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original article

Validation of predictive equations for basal metabolic rate in eutrophic and obese subjects

Validação de equações de predição da taxa metabólica basal em sujeitos eutróficos e obesos

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Abstract – Prediction equations for basal metabolic rate (BMR) continue to be the most common clinical tool for diet prescription; however, the values estimated may differ from those measured by indirect calorimetry (IC), especially in obese subjects. The objective of this study was to determine the BMR of obese and eutrophic subjects by IC, and to compare the results obtained with those estimated by prediction equations in order to identify whether differences exist between predicted values and those measured by IC. Forty men aged 18 to 30 years were evaluated; of these, 20 were grade 1 obese and 20 were eutrophic. The agreement between the prediction equations and IC was evaluated using Bland-Altman (1986) plots. The results showed a variation between the prediction equations and IC of -19.6% to -91% in obese subjects and of 4.2% to 4.4% in eutrophic subjects. In both groups, the Mifflin-St. Jeor equation (1990) was the most accurate, with a difference of -9.1% compared to IC in obese subjects and of 0.9% in eutrophic subjects. This study indicates the Mifflin-St. Jeor equation to be the most adequate to estimate BMR. However, it is important to measure the BMR of obese subjects more accurately and safely in order to establish the best intervention based on physical exercise and healthy eating.

Key words: Basal metabolism; Indirect calorimetry; Obesity.

Resumo – *Equações de predição para taxa metabólica basal (TMB) são amplamente utilizadas para prescrição dietética, porém podem apresentar valores diferentes daqueles medidos por calorimetria indireta (CI), principalmente, em indivíduos obesos. O objetivo deste estudo foi verificar os valores de TMB por meio da CI em indivíduos obesos de grau I e eutróficos e comparar com os resultados obtidos pelas equações de predição, a fim de identificar se existe discrepância nos valores obtidos entre o medido pela CI e o estimado pelas equações. O estudo avaliou 40 homens entre 18 e 30 anos, sendo 20 eutróficos e 20 obesos grau I. Foi verificado o grau de concordância entre as equações e CI por meio da metodologia sugerida por Bland e Altman (1986). Os resultados mostram a variação entre os métodos de predição de -19,6% a -9,1%, quando comparadas a CI nos sujeitos obesos, e de -4,2% a 4,4% nos eutróficos. Em ambos os grupos, a equação que mais se aproxima da estimativa real é a de Miflin St. Jeor (1990), com -9,1% de diferença da CI nos sujeitos obesos e 0,9% nos eutróficos. Desta forma, o presente estudo indica a utilização da equação de Mifflin St. Jeor (1990) para estimar a TMB. Entretanto, é fundamental que se consiga medir a TMB de sujeitos obesos de maneira mais precisa e segura, para melhor conduzir a intervenção baseada em exercícios físicos e boa alimentação.*

Palavras-chave: *Calorimetria indireta; Metabolismo basal; Obesidade.*

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INTRODUCTION

Obesity has become a public health problem since it is strongly associated with an increase in morbidity and mortality[1]. Obesity rates have increased exponentially over the years, with grade 1 obesity (BMI: 30 to 35 kg/m^2) being the most frequent[2].

An increase in body weight is generally the result of an energy imbalance caused by increased food intake and a concomitant reduction in energy expenditure by physical activity[3]. Thus, interventions designed to establish an equilibrated energy balance, such as dietary restriction and physical exercise, are of the utmost importance for the prevention of obesity[4]. In this respect, to balance energy intake, it is essential that the consumption of dietary nutrients is based on the estimation of individual energy requirements[5]. An inexpensive and practical method to obtain estimates of energy intake is the calculation of total energy expenditure, which takes into consideration the basal metabolic rate (BMR), thermic effect of food, and physical activity-related energy expenditure[6]. The BMR refers to the amount of energy necessary to maintain vital functions of the organism[7], which can reach 50% of total energy expenditure in physically active individuals and 70% in sedentary individuals[8,9].

The BMR can be estimated by indirect calorimetry (IC) or by means of predictive equations. In the case of IC, the metabolic rate is determined based on the consumption of oxygen (O_2) and the production of carbon dioxide (CO_2). Assuming that all O_2 consumed is used for the oxidation of macronutrients and all CO_2 produced is captured during the test, it becomes possible to calculate the subject's metabolic rate[10]. Although the method is extremely valid, IC has a high cost, is time consuming and requires specialized personnel for its execution[11]. For these reasons, diet prescription is generally based on prediction equations[12].

Different equations using anthropometric measures have been developed since the 19th century to estimate the BMR in different populations[13]. Most of these equations are old and can often not be applied to the current population in view of the exponential increase in physical inactivity and obesity, increasing the diversity in body composition and, consequently, in energy utilization[14]. Prediction equations generally take into consideration anthropometric variables such as body weight and height, as well as the age of the subjects. As a consequence, these equations do not seem to permit a valid estimation of BMR in subjects with high grades of obesity, normally overestimating it[15-18]. In contrast, in subjects with grade 1 obesity, the values estimated with these equations seem to be closer to those obtained by direct assessment[19], but few studies involving this population have been conducted. Since grade 1 obesity is the most frequent grade and since it does not present a major discrepancy in body weight, the equations should predict BMR more accurately, contributing to diet prescription for weight loss.

Since little is known about the relationship between BMR obtained with predictive equations and by IC in grade 1 obese subjects, the objective of the present study was to evaluate the validity of BMR prediction equations by IC in eutrophic and grade 1 obese subjects, and to compare the results with those obtained with the equations of Harris and Benedict[13], Schofield[20], FAO/WHO/UNU[8], Henry and Rees[21] and Mifflin-St. Jeor[22] in order to determine whether differences exist in the predicted values and those measured by IC.

METHODOLOGICAL PROCEDURES

The sample consisted of 40 men aged 18 to 30 years who were divided into two groups: 20 subjects with grade 1 obesity (30 to 35 kg/m^2) and 20 eutrophic subjects (18.5 to 25 kg/m^2). Altman's nomogram (1982) was used for the calculation of sample size, assuming a power of 80% and a 95% confidence interval. The calculated sample size was 20 subjects per group, for a total of 40 volunteers. The participants were recruited by dissemination of the study at university centers in Porto Alegre, at the outpatient clinic of the University Hospital of Porto Alegre (Hospital de Clínicas de Porto Alegre - HCPA), and in the local media. All subjects agreed to participate in the study by signing the free informed consent form. The study was approved by the Ethics Committee of HCPA (Protocol 110649).

Determination of the basal metabolic rate

The protocol consisted of 10 min of rest on a gurney in dorsal decubitus, followed by 30 min of collection of exhaled gases using a mask and a coupled collection device. A computerized gas analyzer (MedGraphics Cardiorespiratory Diagnostic Systems, model CPX-D) was used for the determination of VO_2 and VCO_2. A breath-by-breath collection system was used.

For calibration of the equipment, the volume of the pneumotachograph was first calibrated electronically by the system, followed by calibration of the collector plates using a known gas concentration. This process was repeated for each test to standardize the measurement[23].

The first 10 min of gas collection were excluded from the analysis; thus, VO_2 and VCO_2 (l/min) obtained during the final 20 min of each collection (mean value of the period) were used for the calculation of BMR. The equation proposed by Weir (1949) was used to obtain values in kcal/min, which does not require the use of protein metabolism by incorporating a correction factor: $[(3.9 \times VO_2) + (1.1 \times VCO_2)]$. Finally, the result in kcal/min was multiplied by 1,440 min to obtain the value for 24 hours. The subjects were asked not to perform any type of physical activity of moderate or high intensity during the 24 hours preceding the test, and not to consume alcohol, caffein or any type of medication during this period. Additionally, the subjects were instructed to fast for 12 hours prior to the test, permitting the *ad libitum* intake of water, and to have a good night sleep of at least 8 hours. Finally, the subjects should preferably come to the test site using a motor vehicle to avoid energy expenditure before the determination of BMR. All tests were performed between 7:30 and 8:30

am in a temperature-controlled (20° to 25°C) and sound-controlled room under low luminosity[19].

Equations used for BMR prediction

The BMR measured by IC was compared to the values obtained with the most commonly used prediction equations (kcal/day, in 24 hours). The equations of Harris and Benedict[13] and Mifflin-St. Jeor[22] use body weight in kg, height in cm, and age in years. In contrast, the equations of Schofield[20], FAO/WHO/UNU[8] and Henry and Rees[21] use only body weight in kg.

Table 1. Prediction equations for basal metabolic rate.

Authors	Equation
Harris and Benedict[13]	66.47 + (13.75 x BW) + (5.00 x height) - (6.76 x age)
Schofield[20]: 18-30 years	[(0.063 x BW + 2.896] x 239)]
FAO/WHO/UNU[8]: 18-30 years	[(15.3 x BW + 679)]
Henry and Rees[21]: 18-30 years	[(0.056 x BW + 2.800)] x 239)]
Mifflin-St. Jeor[22]	(9.99 x BW) + (6.25 x height) – (4.92 x age) + 5

BW: body weight.

Body composition

Skinfolds were measured with a skinfold caliper (Cescorf, Porto Alegre, Brazil). Bone diameters were determined with a caliper and anthropometer (Cescorf, Porto Alegre, Brazil). Circumferences were measured with an anthropometric metal tape measure (Sanny, São Bernardo do Campo, São Paulo, Brazil). Body weight and height were measured with a scale and stadiometer (model OS-180, Urano, Canoas, Rio Grande do Sul, Brazil). The marking of the anatomical sites and measurement technique of skinfolds followed the standards of the International Society for the Advancement of Kinanthropometry (ISAK)[24]. Body composition was calculated using a five-component method[24].

Statistical analysis

The data were analyzed using the SPSS 19.0 package. The Shapiro-Wilk test was used to determine whether the data showed a normal distribution. Differences between BMR measurements obtained by IC and with the prediction equations were determined by the Student *t*-test for independent samples. The results are reported as the mean ± standard deviation (SD). A p value <0.05 was considered to be significant. The method suggested by Bland and Altman (1986) was used to plot the agreement between a) IC versus Harris and Benedict, b) IC versus Schofield, c) IC versus FAO/WHO/UNU, d) IC versus Henry and Rees, and e) IC versus Mifflin-St. Jeor. The Bland–Altman method calculates the mean difference between two methods of measurement (the bias), and 95% limits of agreement as the mean difference (±1.96 SD). The values are expressed as absolute value (kcal) and percentage (%).

RESULTS

The characteristics of the sample are shown in Table 2 and are reported as the mean ± standard deviation. There was a significant difference between groups for body weight (kg), fat mass (kg), muscle mass (kg), BMI (kg/m²) and all BMR prediction equations, with the observation of significantly higher values in obese subjects. No significant difference in the IC result was observed between groups. A significant difference between IC and the equations of Harris and Benedict[13], Schofield[20], FAO/WHO/ONU[8] and Henry and Rees[21] was only observed in obese subjects.

Table 2. Characteristics of the sample, measured basal metabolic rate (BMR), and BMR estimated with the prediction equations.

	Eutrophic (n=20)	Obese (n=20)
Age (years)	23.43 ± 2.92	24.87 ± 3.21
Height (m)	1.74 ± 0.04	1.74 ± 0.06
Body weight (kg)	73.02 ± 3.33	96.83 ± 10.88*
Fat mass (kg)	21.32 ± 3.92	31.11 ± 4.84*
Muscle mass (kg)	32.50 ± 4.96	40.64 ± 5.71*
BMI (kg/m²)	24.22 ± 1.84	31.58 ± 2.09*
Indirect calorimetry (kcal/day)	1723.95 ± 154.73	1791.70 ± 299.27
BMR (kcal/day) Schofield	1791.68 ± 125.56	2150.11 ± 163.86*#
BMR (kcal/day) Harris and Benedict	1780.65 ± 135.07	2104.46 ± 187.62*#
BMR (kcal/day) FAO/WHO/ONU	1796.28 ± 127.59	2160.49 ± 166.51*#
BMR (kcal/day) Henry and Rees	1646.56 ± 111.61	1965.17 ± 145.65*#
BMR (kcal/day) Mifflin-St. Jeor	1704.80 ± 112.82	1943.37 ± 151.08*

*p<0.05, significant difference between groups. #p<0.05, significant intragroup difference between indirect calorimetry and prediction equations.

Figures 1 and 2 show the Bland-Altman plots comparing BMR measurements obtained by IC and with the prediction equations in obese and eutrophic subjects, respectively. In obese subjects, the FAO/WHO/UNU[8] equation was the equation that most overestimated BMR, with a mean difference of -19.6% (-368.79 kcal/day). In contrast, the Mifflin-St. Jeor[22] equation was the most accurate compared to IC, with a difference of -9.1% (-151.67 kcal/day), followed by the Henry and Rees equation[21], with a difference of -10.3% (-173.47 kcal/day). Similar values were obtained for eutrophic subjects. In this group, the Mifflin-St. Jeor equation[22] was also the most accurate compared to IC, with a difference of 0.9% (19.15 kcal/day), underestimating BMR. On the other hand, the equation of Henry and Rees[21] provided the least accurate value in these subjects, with a difference of 4.4% (77.39 kcal/day) compared to IC.

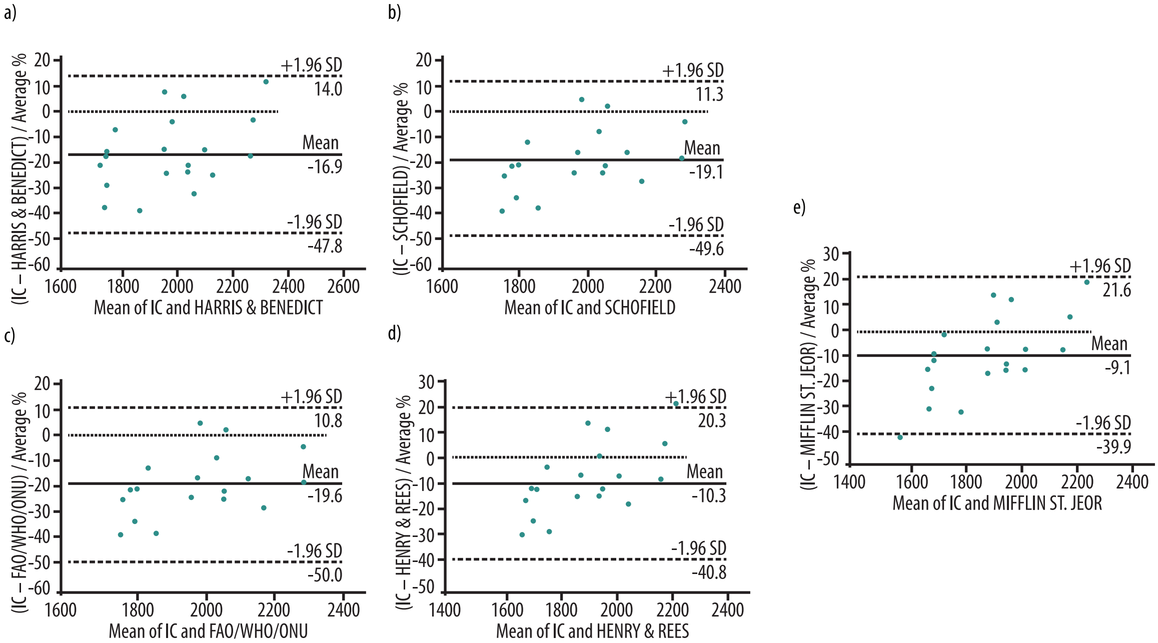

Figure 1. Bland-Altman plots comparing indirect calorimetry (IC) and the following prediction equations for basal metabolic rate in obese subjects: a) Harris and Benedict[13], b) Schofield[20], c) FAO/WHO/UNU[8], d) Henry and Rees[21], and e) Mifflin-St. Jeor[22].

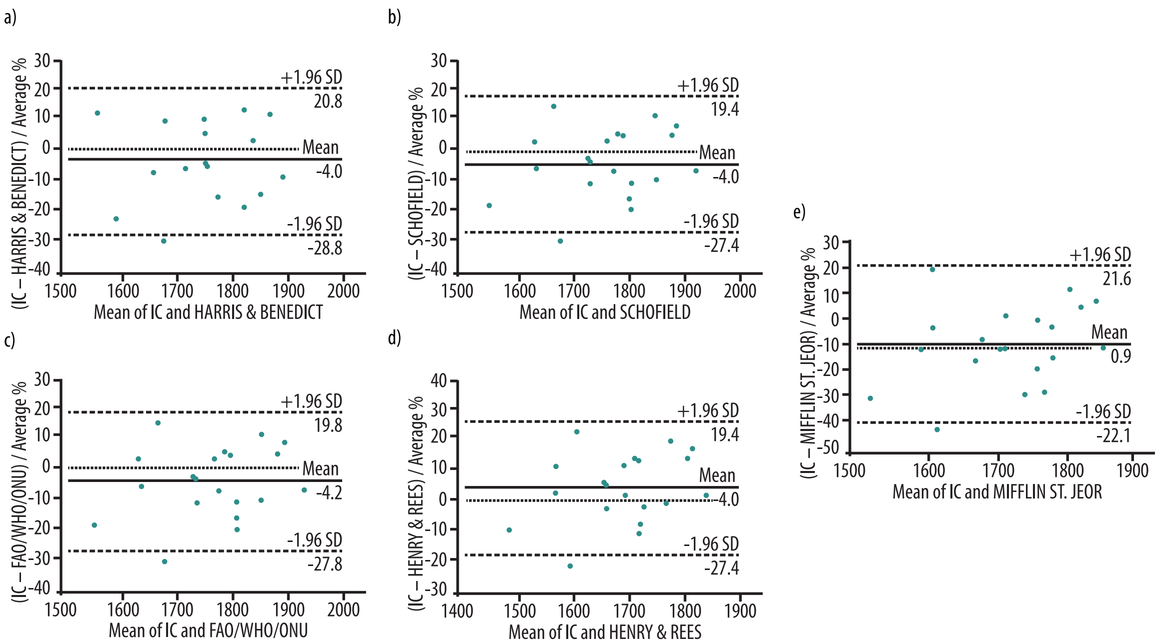

Figure 2. Bland-Altman plots comparing indirect calorimetry (IC) and the following prediction equations for basal metabolic rate in eutrophic subjects: a) Harris and Benedict[13], b) Schofield[20], c) FAO/WHO/UNU[8], d) Henry and Rees[21], and e) Mifflin-St. Jeor[22].

DISCUSSION

The main finding of this study was that, in obese subjects, BMR is overestimated by the prediction equations used, except for the Mifflin-St. Jeor equation[22] , when compared to the value measured by IC. In contrast, in eutrophic subjects all equations analyzed seem to be adequate for predicting BMR. Comparison of eutrophic and obese subjects showed no significant difference between groups in BMR measurements obtained by IC, whereas a significant difference was observed for all equations. This difference might be explained by the fact that the equations consider total body mass. Body mass is generally regulated by the balance between calorie intake and energy expenditure[26]. In obese subjects, the use of predictive equations increases the magnitude of error since changes in body composition do not occur in a uniform manner and the increase in body fat is greater than the increase in muscle mass. Since fat mass and muscle mass differ metabolically, overestimation of BMR may occur[27] .

Bland-Altman plots were used to express the level of agreement between BMR measurements obtained by IC and those predicted with the equations. The Mifflin-St. Jeor equation[22] showed the lowest error difference in obese and eutrophic subjects. These results agree with a study conducted by the American Dietetic Association[18]. According to that study, the Mifflin-St. Jeor equation[22] seems to be more adequate for predicting BMR in the general population, but might be limited when applied to special populations such as different ethnic groups and age groups. The significant difference observed between IC and the Henry and Rees equation[21] in obese subjects might be explained by the fact that these authors collected BMR measurements from people living in the tropics and developed specific equations for these populations. The Henry and Rees equation is therefore very specific for a given population.

The Harris and Benedict equation[13] showed the third largest error difference in obese subjects, a finding that may be related to the fact that the predictive equations did not include obese individuals. Unlike today, the obese population was not significant at the time when this equation was proposed (beginning of the 20th century), and several physiological, morphological and environmental changes have occurred in the population over time. According to Frankenfield et al. (2003), in the Harris and Benedict equation the magnitude of error increases with increasing BMI. This result is in agreement with the present study in which these values are overestimated.

The BMR estimated with the Schofield[20] and FAO/WHO/UNU[8] equations were closely similar, since both equations were derived from a common database. Although the FAO/WHO/UNU[8] equations have been recommended for international use, evidence indicates that these equations are inadequate to estimate the BMR of subjects from different parts of the world, especially the tropics[18, 28,29] . This consequence may also be due to the fact that the database used contained a disproportionate number of Italian subjects who exhibit a higher BMR than other European subjects, North Americans and, apparently, Brazilian subjects[28, 29]. Furthermore, possible differences in the methods used should also be cited, since values of non-fasted subjects were included in the FAO/WHO/UNU equation[8].

Some specific factors should be taken into consideration, such as the region, ethnicity and gender of the subjects, since they can limit the suitability and comparison of the equations[30]. Furthermore, the use of different methods for the determination of body composition should be considered since fat mass and muscle mass are factors that influence BMR. The measurement of BMR based on prediction equations can lead to errors in the values obtained for obese subjects, which may directly influence the energy requirements to be used for diet prescription to reduce body fat mass.

CONCLUSIONS

The Mifflin-St. Jeor equation[22] is the only equation that permits the valid estimation of BMR in obese subjects. The equations of Harris and Benedict[13], Schofield[20], FAO/WHO/UNU[8], and Henry and Rees[21] are not recommended for the prediction of BMR in these individuals, since these equations may overestimate energy requirements. On the other hand, these equations are adequate to evaluate the BMR of eutrophic subjects.

This study suggests the use of the Mifflin-St. Jeor equation to estimate BMR, since this equation was the most accurate in both grade 1 obese and eutrophic subjects. However, it is important to measure the BMR of obese subjects more accurately and safely in order to establish the best non-medicamentous intervention based on physical exercise and nutritional re-education.

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