate TEE by taking into account stress and activity factors. (Equation 13):

(Equation 13) : TEE = BEE x Stress factor x Activity factor
Activity factor is between 1.1 and 1.2 while in bed and inactive, and 1.3 when ambulation.

In the absence of an indirect calorimetry device, metabolic resting energy expenditure (MREE) may be approximated using the HBE equation (MREE equals 110–120 percent of BEE). When a patient has an illness, the stress factor should be of consideration. The stress factor is a multiplying factor as.

Postoperative (no complications)	x1.0
Fractures	x1.15-1.30
Cancer/chronic obstructive pulmonary disease	x1.10-1.30
Sepsis/ Abdominal inflammation	x1.10-1.30
Severe infections/multisystem accidents	x1.20-1.40
Multisystem Organ Failure	x1.20-2.00
Major burns	x1.20-2.00

One can observe that such equations are used in the calculations, if the patient is under intense stress. The computed value is extremely high. Delivering excessive amounts of calories may result in overfeeding of nutrients. This may generate detrimental effects including increased carbon dioxide production, hyperglycemia, and fatty liver. Currently, the BEE value that adjusted by stress factor is between 1.2 and 1.6, and the resultant energy should not exceed 40 kcal/kg/day. If calories are administered at such levels, thorough monitoring by indirect calorimetry measurement is required.

Regarding the equations used in the calculations of the different reported resting energy requirements, Table 4 presents examples of applications for patients in intensive care units [6,19].

Table 4. Calculation formula to estimate resting energy expenditure.

Ireton-Jones's calculation formula (1992) = 1,925 – (10 x age) + (5 x weight) + (281 x weight) If male) +(292 If it is an accident patient) + (851 If it's a major burn.)
Ireton-Jones's calculation formula (1997) = (5 x Weight) – (11 x Age) + (244 x Weight) If it's male) + (239 If it is an accident patient) + (840 If it is a major burn) + 1,784.
Penn State's Calculation Formula (1998) = (1.1 x Values from Harris-Benedict equation) + (140 x Max. Body temperature) + (32 x V_E) – 5,340
Penn State's Calculation Formula (2003) = (0.85 x Values from Harris-Benedict) + (175 x Max. Body temperature) + (33 x V_E) – 6,433
Swinamer's calculation formula (1990) =(945 x Body area) – (6.4 x age) + (108 x Body temperature)+ (24.2 x Respiratory rate) + (817 x V_T) – 4,349
Curreri's calculation formula (1974) =(25 x Weight) + (40 x percentage of surface area of burns, scalding water)

V_E, minute volume (L/min); V_T, tidal volume (L) (Modified with permission from Kaweesak Chittawatanarat. Nutrition support in surgical ICU., in: Kaweesak Chittawatanarat, Editor. Surgical critical care in practice. 1st edition. Chiang Mai: Faculty of Medicine, Chiang Mai University; 2017:323-72.)

ASPEN guidelines for patients in the ICU have evolved from the ASPEN 2009 recommendation, which recommended utilizing equation-based or weight-based estimation. Currently, the ASPEN 2016 and 2022 recommendation suggests using it as a weight base estimate for patients in the ICU [11,18]. When compared to indirect calorimetry, the rationale for these recommendations was based on the published equations, which have an accuracy of only 40–75 percent. In addition, no equation can be employed to accurately predict outcomes for all clinical situations because these equations were created on a diverse population. For instance, the Penn State, Ireton-Jones, or Swinamer equations were developed based on hospitalized patients, while the Harris-Benedict and Mifflin St. Jeor equations were established based on healthy individuals. Because of this, it should be noted that neither version of the prediction is more accurate than others. Although the weight-based method may be less accurate, calculations based on body weight may be accomplished more easily and quickly in practice. For these reasons, the current ASPEN guidelines have transitioned their advice from equation to body weight for estimating energy requirements[11,18].

In the case of a major burn patient who involves more than 50 percent of the body surface area, the energy calculations using Curreri's equations revealed that the energy requirement estimation would be higher than average (more than 40 kcal/kg/day). When dealing with situations, indirect calorimetry measurement should be used for estimating the energy requirement, and nutrition delivery via the enteral feeding should be the first choice. The parenteral route should not be used to as routine that provide such enormous quantities of energy. Overfeeding and their complications should be caution if energy delivery is prescribed more than 40 kcal/kg/d. To mitigate feeding complications, the energy delivery should be slowly progressive increase, and indirect calorimetry should be investigated. Currently, Curreri's recipe has a very low level of popularity.

ENERGY DELIVERY IN ICU PATIENTS

In terms of nutrition delivery in the ICU, underfeeding or hypocaloric feeding is without a precise definition, although it frequently refers to acquiring between 40 - 60 percent of the required amounts of calories [20,21]. Long-term provision of a nutrition below average demand, particularly for individuals at nutritional risk, can increase the likelihood of complications [1,2]. On the other hand, there are several consequences associated with overfeeding, hypercaloric feeding, or hyperalimentation, including hyperglycemia, hypercarbia and elevated blood urea nitrogen levels.

Depending on the patient's characteristics, the nutritional intake in each ICU also differs. Regarding the THAI-SICU study [22], a prospective observation in the surgical ICU at three training institutions with a total of 1,686 cases , It revealed that hospitals in Bangkok delivered higher amounts of calories from EN and overall energy than hospital in Chiang Mai. (Figure 2). However, these effects may be attributable to differences in disease severity and patient nutrition status. When these variables were controlled for in a multivariable analysis, there was no difference in mortality rates, but there were significant differences higher in the incidence of infection and the length of hospital stay [3].

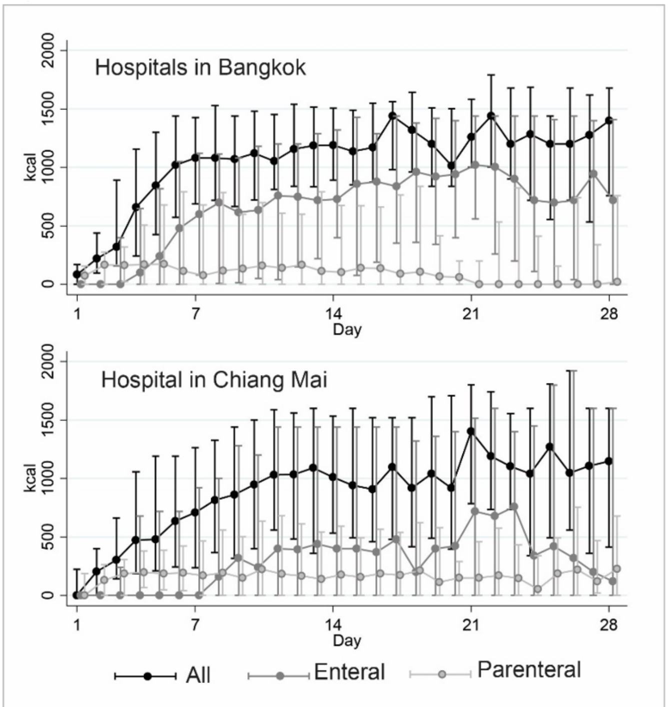

Figure 2. The different of nutrition delivery on different hospitals in THAI-SICU study.

In the studies published in 2016 and 2017, Zusman et al included 1171 patients who were investigated REE levels using indirect calorimetry, either underfeeding or overfeeding was associated with poor outcomes[23,24]. The energy received at 70% of REE was shown to considerably lessen mortality, whereas patients who received energy in excess of this level had significantly longer hospital stays and ventilator duration. The conclusion of this research was that providing the patient neither insufficient nor excessive energy would improve the outcome. The other landmark international observation study involving 7872 mechanically ventilated critically ill patients in the ICU found that the lower risk threshold for 60-day mortality was achieved when the 12-day average percentage of prescribed calories was between 80 and 85 percent of the estimated caloric requirement [25]. Therefore, meeting caloric targets may be related with improved clinical outcomes in critically ill patients.

CONCLUSION

Multiple methods exist for determining the energy requirement. The first method is indirect calorimetry which can measure REE accurately in both spontaneously breathing and mechanically ventilated patients. Another method is an estimation using equation-based formulas; however, they have limited accuracy in a particular patient group. In the absence of indirect calorimetry, current standards advocate utilizing simple weight-based formula. Finally, for optimal outcomes, the quantity of energy provided to the patients should not be excessive or insufficient.

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