Journal of Critical Care (2009) 24, 628.e1–628.e5

ELSEVIER

Journal of Critical Care

Harris-Benedict equation for critically ill patients: Are there differences with indirect calorimetry?

Camila C. Japur MSc[a,*], Fernanda R.O. Penaforte MSc[a], Paula G. Chiarello PhD[a], Jacqueline P. Monteiro PhD[b], Marta N.C.M. Vieira PhD[b], Anibal Basile-Filho PhD[c]

[a]*Departamento de Clínica Médica, Universidade de São Paulo, Brasil*
[b]*Departamento de Pediatria e Puericultura, Universidade de São Paulo, Brasil*
[c]*Departamento de Cirurgia e Anatomia Faculdade de Medicina de Ribeirão Preto, Universidade de São Paulo, Brasil*

Keywords:
Energy expenditure;
Indirect calorimetry;
Correction factors;
Hypometabolism;
Hypermetabolism

Abstract

Purpose: The aim of this study was to compare the measured energy expenditure (EE) and the estimated basal EE (BEE) in critically ill patients.

Materials and Methods: Seventeen patients from an intensive care unit were randomly evaluated. Indirect calorimetry was performed to calculate patient's EE, and BEE was estimated by the Harris-Benedict formula. The metabolic state (EE/BEE × 100) was determined according to the following criteria: hypermetabolism, more than 130%; normal metabolism, between 90% and 130%; and hypometabolism, less than 90%. To determine the limits of agreement between EE and BEE, we performed a Bland-Altman analysis.

Results: The average EE of patients was 6339 ± 1119 kJ/d. Two patients were hypermetabolic (11.8%), 4 were hypometabolic (23.5%), and 11 normometabolic (64.7%). Bland-Altman analysis showed a mean of −126 ± 2135 kJ/d for EE and BEE. Only one patient was outside the limits of agreement between the 2 methods (indirect calorimetry and Harris-Benedict).

Conclusions: The calculation of energy needs can be done with the equation of Harris-Benedict associated with lower values of correction factors (approximately 10%) to avoid overfeeding, with constant monitoring of anthropometric and biochemical parameters to assess the nutritional changing and adjust the infusion of energy.

1. Introduction

Energy requirements estimation of healthy persons is a challenge for professionals because differences in real energy expenditure (EE) may occur even among persons of the same sex, age, weight, and height due to various genetic and environmental characteristics (ethnic origin, body composition, diet, physical activity, environmental temperature, and altitude) [1]. For critically ill patients, these difficulties are even stronger because, in addition to all of those factors, there are influences of the disease itself and the effects of treatment, which may change oxygen consumption (V_{O_2}) and/or carbon dioxide production (V_{CO_2}) [2,3]. There are predictive equations used to estimate energy needs, associated to specific factors to correct the change in EE for each type of disease. Energy expenditure predictive equations may overestimate the energy needs up to 50% [4,5], probably

* Corresponding author.
E-mail address: camila@fmrp.usp.br (C.C. Japur).

0883-9441/$ – see front matter
doi:10.1016/j.jcrc.2008.12.007

causing overfeeding, leading to respiratory and metabolic disorders [6,7], or may underestimate values, leading to patient's underfeeding [4,8].

The objective of the present study was to compare the measured EE and the estimated basal EE (BEE) in critically ill patients.

2. Subjects and methods

2.1. Subjects

A cross-sectional study was conducted in a university hospital intensive care unit (ICU). Seventeen mechanically ventilated and metabolically stable critically ill adults were randomly chosen and evaluated. Clinical data on sex, age, weight, diagnosis, days on mechanical ventilation and in the ICU, and amount and route of energy and protein intake were recorded at the measurement day. Severity of the diseases was assessed by the APACHE II score (Acute Physiology and Chronic Health Evaluation) [9], and the patient's current weight was measured with a portable electronic scale (Slingscale 2002, Instrucom/Hill-Rom series, Hillenbrand Industries, Batesville, IN, USA).

Patients showing at least one of the following conditions were excluded from the study: spontaneous ventilation; absence of a bladder catheter; diuresis less than 50 mL/h; age >85 or <15 years; inspired air oxygen fraction need of more than 60%; mean arterial blood pressure of less than 50 mm Hg; heart rate <50 or >140 beats per minute; presence of a bronchopleural air fistula; irreversible circulatory shock; and brain death. The study protocol was approved by the local institutional review board, and familial/parental written consent was obtained before the beginning of the study.

2.2. Energy expenditure—indirect calorimetry

V_{O_2} and V_{CO_2} were determined by indirect calorimetry, over duplicate periods of 45 minutes each, separated by a 30-minute interval, using a portable calorimeter (DELTATRAC II Metabolic Monitor, Datex-Ohmeda, Helsinki, Finland) coupled to a microprocess respirator, heated for 30 minutes before measurements. Automatic pressure calibration was manually adjusted to local atmospheric pressure, measured with a Torricelli barometer installed in the ICU, and automatically calibrated by a command in the apparatus using 95% oxygen and 5% carbon dioxide gas mixture according to the manufacturer's instructions. Measurements were performed between 11:00 PM and 3 PM, a period in which variables such as minute ventilation, heart rate, respiratory rate, and systolic blood pressure were close to their daily average values, permitting a reliable use of data generated by the calorimeter, and that could be extended over a 24-hour period of EE [10]. All patients laid in supine position; they were fed and were not febrile. Their ventilation parameters were not changed, and diagnostic and therapeutic procedures such as bronchial hygiene, bathing, venous puncture, and examinations were not performed for at least 30 minutes before the respiratory gas measurement.

For the calculation of EE, Weir's modified equation [11] was used: $[(3.941\times V_{O_2}) + (1.106\times V_{CO_2})]1.44$; only data intervals of V_{O_2}, V_{CO_2}, and respiratory quotients considered in steady state were used. The steady state was characterized by a 5-minute interval in which V_{O_2} and V_{CO_2} values varied less than 10% and the respiratory quotient values less than 5%, excluding values that were out of the physiologic range [12,13]. For standardization, it was established that energy requirements corresponded to the measured EE without use of any correction factor, as previously proposed by other authors [5,14].

2.3. Characterization of the metabolic study

Basal EE was estimated by the Harris-Benedict formula, which uses weight (kilograms), height (centimeters), age (years), and sex [15].

$$BEE_{men} = 66.4730 + (13.7516 \times \text{weight}) + (5.0033 \times \text{height}) - (6.7550 \times \text{age})$$

$$BEE_{women} = 655.0955 + (9.5634 \times \text{weight}) + (1.8496 \times \text{height}) - (4.6756 \times \text{age})$$

The metabolic state (EE/BEE) was determined according to the following criteria: hypermetabolism, 130% or greater; normal metabolism, between 90% and 130%; and hypometabolism, 90% or less [16].

2.4. Statistical analysis

The results are expressed as mean and SD. The coefficients of variation of EE and BEE were calculated as the ratio between the SD of the sample and the mean, multiplied by 100. In addition, we conducted a Bland-Altman analysis to determine the limits of agreement between measured and calculated EE. Limits of agreement between methods were defined as the mean difference ± 2 SD [17]. Statistics were analyzed using SPSS 10.0 program (SPSS, Chicago, Ill).

3. Results

Seventeen critically ill patients were evaluated in the present study. The diagnoses were varied, including neurologic, renal, respiratory, and gastroenterologic diseases. The APACHE II obtained ranged from 7 to 38 (mean, 22 ± 8), and the mortality rate was 35% (Table 1). The patient ICU length of stay and mechanical ventilation duration were 17.1 ± 14.4 and 18.7 ± 14.1 days, respectively. The longer mechanical

Table 1 Characterization of the patients studied

Case	Diagnosis	Sex (F/M) [a]	Age (y)	Apache II
1	Acute respiratory insufficiency, status epilepticus	F	52	20
2	Huntington disease, pneumonia	M	24	20
3	Acute renal failure	F	79	38
4	Hypoxic encephalopathy, pneumonia	M	20	17
5	Respiratory insufficiency secondary to pneumonia, chronic renal failure	M	80	33
6	Churg-Strauss syndrome, mesenteric ischemia	F	52	25
7	Neurotoxoplasmosis, status epilepticus, pneumonia	F	56	23
8	Guillain-Barré syndrome	M	38	7
9	Respiratory insufficiency secondary to Guillain-Barré syndrome, pneumonia	F	69	18
10	Chronic respiratory insufficiency, pneumonia	F	74	19
11	Meningoencephalitis, acute renal failure (in reduction)	F	60	35
12	Severe cranioencephalic trauma	M	16	15
13	Respiratory insufficiency secondary to malnutrition	F	29	23
14	Enterectomy, fecal peritonitis	M	56	19
15	Late postoperative (bone marrow transplantation), multiple sclerosis, pneumonia	M	50	23
16	Postoperative abdominal aneurismectomy, pulmonary obstrutive syndrome	M	78	22
17	Systemic lupus erythematosus/systemic sclerosis, Hypercapnic respiratory insufficiency, pneumonia	M	31	10
Mean ± SD			51 ± 21	22 ± 8

[a] F: female; M: male.

ventilation duration can be explained by the patient's need to start the artificial respiration before ICU admission.

The measured EE of patients ranged from 4732 to 9707 kJ/d (and from 59 to 153 kJ/kg per day), and the average value was 6339 ± 1119 kJ/d (Table 2). Two patients were hypermetabolic (11.8%), 4 were hypometabolic (23.5%), and 11 normometabolic (64.7%).

Bland-Altman analysis showed a mean of −126 ± 2135 kJ/d for EE and BEE. Only one patient was outside the limits of agreement between the 2 methods (indirect calorimetry and Harris-Benedict), which were −2261 to 2009 kJ/d (Fig. 1).

4. Discussion

The critically ill patients showed great variation in their energy needs, with a predominance of normal metabolism and hypometabolism. The EE measured by indirect

Table 2 Energy expenditure and basal energy expenditure

Patient	EE		BEE		EE/BEE
	kJ/d	kJ/kg per day	kJ/d	kJ/kg per day	
1	6699	85.4	6138	78.2	1.09
2	6920	120.5	6427	111.7	1.08
3	5828	69.5	5782	69.0	1.01
4	5586	98.3	6494	114.6	0.86
5	6226	76.6	6305	77.8	0.99
6	7305	123.8	5339	90.4	1.37
7	5351	64.0	6247	74.9	0.86
8	5715	89.5	6711	105.0	0.85
9	5644	70.7	5816	72.8	0.97
10	6753	58.6	7171	62.3	0.94
11	5703	90.0	5289	83.3	1.08
12	5502	90.0	6858	112.1	0.80
13	4732	106.3	5263	118.4	0.90
14	7192	87.9	7180	87.4	1.00
15	9707	129.3	6971	92.9	1.39
16	6494	84.1	6443	83.3	1.01
17	6406	153.1	5197	124.3	1.23
Mean ± SD	6339±1119	94.0±25.5	6213±670	91.7±19.1	1.03 ± 0.17
CV (%)	18	27	11	21	17

CV indicates coefficient of variation.

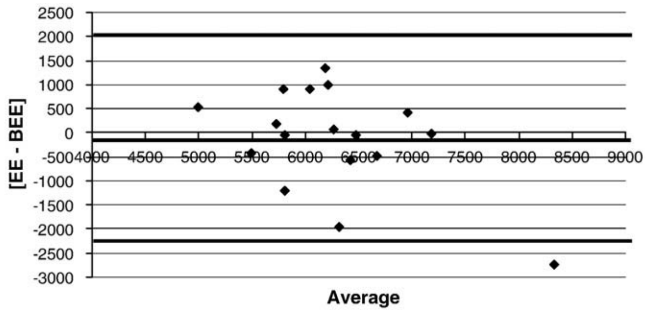

Fig. 1 Bland-Altman analysis between measured energy expenditure (EE) and estimated basal energy expenditure (BEE).

calorimetry showed good agreement when compared to calculated by the equation of Harris-Benedict; however, when we evaluate by the clinical point of view, this change could represent an important deficit or excess of energy.

The method used to determine the real energy requirements, indirect calorimetry, provided data about EE plus the thermal effect of foods because the patients were being fed at the time of measurement. The patients were bedridden, and the effect of physical activity was limited to the activities of respiratory physiotherapy, changes of position in bed, weighing, and bathing provided by professionals of the unit. Swinamer et al [18] reported that, among others, these activities influence the total expenditure by 1% to 4% during the 24 hours. However, for standardization, in the present study, we chose to consider the measured EE as the total daily EE.

Important variations in measured EE were detected among patients, probably due to different phases of disease, to the presence and magnitude of infection and inflammation, to the medication administered, and to the biological variation itself (weight, height, age and sex). A limitation of the study was the presence of great variation of medical diagnoses found among patients, but it reflects the reality of an ICU that not only serves patients from a particular disease. Nevertheless, 2 recent studies agreed in reporting the lack of influence of the type of injury on the measured EE. The first evaluated 87 critically ill afebrile patients who required mechanical ventilation, stratified by type of injury (clinical, surgical, or traumatic), and showed no significant differences in the EE/BEE ratio [19]; and the second evaluated 27 patients and detected mean EE/BEE ratios of 1.23, 1.26, and 1.18 for clinical, surgical, and traumatized patients, respectively, with no significant difference between groups [4].

In the present study, there was a predominance of normal metabolism and hypometabolism (88%) in contrast to the statement that critically ill patients in most cases are hypermetabolic. Modern mechanical ventilation instruments and drug therapies widely used in ICUs such as sedatives, analgesics, and muscle blockers seem to induce a reduction of metabolic and systemic stress, with a consequent reduction of energy requirements [2,4,20].

Brandi et al discussed the results of several studies in which 30% to 50% of critically ill patients were normometabolic, 35% to 65% were hypermetabolic, and 15% to 20% were hypometabolic [14]. Hoffer stated that many critically ill patients have a measured EE that characterizes them as normometabolic [21]. He pointed out the study by Zauner et al [22] who detected a mean of 96 kJ/kg per day before and during the administration of parenteral nutrition, indicating that these patients, who were inactive, under moderate stress and continuously fed, had a mean measured EE close to the total daily EE.

The large number of normometabolic and hypometabolic patients may be explained by the predominance of diagnosis of chronic neurologic diseases that involve muscle paralysis, the absence of fever, and the long time of hospitalization in the ICU (17.1 ± 14.4 days). Raurich et al [19] studied the EE of patients within 48 to 96 hours of mechanical ventilation and observed that 63% of them were hypermetabolic but, in contrast to the present study, they used an EE of more than 115% of the BEE as the parameter for hypermetabolism.

The mean EE/BEE ratio was very close to 1.00, with a coefficient of variation of 17% and with a variation of ±10% in 10 (59%) of the 17 patients evaluated. Schoeller [23] pointed out that EE measurement is preferable because predictive equations show errors of more than 10% in one third of all patients. Recent studies have recommended the use of EE with no correction factor [5,24,25] or complemented with 10% to 20% at most, to prevent metabolic overload due to excess feeding [18,26,27] and the use of 1.0 to 1.2 for BEE [16,20,28], of 1.3 [4] and up to 1.6 for a short period of nutritional therapy [29]. This characterizes a wide variation of correction in EE measured by indirect calorimetry or estimated by predictive equations such as the Harris-Benedict equation, with a consequent considerable difficulty in choosing the best factor to be used for this specific population.

In addition to the wide variation of the recommended correction factors, there is variation in the results of the studies that evaluated the EE/BEE ratio. In a study on hospitalized patients, Miles [28] detected a variation of 0.94 to 1.30 in the EE/BEE ratio, and in our study, this variation was even greater, from 0.80 to 1.39. However, the mean ratio detected in most recent studies ranges from 1.0 to 1.2 [5,19,28], emphasizing the importance of caution about the use of higher correction factors such as those proposed by Long et al [30] in 1979, which are still used at some centers. Coletto et al [5] evaluated the use of these factors and observed overestimates in more than 50% of the patients studied, and Miles [28] also pointed out the importance of carefully considering these factors to avoid inadequate energy intake because in his study he detected a correction of BEE of only 13% on average.

Bland-Altman analysis showed that all the plotted data, except for those referring to one patient, were within the limits of agreement, but we believe that the wide variation observed between the minimum and maximum values of these limits is clinically important. On this basis, we propose that there may be individual under- or overestimates when

EE measurement by indirect calorimetry is replaced with prediction by the Harris-Benedict equation.

The ideal situation would be to perform calorimetry measurements in all patients, but this kind of equipment is not always available in an ICU. Thus, the calculation of energy needs can be done with the equation of Harris-Benedict associated with lower values of correction factors (approximately 10%) to avoid overfeeding, with constant monitoring of anthropometric and biochemical parameters to assess the nutritional changing and adjust the infusion of energy.

References

[1] Institute of Medicine. Energy. Dietary references intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein and amino acids. Washington, DC: National Academic Press; 2005. p. 131-51.
[2] Chioléro R, Revelly JP, Tappy L. Energy metabolism in sepsis and injury. Nutrition 1997;13:45S-51S.
[3] McClave SA, Snider HL. Understanding the metabolic response to critical illness: factors that cause patients to deviate from the expected pattern of hypermetabolism. New Horiz 1994;2:139-46.
[4] Reid CL. Poor agreement between continuous measurements of energy expenditure and routinely used prediction equations in intensive care unit patients. Clin Nutr 2007;26:649-57.
[5] Coletto FA, Marson F, Campos AD, et al. Análise comparativa do gasto energético entre as equações de Harris-Benedict e de Long e a calorimetria indireta em pacientes sépticos. RBTI 2003;15:93-100.
[6] Battezzati A, Viganò R. Indirect calorimetry and nutritional problems in clinical practice. Acta Diabetol 2001;38:1-5.
[7] Klein CJ, Stanek GS, Wiles CE. Overfeeding macronutrients to critically ill adults: metabolic complications. J Am Diet Assoc 1998; 98:795-806.
[8] Kyle UG, Genton L, Heidegger CP, et al. Hospitalized mechanically ventilated patients are at higher risk of enteral underfeeding than non-ventilated patients. Clin Nutr 2006;25:727-35.
[9] Knaus WA, Draper EA, Wagner DP, et al. APACHE II: a severity of disease classification system. Crit Care Med 1985;13:818-29.
[10] Smyrnios NA, Curley FJ, Shaker G. Accuracy of 30-minute indirect calorimetry studies in predicting 24-hour energy expenditure in mechanically ventilated, critically ill patients. JPEN 1997;21:168-74.
[11] Weir JBV. New methods for calculating metabolic rate with special reference to protein metabolism. J Physiol 1949;109:1-9.
[12] Joosten KFM. Why indirect calorimetry in critically ill patients: what do we want to measure? Intensive Care Med 2001;27:1107-9.
[13] Matarese LE. Indirect calorimetry: technical aspects. J Am Diet Assoc 1997;97:S154-60.
[14] Brandi LS, Bertolini R, Calafà M. Indirect calorimetry in critically ill patients: clinical applications and practical advice. Nutrition 1997;13: 349-58.
[15] Harris JA, Benedict FG. A biometric study on basal metabolism in men. Washington, DC: Carnegie Institute of Washington; 1919. Public N° 279.
[16] McClave SA, Lowen CC, Kleber MJ, et al. Are patients fed appropriately according to their caloric requirements? JPEN 1998; 22:375-81.
[17] Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1: 307-10.
[18] Swinamer DL, Phang PT, Jones RL, et al. Twenty-four hour energy expenditure in critically ill patients. Crit Care Med 1987;15:637-43.
[19] Raurich JM, Ibáñez J, Marsé P, et al. Resting energy expenditure during mechanical ventilation and its relationship with the type of lesion. JPEN 2007;31:58-62.
[20] Boullata J, Williams J, Cottrell F, et al. Accurate determination of energy needs in hospitalized patients. J Am Diet Assoc 2007;107: 393-401.
[21] Hoffer LJ. Protein and energy provision in critical illness. Am J Clin Nutr 2003;78:906-11.
[22] Zauner C, Schuster BI, Schneeweiss B. Similar metabolic responses to standardized total parenteral nutrition of septic and nonseptic critically ill patients. Am J Clin Nutr 2001;74:265-70.
[23] Schoeller DA. Making indirect calorimetry a gold standard for predicting energy requirements for institutionalized patients. J Am Diet Assoc 2007;107:390-2.
[24] Holdy KE. Monitoring energy metabolism with indirect calorimetry: instruments, interpretation and clinical applications. Nutr Clin Pract 2004;19:447-54.
[25] McClave S, Spain DA, Skolnick JL, et al. Achievement of steady state optimizes results when performing indirect calorimetry. JPEN 2003; 27:16-20.
[26] Kan MN, Chang HH, Sheu WF, et al. Estimation of energy requirements for mechanically ventilated, critically ill patients using nutritional status. Crit Care 2003;7:R108-15.
[27] Weissman C, Kemper M, Elwyn DH, et al. The energy expenditure of the mechanically ventilated critically ill patient: an analysis. Chest 1986;89:254-9.
[28] Miles JM. Energy expenditure in hospitalized patients: implications for nutritional support. Mayo Clin Proc 2006;81:809-16.
[29] MacDonald A, Hildebrandt L. Comparison of formulaic equations to determine energy expenditure in the critically ill patient. Nutrition 2003;19:233-9.
[30] Long CL, Schaffel N, Geiger JW, et al. Metabolic response to injury and illness: estimation of energy and protein needs from indirect calorimetry and nitrogen balance. JPEN 1979;3:452-6.