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Predictive equations are inaccurate to assess caloric needs in non-white adults from Chile

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ABSTRACT

Objectives: Predictive equations are frequently used to estimate resting energy expenditure (REE) because indirect calorimetry (IC) is not always available and is expensive. The aim of this study was to determine the concordance between the estimation of REE using predictive equations and its measurement by IC.
Methods: This was an analysis of the registry of indirect calorimetry performed in non-hospitalized participants. Harris–Benedict, FAO/WHO/UNU, Mifflin St. Jeor, and European Society for Clinical Nutrition and Metabolism (ESPEN) equations were used to estimate REE in these individuals. The concordance between measured and estimated REE using real, ideal, and adjusted weight was calculated using the concordance coefficient analysis of Lin and Bland– Altman plots in all participants and in subgroups separated according to their body mass index.
Results: We retrieved 680 measurements and discarded 247 that did not comply with the inclusion criteria. Thus, we studied 433 participants ages 36 y (29–48 y). Of the participants, 341 were women (79%) and the participants had a body mass index (BMI) of 30 kg/m^2 (26.7–33.1 kg/m^2). All predictive equations had concordance values <0.90. The proportion of participants in which the difference was >10% ranged from 36% to 87%. The ESPEN equation had the greater proportion of erroneous estimations of REE in all participants and BMI subgroups when real weight was used.
Conclusions: We observed a low level of concordance between REE estimated using predictive equations and measured by IC. These results should alert clinicians about the inaccuracy of predictive equations.

Introduction

Indirect calorimetry (IC) is a reference method used to measure resting energy expenditure (REE); however, it is impractical and expensive for routine use. Thus, predictive equations are used as an alternative method to estimate REE [1].

An accurate prediction of REE should have a discrepancy with IC not exceeding 10%, considering that the measurement error of IC is ~5%. This cutoff point also has a clinical meaning because when nutritional support of hospitalized patients based on REE prediction provides calories >10% of the real requirements, the risk for adverse outcomes increases [2,3].

Several publications report that REE prediction equations are inaccurate in white adults [4,5]. The evidence for other racial groups such as Latin Americans is limited. We have observed that body composition cutoff values determined for white populations render unreliable results when applied to Chilean individuals [6]. As a corollary, the same may happen with REE estimation using equations.

Thus, we aimed to evaluate the concordance between estimated and measured REE in a group of Chilean participants who underwent an IC for clinical or research purposes.

Material and methods

In a cross-sectional descriptive study, we analyzed all ICs performed at the Institute of Nutrition and Food Technology between April 2012 and November 2017. Study participants were otherwise heathy obese individuals referred for IC or healthy participants of research projects on nutrition and exercise.

REE was measured using a Sensormedics Vmax Encore 29 equipment after an overnight fast in a quiet room at a temperature ranging from 20°C to 23°C. Flow, oxygen, and carbon dioxide sensors were calibrated before each examination. The test was ended when the equipment detected a steady state, defined as a variability in <10% in oxygen uptake and carbon dioxide consumption and <5% variability in the respiratory quotient. The test was also stopped if it lasted >30 min and a

FCG, TJ, and DB conducted the research. FCG, SH, and DB analyzed the data. SH, DB, and MPdlM prepared and wrote the manuscript.

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Table 1
Resting energy expenditure predictive equations and weight definitions used

Equation	Ethnicity and nutritional status	
Harris–Benedict [28]	White, normal-weight participants	F = 665.0955 + 9.5634 × W + 1.8496 × H – 4.6756 × A M = 66.4730 + 13.7516 × W + 5.0033 × H– 6.7759 v A
FAO/WHO/UN [29]	White participants with normal weight, overweight, or obesity	18–30 y of age F = 13.3 × W + 334 × H^m + 35 M = 15.4 v W - 27 v H^m + 717 31–60 y of age F = 8.7 × W – 25 × H^m + 865 M = 11.3 × W + 16 × H^m + 901
Mifflin St. Jeor [30]	White participants with normal weight, overweight, or obesity	F = 9.99 × W + 6.25 × H – 4.92 × A – 161 M = 9.99 × W + 6.25 × H – 4.92 × A + 5
ESPEN [31]	Nonspecific	25 kcal/kg
Ideal weight	$(H^m)^2 \times 22$	
Adjusted weight	[(Measured weight – Ideal weight) × 0.25] + ideal weight	

A, age in years; H, height in cm; H^m, height in meters; W, weight in kg.
All equations calculate resting energy expenditure in kcal/d.

steady state was not attained. REE was expressed as kcal/24 h. All participants provided written consent at the moment of the examination to use their data for secondary purposes.

We excluded from analysis participants who did not reach a steady state during the IC. We also excluded those <18 and >60 y of age, those with a body mass index (BMI) <18.5 kg/m^2, and individuals with chronic diseases.

REE was estimated using Harris–Benedict, FAO/WHO/UN, Mifflin St. Jeor and European Society for Clinical Nutrition and Metabolism (ESPEN) equations. These formulas are commonly used and are shown in Table 1.

Data analysis

Participants were divided, according to their BMI in normal weight (≥18.5 and <25 kg/m^2), into groups of overweight or obese (≥25 kg/m^2). The real weight was used in predictive equations for those with a BMI ≤25 kg/m^2. In individuals with a BMI over this value, real, adjusted, and ideal weights were used in the equations. These are defined in Table 1.

For each participant, the difference between measured and estimated REE was calculated and expressed as a percentage of measured REE. When the difference was >10%, the estimation was considered inaccurate.

Normality of variable distribution was analyzed using the Shapiro–Wilk test. Because most variables had a non-normal distribution, results are expressed as median (interquartile range). Differences between proportions were evaluated using Fisher or χ^2 tests. Agreement between REE measured by IC and the estimated value using prediction equations was determined using Lin's concordance correlation coefficient (Rho-c) and Bland–Altman plots. When Rho-c was >0.99, agreement was considered almost perfect. For values between 0.95 and 0.99, agreement was considered substantial. For values between 0.60 and 0.90, agreement was considered moderate. For lower values, agreement was considered weak. According to Bland and Altman [7], the correlation between the difference and the mean of estimated and measured energy expenditure was also calculated. The significance of this correlation was calculated using the Bradley–Blackwood equation [8]. A significant correlation indicates a lack of concordance or a significant slope of the curve.

Table 2.

Table 2
Concordance between measured and estimated energy expenditure

	Rho-c	Difference between measured and estimated energy expenditure*	Correlation between difference and mean (Bland–Altman)	Bradley-Blackwood F	*P*-value for F†
All participants using real weight (N = 433)					
Harris–Benedict	0.74	–74 (–414 to 267)	0.25	56	<0.01
FAO/WHO/UN	0.71	94 (–440 to 252)	0.26	81.9	<0.01
Mifflin-St Jeor	0.77	21 (–319 to 361)	0.28	21.8	<0.01
ESPEN	0.32	–466 (–1028 to 95)	–0.40	724.4	<0.01
Participants with BMI <25 kg/m^2 using real weight (n = 63)					
Harris–Benedict	0.71	44 (–365 to 277)	0.50	13	<0.01
FAO/WHO/UN	0.69	–60 (–390 to 269)	0.46	13	<0.01
Mifflin-St Jeor	0.74	28 (–299 to 355)	0.29	3.8	<0.05
ESPEN	0.50	–115 (–537 to 306)	0.29	12.4	<0.01
Participants with a BMI ≥25 kg/m^2 using real weight (n = 370)					
Harris–Benedict	0.73	–79 (–422 to 265)	0.25	51.3	<0.01
FAO/WHO/UN	0.70	–100 (–447 to 248)	0.27	76.8	<0.01
Mifflin-St Jeor	0.76	19 (–323 to 362)	0.29	19.4	<0.01
ESPEN	0.28	–526 (–1021 to –31)	0.31	906.0	<0.01
Participants with a BMI ≥25 kg/m^2 using ideal weight (n = 370)					
Harris–Benedict	0.40	179 (–240 to 598)	0.67	381	<0.01
FAO/WHO/UN	0.41	157 (–258 to 573)	0.72	409.3	<0.01
Mifflin-St Jeor	0.36	266 (–143 to 674)	0.52	474.9	<0.01
ESPEN	0.47	90 (–334 to 515)	0.67	210.7	<0.01
Participants with a BMI ≥25 kg/m^2 using adjusted weight (n = 370)					
Harris–Benedict	0.55	114 (–270 to,499)	0.63	222.1	<0.01
FAO/WHO/UN	0.57	93 (–288 to 475)	0.67	230.7	<0.01
Mifflin-St Jeor	0.48	204 (–177 to 585)	0.50	335.4	<0.01
ESPEN	0.64	–64 (–434 to 307)	0.58	123	<0.01

BMI, body mass index.
*Expressed as mean (95% limit) in kcal/d.
†A low probability rejects the null hypothesis that both determinations are concordant.

Statistical significance was set at a probability to reject the null hypothesis of <0.05.

Results

Of the 680 IC recordings, 247 participants did not meet the inclusion criteria. Participant flow is shown in Figure 1. Therefore, we analyzed data from 433 participants ages 36 y [29–48 y], of whom 79% were women. Participants had a BMI of 30 kg/m^2 (26.7–33.1 kg/m^2). The percentage of participants with normal weight and overweight or obesity was 14.5% and 85.5%, respectively. Measured REE was 1474 kcal/d (1305–1676 kcal/d), and the respiratory quotient was 0.84 (0.79–0.91).

The agreement between predictive equations and measured REE is shown in Table 3. Predictive equations had a weak agreement with measured energy expenditure in all participants. Mifflin St. Jeor equation using the real weight had the higher Rho-c. In individuals with a BMI ≥25 kg/m^2, predictive equations calculated using ideal or adjusted weight had lower concordance with measured energy expenditure than when the calculations were done using real weight. Bradley–Blackwood correlations were significant and positive for all equations and in all the groups of participants. Therefore, there was a significant slope in the Bland–Altman plot, indicating that the prediction of REE by the equations was asymmetrical, generating an overestimation for low values and a subestimation for high values.

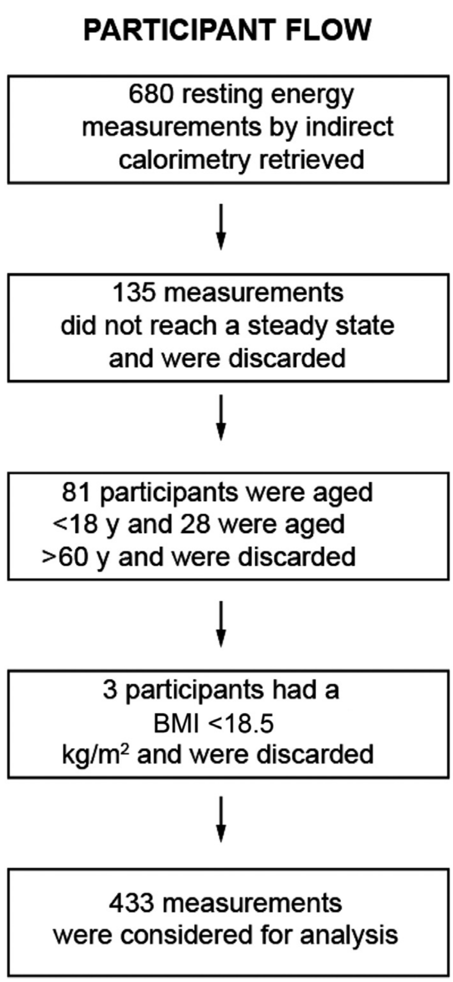

Fig. 1. Participant flow. BMI, body mass index.

The differences between estimated and measured energy expenditure expressed as a percentage of the measured value and the proportion of participants in whom the difference was >10% are shown in Table 3. The percentage of inaccurate estimations ranged between 33% and 87% in all participants, depending on the formula used. The ESPEN equation was the worst predictor of REE, when the real weight was used to estimate the REE of all participants and BMI subgroups. When ideal or adjusted weight was used among participants with a BMI ≥25 kg/m^2, the Mifflin equation had the higher proportion of erroneous estimations.

We performed the regression using calorimetry as the dependent variable and as independent variables those used in the predictive equations, mainly sex, age, body weight, and height. The value of the regression was $R^2 = 0.62$. When men and women were analyzed separately, the R^2 values were 0.51 and 0.43, respectively. These values did not improve when ideal or adjusted weight rather than real weight, were used as independent variables.

Discussion

The main finding of the present study was that predictive equations used to estimate REE have a low concordance and a high proportion of disagreement with the measured value using IC in healthy and mildly obese Chilean individuals.

We used IC as the gold standard for the measurement of REE. We took all possible precautions to assure that our measurements were accurate. The equipment was calibrated before each measurement, which was carried out in quiet room with a constant temperature. All participants were instructed and encouraged to fast for ≥10 h. However, we cannot be sure that these indications were fulfilled by participants.

Two large studies published recently also address the accuracy of predictive equations for REE. Bedogni et al. [5] reported an analysis of 16 900 observations and Jesus et al. [9] evaluated 1726 patients. Both reports show approximately the same level of inaccuracy for a variety of predictive equations and report the tendency of the equations to overestimate REE. Although both studies chose certain equations as having a better predictive value, the proportion of erroneous predictions continues to be high. Noteworthy is that the study by Jesus et al. found that the Huang equation [10], which uses body composition instead of weight and height, was the most accurate. This agrees with the concept that muscle or lean body mass is the major determinant of REE [11,12] and that fat mass only introduces errors to the equations, explaining their lower predictive capacity in obese individuals [13,14]. It should be noted that Chileans have less muscle mass than other populations [6], therefore the estimation of energy expenditure by estimation becomes more difficult.

The level of inaccuracy is also related to the R^2 of the predictive equations. The value of 0.62 that we found indicates that the equation based on age, sex, weight, and height accounts only for 62% of the variance of REE, rendering 40% inaccuracy, a value that is close to the proportion of wrong values that we found with the predictive equations that we tested. The same R^2 values are reported by Mifflin et al. [11], whose equations are considered accurate and are popular among clinicians. This probably means that the lack of precision of the equations does not rely on the populations tested or the number of observations considered, but on the lack of parameters that really determine REE. The problem is that we do not have good candidates at the moment to substitute weight or fat-free mass determined by bioimpedance or dual-energy x-ray absorptiometry. Although it should be noted that predictive equations based on lean body mass do not necessarily improve the R^2 of REE prediction [15] and if they do so, they still are inaccurate [16].

Table 3
Difference between the measured and predicted resting energy expenditure, expressed as percentage of the measured energy expenditure, for the different predictive equations

Predictive equation	Difference between measurement and prediction (measurement−prediction)	Percentage of observations with a difference >10%	*P*-value*
All participants (N = 433)			
Harris−Benedict	−5.3 (−14 to 2.2)†	44	
FAO/WHO/UN	−7.2 (−15.7 to 1.3)	46	χ^2 = 276
Mifflin-St Jeor	0.6 (−7 to 8.2)	36	$P < 0.01$
ESPEN	−32.6 (−44.7 to 18.9)	87	
Participants with a BMI <25 kg/m^2 (n = 63)			
Harris−Benedict	−4.7 (−12.3 to 4.4)	46	
FAO/WHO/UN	−5.8 (−15.6 to 4.4)	46	χ^2 = 8.3
Mifflin-St Jeor	−2.9 (−15.2 to 10.3)	32	P = 0.04
ESPEN	−10.3 (−21.4 to 2.9)	57	
Participants with a BMI ≥25 kg/m^2 (n = 370) using their real weight			
Harris−Benedict	−5.4 (−14.4 to 2.1)	44	
FAO/WHO/UN	−7.3 (−15.9 to 0.6)	46	χ^2 = 328
Mifflin-St Jeor	0.6 (−7.1 to 8.2)	37	$P < 0.01$
ESPEN	−35.9 (−47.2 to 23.2)	92	
Participants with a BMI ≥25 kg/m^2 (n = 370) using their ideal weight			
Harris−Benedict	10.9 (1.4 to −18.7)	59	
FAO/WHO/UN	9.5 (−0.4 to 16.8)	57	χ^2 = 43.6
Mifflin-St Jeor	16.7 (9.1 gto 24.3)	73	$P < 0.01$
ESPEN	4.5 (−4.7 to 13.5)	51	
Participants with a BMI ≥25 kg/m^2 (n = 370) using their adjusted weight			
Harris−Benedict	6.9 (−2.1 to 14.2)	48	
FAO/WHO/UN	5.4 (−3.7 to 12.8)	49	χ^2 = 35.8
Mifflin-St Jeor	13 (5.1 to 20)	65	$P < 0.01$
ESPEN	−5.3 (−14.9 to 3.2)	45	

BMI, body mass index.
*Probability for a difference in proportions between the different predictive equations.
†Median (interquartile range).

Bedogni et al. and Jesus et al. [5,9] do not report a concordance analysis as we do. These calculations allowed us to uncover another source of inexactitude. The four equations tested overestimated low REE values and vice versa. This asymmetrical lack of exactness introduces another source of error that must be considered.

Prediction equations are used mainly in two clinical settings, namely for the indication of nutritional support for sick patients and for hypocaloric diets for obese patients. In the case of nutritional support, the poor accuracy of the equations may be critical. First, they tend to overestimate energy needs, which could lead to overfeeding patients, which is associated with adverse consequences [17–19]. Both the American Society for Parenteral and Enteral Nutrition [20] and ESPEN [12] guidelines recommend performing an IC to determine REE. But if this measurement is not available, both recommend estimating energy needs using 25 to 30 kcal/kg of body weight. Both guidelines do not specify which weight should be used (real, ideal, or adjusted), introducing a level of uncertainty. According to our results, the ideal or adjusted weight improve the precision of the equations, especially in obese patients.

There are reports showing that permissive underfeeding is not associated with a higher proportion of nutrition-associated complications in critical patients [21]. These results could mean that clinicians should not worry too much about providing an adequate amount of calories to acute patients during their hospital stay. If requirements are underestimated, this would not become a big deal. However, a recent report has shown that providing the adequate amount of calories during nutritional support of hospitalized patients is effectively associated with lower incidence of complications and mortality when compared with patients who received the standard hospital care [22]. These results stress the need to calculate as accurately as possible the nutritional needs of sick hospitalized patients. Predictive equations are clearly not a solution, considering our results and those of other authors. Therefore, the only realistic solution to the problem is to consider ICs as an indispensable tool to provide a precise and beneficial nutritional support.

Less critical is the problem of dietary prescription for weight reduction in obese and overweight individuals. Probably, the erroneous calculation of energy needs using these predictive equations will be the least problem in the large number of factors that render dietary treatment of obesity so inefficient [23]. First, the great variability in energy expenditure in ambulatory individuals is due to their level of physical activity. Thus, measuring only REE, even with precise methods, will not consider physical activity. Therefore, total energy expenditure should be measured and the use of actigraphy can be a practical solution, which is less expensive than using doubly labeled water [24,25]. Second, the lack of compliance with dietary prescription is the most important factor that influences weight loss. A better motivation to reduce energy intake, rather than a precise dietary prescription, will have a greater effect in weight reduction [26].

There were some limitations to the present study. It was cross sectional, and the number of observations was considerably less than other recent studies. There also was no data on body composition or body fat distribution to test whether these variables improved the R^2 of the regression equations with REE as the dependent variable.

The main strength of this study was that it was done with Latin American participants, in whom seldom studies have assessed the accuracy of REE predictive equations. Another advantage was that the sample was quite representative of our reality, where there is a high prevalence of overweight and obesity [27]. Another strength is that we performed a full concordance analysis and the Bland−Altman plots showed that the inaccuracy of the predictive equations is asymmetrical along values of REE, introducing another source of bias.

Conclusions

The lack of precision of equations to estimate REE that we and others have observed, casts serious doubts on their real usefulness in the nutritional management of individual patients. Although there are certain differences in the exactness of different equations, their error level is always high. Future research should focus on detecting better predictive parameters for REE such as body composition and fat distribution parameters. Another practical solution is devising less-expensive and less cumbersome calorimeters that are suitable for bedside use.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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