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Revisión

Energy expenditure: components and evaluation methods

A. C. Pinheiro Volp[1], F. C. Esteves de Oliveira[2], R. Duarte Moreira Alves[3], E. A. Esteves[4] y J. Bressan[5]

[1]Assistant Professor. Nutrition School. Federal University of Ouro Preto. Minas Gerais. Brazil. [2]Candidate for Doctoral degree in Food Science and Technology. Federal University of Viçosa. Minas Gerais. Brazil. [3]Candidate for Doctoral degree in Nutrition Science. Federal University of Viçosa. Minas Gerais. Brazil. [4]Assistant Professor. Department of Nutrition. Federal University of Vales do Jequitinhonha and Mucuri. Minas Gerais. Brazil. [5]Associated professor. Nutrition and Health Department. Federal University of Viçosa. Minas Gerais. Brazil.

Abstract

Introduction: **The determination of energy expenditure, considering the physical activity level and health status, is very important to adjust the individuals' nutritional supply. Energy expenditure can be determined by using indirect calorimetry, bioelectrical impedance, doubly labeled water, predictive equations, among others. All these methods have been used in clinical and research areas. However, considering the inconsistence in several research results, there is no consensus yet about the applicability of many of these methods.**

Objectives: **The aim of this review is to describe the components of energy expenditure and the methods for its determination and estimation, summarizing their main advantages and limitations.**

Results and discussion: **Indirect calorimetry and doubly labeled water are considered more accurate methods, but expensive. On the other hand, even though other methods present limitations, they are convenient and less expensive, and can be used with some caution.**

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Key words: *Energy metabolism. Energy expenditure. Caloric intake. Methods. Equations.*

GASTO ENERGÉTICO: COMPONENTES Y MÉTODOS DE EVALUACIÓN

Resumen

Introducción: **Determinar el gasto energético (GE), considerando la actividad física y el estado de salud, es muy importante para ajustar el cálculo de la necesidad nutricional para cada individuo. Para eso, se pueden utilizar técnicas como la calorimetría indirecta, la bioimpedancia eléctrica, el agua doblemente marcada, las ecuaciones predictivas, entre otras. Estos métodos son utilizados en la práctica clínica y en estudios científicos. Sin embargo, debido a la inconsistencia de los resultados de estas investigaciones, todavía no hay un consenso respecto a su aplicabilidad.**

Objetivos: **De esa forma, esta revisión tiene como objetivo discutir los componentes del gasto energético, así como las técnicas para su determinación y estimativa, señalando sus ventajas y limitaciones.**

Resultados y discusión: **La calorimetria indirecta y el agua doblemente marcada son métodos considerados más acurados, sin embargo onerosos. Los otros métodos presentan limitaciones, pero por su practicidad y bajo coste, algunos de ellos pueden ser usados con cautela.**

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Palabras clave: *Metabolismo energético. Gasto energético. Ingesta calórica. Métodos. Ecuaciones.*

Abbreviations

%: Percentage.
A: Age (years).
ATP: Adenosine triphosphate.
BEE: Basal energy expenditure.
BIA: Bioelectrical Impedance Analysis.
BMI: Body Mass Index.
BW: Body weight (kg).
CIC: Circulatory indirect calorimetry.
CO_2: Carbon dioxide.
DC: Direct calorimetry.
DIT: Diet-induced thermogenesis.
DLW: Doubly labeled water.
EE: Energy expenditure.
EER: Estimated Energy Requirement.
H: Height (m).
h: Hours.
H^2: Deuterium.
IC: Indirect calorimetry.

Correspondence: Ana Carolina Pinheiro Volp.
Campus Universitario.
Morro do Cruzeiro, s/n.
P.O. BOX: 35400-000 Ouro Preto, MG. Brazil.
E-mail: anavolp@gmail.com

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ICU: Intensive care unit.
kcal: Kilocalories.
kg: Kilograms.
kj: Kilojoules.
M^2: Square meters.
METs: Metabolic equivalents.
Min: Minutes.
mL: Milliliters.
O^{18}: Oxygen-18.
O_2: Oxygen.
PA: Physical activity.
PAL: Physical activity level.
REE: Resting energy expenditure.
IC: Indirect calorimetry.
TEE: Total energy expenditure.
W: Weight (m).

Introduction

The energy that human body requires to maintain its organic and vital functions is obtained by the oxidation of macronutrients from foods.[1] Energy expenditure (EE) can be considered a process of energy production from energy substrates (carbohydrates, lipids, proteins and alcohol) combustion, in which there is an oxygen consumption (O_2) and carbon dioxide production (CO_2). Part of this chemical energy is lost as heat and in urine, and the remain energy is stored in high-energy molecules known as adenosine triphosphates (ATPs).[2]

Total energy expenditure (TEE) is the energy required by the organism daily and it is determined by the sum of 3 components: basal energy expenditure (BEE), diet-induced thermogenesis (DIT) and physical activity (PA).[3]

There are several methods for EE measurementsuch as indirect calorimetry (IC) and direct calorimetry (DC), bioelectrical impedance (BIA), doubly labeled water (DLW), predictive equations, and others.[4,5] The EE determination is important to adjust the individuals' nutritional offer, and must consider the demand of energy for physical activity and specific health conditions. Most of these methods have been widely used in human studies for different clinical applications (enteral and parenteral nutrition, obesity and others). However, there is no consensus about the applicability of some of them due to different results from literature. Therefore, this review describes the energy expenditure components as well as discusses several methods for energy expenditure estimation, emphasizing their advantages and limitations.

Methods

This review was performed using a variety of medical and scientific databases including Medline, PubMed, Scielo, and *Lilacs* to identify relevant articles focused on energy expenditure measurement methods. The following key words, in English, Spanish and Portuguese were used: indirect calorimetry, energy expenditure, bioelectrical impedance, doubly labeled water, predictive equations, circulatory indirect calorimetry, food intake measurement, portable *Armand* and physical activity questionnaire. Articles were selected after an abstract pre-reading and independently of their publication year, since we were interested in articles which described original methodologies for measuring energy expenditure.

Components of Total Energy Expenditure (TEE)

Basal Energy Expenditure (BEE)

The BEE is the amount of calories spent per minute or per hour which can be extrapolated to 24 hours, it also represents the minimal energy required for body vital function maintenance.[6] The BEE is one of the most important physiological information in clinical and epidemiological nutritional studies, since it is used to determine the energy requirement of an individual or population.[7]

The BEE contributes for 60% to 70% of daily energy requirement for most sedentary individuals and nearly 50% for those physically active. Its determination is useful to compare the energy metabolism between individuals.[6,8]

This component of TEE must be measured under standardized ambient conditions such as controlled temperature and humidity. Subject must be at complete rest after at least 8 hours of sleep and after a 12-14 hour overnight fast. Also, during the measurement, subject must be kept fully awake, lied down quietly, completely relaxed and breathing normally.[3,9] The value obtained is extrapolated to the 24 hours of the day and, therefore, is referred to basal with minimal influence of DIT and PA in the TEE.[3] However, the measurement of BEE requires the subject to sleep overnight in the metabolic unit. Thus, instead of BEE, the resting energy expenditure (REE) is usually measured, since there is little difference between them.[10]

Many individual factors may affect BEE, such as ethnicity, weight, lean body mass, age, smoking habits, PA, diet, menstrual period and fasting. Room's conditions (temperature, noise and time of resting) and technical factors related to the equipments used may also affect the BEE measurement. For example, the metabolic monitor must be heated and stabilized 30 minutes before each determination and the gas analyzers must be calibrated with a known gas concentration and periodically validated with the use of methanol flame.[1,7,11] Other factors which may also affect BEE at different levels would be thyroid and sexual hormones; growth; fever; sleep; metabolic stress; diseases; and others.[11]

Resting Energy Expenditure (REE)

The REE is a component of EE that is also measured by indirect calorimetry (IC). It can be 3-10% higher than BEE due to DIT and the influence of most recent PA.[10]

The procedures for measuring REE are very similar to those for BEE. The greatest difference between them is that in REE estimation the subjects have to be resting and fasting for shorter time, at least 30-minute rest and 3-hour fasting.[12]

Thermic effect of food or Diet-Induced Thermogenesis (DIT)

Diet-induced thermogenesis (DIT) is the EE component related to the energy required for the digestion, absorption, usage and storage of nutrients after food intake.[13,14] The DIT represents 5% to 15% of the TEE, and plays an important role in the regulation of energy balance and of body weight.[9,13] The thermic effect of food on TEE varies according to the type of macronutrient intake: 0-3% for lipids, 5-10% for carbohydrates and 20-30% for proteins.[13]

DIT is higher for proteins because their synthesis requires at least four high-energy phosphate bonds (ATP) per amino acid incorporated into a protein molecule, with the dispent of 0,75 kcal/g of synthesized protein, and the high metabolic cost of ureogenesis and gluconeogenesis.[9,15]

DIT can be divided into two distinct phases: the cephalic and the gastrointestinal phases. The first one is related to sympathetic nervous system action which is activated by food sensory properties, while the second is characterized by ATP consumption during the absorption and utilization of nutrients.[16]

There are some factors that may influence and modulate DIT, such as the stimulus to the autonomic nervous system,[13] hormones, diet palatability, PA, body composition, adiposity,[17] and the most important, diet composition.[18,19]

Physical activity (PA)

Physical activity (PA) represents the thermic effect of any movement that exceeds BEE,[10] which have a great variability inter and intra individual. In active individuals, the energy required for PA can corresponds as one to two times the basal energy expenditure while in sedentary individuals it can represent less than half of the BEE.[3]

Available methods for determination of energy expenditure

There are many methods for determining EE, but there is no consensus about which is the most accurate one for specific individuals or populations. The table I summarizes the advantages and limitations of each method for assessing energy expenditure.

Direct calorimetry (DC)

The directly determination of EE represents the measurement of heat exchange between body and environment. This method measures the sensible heat released by the body, as well as the water steam released through respiration and skin. It requires an isolation chamber, hermetically sealed, highly sophisticated and large enough to allow some degree of activity.[4,20] Although it is considered a gold standard method, it is not widely used due to its high complexity and cost, moreover, it requires the individual a confinement of 24 hours or more.[21]

Respiratory indirect calorimetry

Respiratory indirect calorimetry, or only indirect calorimetry (IC) as it is often known by most authors, is a noninvasive and very accurate method which has an error lower than 1%. It has high reproducibility and has being considered a gold standard method. This method allows estimating BEE and REE, and also allows identifying which energy substrates is predominantly being metabolized by body in a specific moment. It is based on the indirect measure of the heat expended by nutrients oxidation, which is estimated by monitoring oxygen consumption (O_2) and carbon dioxide production (CO_2) for a certain period of time.[12,22]

The calorimeter has a gas collector that adapts to subject, a canopy and a system that measures the volume and concentrations of O_2 and CO_2 minute by minute.[1,20,23,24] Through a unidirectional valve located in the ventilated canopy, the calorimeter collect and quantify the volume and concentration of O_2 inspired and of CO_2 expired by the subject.[20,23,24] After meeting the volumes, EE is calculated by the Weir formula and results are displayed in a *software* attached to the system.[1,20,23,24]

The procedures for using IC requires the same standardized protocol for determining BEE and REE, which includes environmental, individual, and technical aspects.[1] One advantage of using this method is the fact that it allows a short term measurement due to the scarce O_2 body reservoirs and the limited capacity of body of anaerobic ATP synthesis.[2,20] However, it is costly, relatively complex and requires trained personnel for its correct use.

Circulatory Indirect Calorimetry (CIC) or Fick Principle

REE can also be measured by CIC which is a practical and simple method. The CIC is commonly used to monitor O_2 consumption and EE when an intensive care unit (ICU) does not have IC and patients' nutritional support must be done with caution.[22,25]

This method is based on a thermo dilution technique that requires the insertion of a catheter (Swan-Ganz catheter) into the pulmonary artery for estimating cardiac output.[25] Besides, the use of this catheter allows analyzing the arterial and venous blood gasometry

Table I
Advantages and limitations of assessment methods of energy expenditure

Method	*Advantages*	*Limitations*
Direct calorimetry[4,20,21]	Highly sophisticated method, considered a gold standard for measuring the total energy expenditure, allows the subject some degree of activity.	High complexity method, high cost and requires the confinement of the subject for 24 hours or more.
Indirect calorimetry[2,12,20,22]	This method is considered a gold standard for measuring REE and BEE. It is a non-invasive method, reasonably accurate and has a high reproducibility. It also allows to quantify and to identify energy substrates oxidation. Allows short-term measurements of EE.	High cost, relatively complex. Requires trained personnel for its correct use.
Circulatory indirect calorimetry[9,22,25]	Practical and simple method. It can be used with caution when there is no other way to assess EE in critically ill patients who have already have a thermo-dilution catheter inserted.	It is Invasive. The use of the catheter may contribute to metabolic complications. It is based on instantaneous measurements. It is not equivalent to CI because it underestimates the REE.
Double labeled water[29,36]	This is a gold standard method which accuracy is 97-99% compared to CI. It measures precisely the TEE in free living subjects and because it uses deuterium (H2) and oxygen-18 (O18), it is a safe method.	It is costly and requires sophisticated equipments as well as trained personnel. It does not provide the information of energy expedited on physical activity neither it gives the information about the substrates oxidation.
Bioelectrical impedance analysis[37,38]	This is an affordable and non-invasive method. It quickly estimates the REE based on its estimation of body compartments including the body fluid distribution considering intra and extracellular spaces.	Several factors may influence its results such as hydration state of the subject, prandial/fasting state, exercises, diuretics use, menstrual period, age, ethnicity, body shape or healthy and nutritional condition.
Sensor of heat and movement[41,42,43]	Easy and practical use device that estimates EE.	Studies indicate that the device needs adjusts, especially the equations for obese subjects.
Physical activities records[45,46]	• Low cost method that estimates EE from an extremely detailed registry off all physical activity perform daily. • Wide variety of types of activities listed. The list is frequently updated which allows the inclusion or the correction of typical activities from specific regions or country.	• The comparison of results between different studies is limited due to various existing codes for activities. • The estimated EE does not take into account inter-individual differences which may affect the energetic cost of a movement.
Dietary questionnaires[49,50]	Simple and affordable method. It can be viable if properly used.	• Subjects can underreport their food intake, which will reduce de accuracy of the method. • This method is valid only for subjects with stable weight, so in a energy balance equilibrium. • Bias can occur because of interferences from the interviewer as well as bias inherent in the chosen method.
Predictive equations[52,53]	Simple, fast and affordable method. It can be viable if properly used.	It can overestimate or underestimate the GEB GET of subjects of the same population.

which is based on the measurement of the serum hemoglobin concentration and its O_2 saturation. It is possible to calculate O_2 consumption through the artero-venous difference of the O_2 content multiplied by the cardiac output.[22] Thus, REE can be estimated based on the Fick equation. However CIC requires a surgical procedure to insert the catheter, so that this method should only be used when critical patients has already had a catheter inserted in their artery for hemodynamic control.[26]

Similarly to other method, CIC also has some limitations as it is invasive and the usage of catheters may contribute for complications. Furthermore, it is based on instantaneous measures[22], thus extreme values of cardiac output decrease the specificity of thermo dilution, as well as the omission of the O_2 dissolved in the plasma and exclusion of the pulmonary O_2 mixed to the O_2 coming from other organs can decrease its specificity.[9,25]

Raurish and Ibanez[27] evaluated the EE of 15 critically ill patients on mechanical ventilation through the IC and CIC, and they found no significant difference between these two methods. Despite the lower reproducibility of Fick compared to IC, they concluded that both methods can be used considering the clinical point of view. However, Ogawa et al.[28] evaluated the EE of 40 critically ill patients in ICU and although they did not find a significant difference between IC and CIC, the use of Fick equation on CIC underestimated the absolute values. Similarly, in another study with 36 patients on mechanical ventilation and parenteral nutrition, the Fick equation underestimated significantly REE compared to IC, and these methods had a poor correlation ($r = 0.31$).[25]

The CIC can be a useful tool if used with caution when there is no other way to assess the EE of critically ill patients who already have a thermo dilution catheter inserted. However, it is important to emphasize that this method is not equivalent to IC, because it underestimates REE values.

Doubly Labeled Water (DLW)

The DLW is an accurate and precise method for measuring TEE of subjects who are not in confinement, and with no change their routine, it also useful for measuring TEE over some days or weeks. It is considered safe because uses deuterium (H^2) and oxygen-18 (O^{18}), non-radioactive elements which are naturally found in human body. The DLW accuracy is 97-99% compared to IC, and it is also considered a gold standard.[29]

This method is based on the principle of isotope dilution. Subject ingests those elements at a known concentration and volume (C1 and V1) that diffuses throughout the body fluid (which has a different volume (V2), and the new concentration (C2) can be calculated by the formula C1 x V1= C2 x V2.[30] Thus, the DLW method considers that the O_2 *turnover* is determined by the body water flow and the inspired O_2 and expired CO_2, while the H_2 *turnover* is determined exclusively by the water flow through the body.[31]

To measure the total body water, a pre-established volume and concentration of the H^2 and O^{18} isotope is orally administered, which diffuses throughout the body over 2 to 6 hours. As the energy is spent by the body, CO_2 and water[30,32] are produced. The CO_2 is eliminated by the lungs, and the water, by lungs, skin and urine.[33] The H^2 and O^{18} disappearance rate is determined by measuring repeatedly their concentrations in the body fluids (saliva, urine or blood). The difference between the disappearance rate of the two isotopes is used to estimate the CO_2 production rate and, thus, determine the EE, based on the equation of Weir.[30,32]

Many studies have used DLW to validate other methods.[34,35] However, this method is expensive, requires sophisticated equipments and trained personnel. Besides, it does not provide information of performed physical activity and substrate oxidation.[36]

Bioelectrical Impedance Analysis (BIA)

BIA is a fast and noninvasive method that estimates body composition, including the distribution of body fluids of intra and extracellular spaces. It also estimates REE by predictive equations based on the lean body mass.

This method can be performed by devices with 2, 4 or 8 electrodes. It is based on the principle that tissues have different electrical proprieties such as large at small opposition to the flow of an electric current. Lean tissues have a high conductivity of electric current, due to the large amount of water and electrolytes. On the other hand, adipose tissue (fat body mass), bones and skin have low conductivity.[37] This method mesures the level of resistance (measure of pure opposition to the electric current flow through the body) and reactance (opposition to the electric current flow caused by the capacitance produced by the cell membrane) of the body to a low intensity electric current. By doing so, the analyzer evaluates the total body water, assuming a constant hydration, predicts the amount of lean body mass and estimates REE based on this value.

The usage of BIA has some limitations related to individuals' hydration status. In case of hyperhydration or fluid retention, both lean body mass and REE will be overestimated.[38] Besides, other factors may affect the results of BIA, such as diet, physical activity, use of diuretics, menstrual period, age, ethnic group, body shape or clinical and nutritional status.[37,38]

Korth et al.[39] reported that EE estimation through equations based on the lean body mass may be more accurate than those that the estimation is mainly based on body weight, assuming that the lean body mass is the responsible for 60-70% of the REE variation.

Strain et al.[40] studied severe obese adults and evaluated body composition by BIA and DLW, and EE by BIA and IC. The BIA and DLW methods showed high correlation ($r = 0,92$) for estimation of total body water and lean body mass, as well as equivalence by the Bland and Altman analysis. The REE values obtained by BIA and IC did not differ significantly, and showed high correlation ($r = 0.88$). Therefore, those authors suggested the use of bipolar BIA to estimate the body composition and REE of obese individuals.[40] However, for normal weight and overweight individuals, Oliveira et al.[8] found that comparing to IC, tetrapolar BIA significantly underestimated the BEE of healthy women, but the same did not occur to men.

Korth et al.[39] evaluated lean body mass of 104 normal weight adults by different methods, and the EE by IC and equations which consider body composition. Lean body mass estimated by those several methods did not differ significantly, and all methods were highly correlated ($r = 0.95$-0.99). The variations observed for REE estimated by equations were better explained by the differences on their mathematical model and data that used in their determination than the method for body composition itself. Those authors conclude that there is no advantage in using a more accurate method for body composition[39] when the objective is to estimate the EE based on the lean body mass. But it is important to use the appropriate equation for a specific population.

The REE estimation by BIA is valid for clinical practice, when the right protocol for this method is respected, mainly because it is a noninvasive and less expensive when compared to IC.

Sensor of heat and movement

The heat and movement sensor *SenseWear Pro 2 Armband* (SWA; BodyMedia, Inc., Pittsburgh, PA) is a practical device recently developed.[41] This device estimates the EE through equations developed by the manufacturer which considers several parameters (heat flow, accelerometer, galvanic skin response, skin temperature, temperature close to the body) and characteristics of each subject (sex, age, height, body weight, right-handed or left-handed and smoker and non-smoker).[42,43]

St-Onge et al.[43] measured the TEE and EE considering physical activity of individuals in free-living conditions, by using *Armband* and compared the results with the DLW technique. The authors observed a slight underestimation in the TEE (117 kcal/day) compared to the DLW, and a good correlation between these methods ($r = 0.81$; $P < 0.01$). On the other hand, the EE considering physical activity estimated by *Armband*, were less accurate, showing a 218 kcal/day underestimation compared to the DLW and both had a correlation of 46% ($P < 0.01$). However, it is well known that EE considering physical activity measured by DLW is obtained from a derived value. So that there is a potential error associated with the addition or subtraction of other components (BEE and DIT). Therefore, it is unclear if the lower accuracy in the determination of the EE considering physical activity is due to a limitation of *Armband* to capture different types of physical activity, or the inaccuracy of DLW for physical activity.[43]

Papazouglou et al.[41] tested the reliability and validity of the *SenseWear Pro 2 Armband,* during rest and exercise compared to the IC in obese people. They found poor accuracy of *Armband* in the measurement of the EE, both at rest and in exercise, mainly in obese with higher EE values. According to those authors, it is necessary to incorporate new algorithms specific for obesity to the software in order to improve its accuracy. Similarly, a low concordance between these two methods to estimate the REE was found by Bertoli et al.[44] in a study carried out in 169 adults of which 48% were obese. The device significantly overestimated the REE compared to IC for both gender. Through the Bland Altman analysis, the authors concluded that these methods are not equivalent. Thus, until this moment, studies showed that the sensor of heat and movement device needs adjustments for estimating more accurately the EE.

Physical Activity Records

Physical activity records estimates EE from a very detailed report of all physical activities (PA) performed daily. Most of the times, it is considered a complementary method, due to its subjectivity.[45]

The PA data are encoded according to its type and intensity and is used to describe a population physical activity pattern and to study its determinants. Moreover, through these records it is possible to investigate the relationships between PA, health and disease. It also can be used to evaluated the contribution of several types of PA to TEE, providing additional categories for the type of activities routinely performed.[46]

Among the lists of codes that exist, there is The Compendium of Physical Activity, published in 1993.[47] The compendium consists of five-digit codes that represent specific activities carried out in several situations with their respective levels of intensity expressed in metabolic equivalent units (METs).[45]

The EE is expressed in $kcal.kg^{-1}$ of body $weight.h^{-1}$; $kcal.min^{-1}$; $kcal.h^{-1}$ or kcal.24 h^{-1}. It is possible to estimate individual EE (kcal) by multiplying body weight (kg) by the duration of the PA (minutes) and by MET value obtained in the compendium.[45]

Generally, it is assumed that the REE of any individual is equal to 1 MET. Therefore, in this case, the EE with physical activities must be expressed in resting METs. The steps for calculating EE is showed below:

1,000 ml O_2 = 5 kcal.
200 ml O_2 = 1 kcal.
1 MET = 3.5 mL O_2/ kg /min (VO_2 at rest).
3.5 mL O_2/kg /min : 200 ml O_2 = 0.0175/kg/min or
Equation: 0.0175 x weight (kg) x METs = kcal/min.

The O_2 consumption varies with age resulting in different values of METs. For example, for teenagers between 16 and 17 years, 1 MET corresponds to 4.0 mL O_2/kg/min. For individuals between 12 and 13 years of age, 1 MET corresponds to 4.58 mL O_2/kg/min and for children below 5 years of age is 7.0 mL O_2/kg/min.[48]

Conway et al.[35] in a study with 24 adult men with Body Mass Index (BMI) of 25,1 ± 0,5 kg/m^2, compared the TEE measured by DLW, with 7-day physical activities records and with a 7-day physical activity recalls. They found a good correlation between the physical activity records and the DLW, while the physical activities recalls had a limited application in estimating daily energy due to its overestimation of 30,6%.[35]

However, the major problem of this method is that different authors use different codes for the same type and intensity of physical activities. Although there are similarities in some publications, the comparison of results among the several studies is limited.[45] Another important limitation is that EE estimated through this method does not consider the individuals' differences that can influence the energy cost of the movement. Therefore, a correction factor would be necessary for individual adjustments considering gender, age, physiological status, body composition, and others, which does not exist yet.[45]

On the other hand, the major advantage of using this method is the wide variety of activities listed that have constant updates because of studies that include this method, which allow the inclusion or correction of specific activities to a particular region or country. When using this method, it is recommended to record physical activity instead of a recall.

Food Intake Questionnaires

The use of food intake questionnaires to estimate TEE has been widely discussed, mainly because people usually under-report their intake.[49,50] Furthermore, the use of these methods would only be valid for individuals with stable weight which means in an energy balance.

A study carried out by Tooze et al.[34] compared the TEE obtained by DLW and by evaluating caloric intake by a food frequency questionnaire and 24-hour recalls. This study involved 484 subjects between 40 and 69 years old. Authors notice that, for men the TEE was underestimated in 11% by 24-hour recalls and 30% by food frequency questionnaire and for women, these underestimated in 17% and 34%, respectively, when compared to the TEE measured by DLW.[34] The use of a 7-day food record to estimate EE was tested in elderly people by Goris et al.[51] by comparing the EE estimated through the food records with the results of DLW and with EE estimated by IC associated with an accelerometer. The results showed that food records underestimated the EE in 18%.

Therefore, the methods of dietary intake may provide an estimate of the calorie intake and indirectly from the TEE when subject is in an energy balance state. However, it should be interpreted with caution, due to the underestimation or overestimation of food intakes reported by individuals, as well as errors inherent to the interviewers. The estimation of EE by a food intake questionnaire must be used in conjunction with other methods of assessing the TEE in order to obtain a more reliable result.

Predictive Equations

Several predictive equations for EE determination can be found in literature.[52] Most of them were developed from groups of healthy individuals by using regression analysis involving weight, height, gender and age as independent variables, and the measurement of EE by IC as dependent variable.[52,53]

The first ones were published in 1919 by Harris and Benedict (table II) and they are based on data from a normal weight population.[54] Therefore, these equations have shown an underestimation of the REE of obese individuals when using the ideal body weight and an overestimation when using the actual body weight.[55,56] On the other hand, when adjusted weight is used it can reduce the risk of overestimation, but it increases the maximum error of underestimation. Carrasco et al.[55] notice that the Harris and Benedict equation using actual body weight has a 64% of agreement with the IC, while using the adjusted weight it dropped to 26%, considering severe and morbid obese women.

Based on a compilation of BEE data of 114 studies, Schofield[57] developed predictive equations (table II), that were considered appropriate for international use. These were later adopted by FAO/WHO/ UNU (1985)[58] after few modifications based on an expanded database. These equations were mainly based on information from Europeans and north Americans.[12,57]

According to the study of Oliveira et al.,[8] which evaluated healthy men and women, a significant underestimation among the predictive equation of FAO/WHO/UNU of 1985 and 2001 compared to IC was observed for both genders. However, in Cuerda-Compés et al. study[59] it was verified an overestimation of 18% of BEE by the use of FAO/1985 equations compared to IC, consequently leading to an overestimation of TEE.

Henry and Rees[60] proposed new equations (table II), based on the evidences that Schofield's equations overestimated BEE of subjects who live in tropics region. Although Henry and Rees equations provide lower values of estimated BEE compared to those obtained from FAO/WHO/UNU (1985), the values estimated by them still seem to overestimate BEE in tropical regions.[12] Cruz et al.[61] evaluated the BEE of female university students of Rio de Janeiro, Brazil and found an overestimation of 7.2% in BEE obtained from Henry & Rees' equation compared to the results of IC. However, the superestimation observed for Henry & Rees' equation was lower than those 12.5% of superestimation for equation from FAO/WHO/UNU compared to IC.

In 1989, Ireton-Jones et al., developed an equation (table II) to estimate the energy requirements of obese patients. Alves et al.,[62] in a study with overweight and obese individuals (using or not mechanic ventilation), found correlation between EE estimated by Ireton-Jones' equation and the EE measured by IC. However, it was observed a wide variability for maximum and minimum values. Therefore, these authors did not recommend the use of these equations for hospitalized obese patients.

Another existing equation is the one developed by Mifflin-st Jeor[63] (table II), which was derived from a

Table II
Predictive equations for basal energy expenditure

Author	*Age (years)*	*Sex*	*Equation*
Harris and Benedict (1919)[54] in kcal/day	15-74	Male	66.4730 + 13.7516(W) + 5.0033(H) – 6.7550(A)
	15-74	Female	655.0955 + 9.5634(W) + 1.8496(H) – 4.6756(A)
Schofield (1985)[57] in MJ/day	10-17	Male	0.074(W) + 2.754
		Female	0.056(W) + 2.898
	18-29	Male	0.063(W) + 2.896
		Female	0.062(W) + 2.036
	30-59	Male	0.048(W) + 3.653
		Female	0.034(W) + 3.538
	> = 60	Male	0.049(W) + 2.459
		Female	0.038(W) + 2.755
FAO/ WHO/ UNU (1985)[58] in MJ/day	10-17	Male	0.0732(W) + 2.72
		Female	0.0510(W) + 3.12
	18-29	Male	0.0640(W) + 2.84
		Female	0.0615(W) + 2.08
	30-60	Male	0.0485(W) + 3.67
		Female	0.0364(W) + 3.47
	> = 60	Male	0.0565(W) + 2.04
		Female	0.0439(W) + 2.49
Henry and Rees (1991)[60] in MJ/day	10-17	Male	0.084(W) + 2.122
		Female	0.047(W) + 2.951
	18-29	Male	0.056(W) + 2.800
		Female	0.048(W) + 2.562
	30-59	Male	0.046(W) + 3.160
		Female	0.048(W) + 2.448
**Ireton-Jones (1989)[68] in kcal/day*			*Spontaneous Breathing*
		Male	629 – (11 x H) + (25 x W) – 609 x O
		Female	629 – (11 x H) + (25 x W) – 609 x O
			Mechanical Ventilation
		Male	606 + (9 x W) – (12 x H) + (400 x MV) + 1,444
		Female	(9 x W) – (12 x H) + (400 x MV) + 1,444
Mifflin-St Jeor (1990)[63] in kcal/day	19-78	Male	10 x W + 6,25 x H – 5 x A + 5
	19-78	Female	10 x W + 6,25 x H – 5 x A – 161
Owen (1986)[66] and Owen (1987)[65]	18-65	Female	795 + 7.18 × W (kcal/day)
	18-65	Male	879 + 10.2 x W (kcal/day)

Adapted from Oliveira et al. (2010)[52]. Abbreviations: W= body weight (kg); H= Height (cm); A= Age (years); O = obesity; O absent = 0; O present = 1; MV = Mechanical Ventilation; MV absent = 0; MV present = 1. * Age group is not available. NOTE: to convert MJ into kcal, multiply the result by 239.

sample of normal weight, overweight, obese and very obese individuals. The study does not specify the ethnicity of the individuals and a limitation is that the representation of elderly people was small.[63]

In a validation study of 27 equations for overweight and obese people from the United States and The Netherlands, it was showed that the Mifflin's equation have the best accuracy in the estimation of REE (79%) for men and women from the United States compared to the values obtained by IC. For the overweight sample from The Netherlands, the FAO/UNU/WHO equation showed the best accuracy in predicting REE (68%) compared to IC.[64] Thus, it seems that the geographic location, the body composition and the ethnicity of individuals are factors that must always be considered while choosing the method for REE estimation.

Owen et al.[65] and Owen et al.[66] developed REE equations based on women and men data (table II). The sample included whites, blacks and Asian men, with BMI ranged from normal weight to obesity. Again, the elderly were not well represented. The female sample included extremely obese, obese, normal weight and malnourished women. Data from athletes and elderly women were excluded. Additionally, there is no information about the ethnicity of these women.

Fett et al.[4] evaluated REE measured by IC compared to that estimated by equations of sedentary women, most of them with overweight. They showed that the Owen equation was inadequate for obese women because this equation underestimated REE in approximately 16%. Similarly, Wilms et al.,[67] evaluated the accuracy of 11 predictive equations for REE in obese women. It was

Table III
Predictive equations for total energy expenditure for adults older than 19 years old according to nutritional status

	Men	*Women*
Normal weight (a)	EER = 662 – 9.53 x A + PA x (15.91 x W + 539.6 x H) PA = 1.00 if sedentary PA = 1.11 if low active PA = 1.25 if active PA = 1.48 if very active	EER = 354 – 6.91 x A + PA x (9.36 x W + 726 x H) PA = 1.00 if sedentary PA = 1.12 if low active PA = 1.27 if active PA = 1.45 if very active
Overweight obesity (b)	EER = 1086 – 10.1 x A + PA x (13.7 x W + 416 x H) PA = 1.00 if sedentary PA = 1.12 if low active PA = 1.29 if active PA = 1.59 if very active	EER = 448 – 7.95 x A + PA x (11.4 x W + 619 x H) PA = 1.00 if sedentary PA = 1.16 if low active PA = 1.27 if active PA = 1.44 if very active
Normal Weight Overweight Obesity (c)	EER = 864 – 9.72 x A + PA x (14.2 x W + 503 x H) PA = 1.00 if sedentary PA = 1.12 if low active PA = 1.27 if active PA = 1.54 if very active	EER = 387 – 7.31 x A + PA x (10.9 x W + 660.7 x H) PA = 1.00 if sedentary PA = 1.14 if low active PA = 1.27 if active PA = 1.45 if very active

Source: Oliveira et al. (2010) and IOM (2002)[33]. Abbreviations: EER = *estimated energy requirement*; W= body weight (kg); H = height (m); A = age (years); PA = physical activity; Sedentary if the category physical activity level (PAL) is estimated to be ^{3}1.0 < 1.4; low active if PAL is estimated to be ^{3}1.4 < 1.6; Active if PAL is estimated to be ^{3}1.6 < 1.9; Very active if PAL is estimated to be ^{3}1.9 < 2.5.
if PAL is estimated to be ≥1.0 < 1.4.

observed that the Owen equation showed one of the highest underestimation of REE (-317.6 ± 221.0 kcal/day) compared to values obtained by using IC.

In 2002, new equations for estimated energy requirement (EER) were published by the *Institute of Medicine* (IOM),[3] in which authors developed equations for normal weight individuals (BMI from 18,5 to 25 kg/m^2), from 0 to 100 years of age based on EE data measured by the DLW method (table III (a)). Considering that EERs were defined to maintain the health state for a long period they are not applicable to overweight or obese people so that, new equations were developed (table III (b)). Moreover, combined equations for normal weight, overweight or obese individuals were proposed (table III (c)).

According to the results of Oliveira et al.,[8] the EER has a lower overestimation compared to the 1985 and 2001 FAO/WHO/UNU's predictive equations. This results are probably due to the fact that IOM's equations had been based in the DLW method, and also because FAO equations were based on data from mainly North American and European individuals with different pattern of food intake, physical activity level, physical characteristics and climatic conditions from other populations.

Conclusion

After reviewing the components of the energy metabolism, as well as their assessment methods for humans, it is possible to verify the existence of several factors that may affect its determination. Yet, even the most sophisticated methods can not accurately reproduce the number and the complexity of the activities performed by individuals daily.

Methods to estimate the energy expenditure, such as respiratory indirect calorimetry and doubly labeled water have a higher accuracy, but they are more expensive and require trained personnel. Bioelectrical impedance is a practical and noninvasive method that provides good results when the right protocol is followed. The use of predictive equations, a simple, fast and low cost method, can be viable if correctly used. These equations have some limitations, but are also the starting point to determining individual energy requirements. It is important to point out that the average values of the BEE estimated by equations can be overestimated or underestimated in individuals of the same population.

The evaluation of the energy expenditure of critically ill patients hospitalized is still a challenge when the institution does not have the equipment for IC. The suitability of using the circulatory indirect calorimetry method should be discussed case by case. Measuring TEE and the energy used during a physical activity is also a challenging, since heat and movement sensor devices are not yet validated. The use of questionnaires to evaluate the EE, based on the daily activities or on food intake is not reliable, due to over or under-reports.

Therefore, analysis of a sample of people from a particular country or region, when extrapolated for other populations, should be evaluated with caution in order to reduce bias since individuals from the same population may have different energy expenditure due to the complexity of multiple factors that affect it. Thereby, studies for the mayor countries population are necessary, with specific equations focused on the context and needs of the different regions of the country.

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