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Ability of the Harris Benedict formula to predict energy requirements differs with weight history and ethnicity

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Abstract

The objective of this study was to assess the effects of weight history status and ethnicity on the ability of the Harris Benedict (HB) formula to: 1) predict measured resting energy expenditure (REE), and, 2) accurately estimate energy needs over a 2-week test period. Subjects were never-overweight (BMI ≤ 25 kg/m^2, n=47), overweight (BMI 27-30 kg/m^2, n=170), and weight-reduced (BMI ≤ 25 kg/m^2, n=51) healthy, adult African-American (AA) and Caucasian (C) women. Food was provided for 2 weeks at an energy level calculated using the HB formula multiplied by a 1.35 activity factor. After 2 weeks, weight, REE (by indirect calorimetry), and body composition (by dual-energy X-ray absorptiometry) were assessed. Data were analyzed using 2-way ANOVA at $p<0.05$ significance. The HB formula overestimated REE 1) in each weight history group (by 160 ±125 kcals among never-overweight, 295 ±189 kcal among overweight, and 105 ±135 among weight-reduced) such that there was a group effect on overestimation ($P<0.001$) and 2) between ethnicities, with a greater overestimation in AA vs. C ($P<0.001$). There was a significant effect of weight history group on weight change ($P<0.001$) over 2-weeks, such that weight-reduced women gained more weight than the other two groups ($P<0.05$). In conclusion, the ability of the HB formula to estimate REE differed with weight history status and ethnicity. The accuracy of the HB formula to predict dietary energy needs was affected by weight history status. These results suggest that formulas used to calculate energy needs should take into account weight history and ethnicity.

Keywords

Overweight; ethnicity; weight change; Harris Benedict; resting energy expenditure; women

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1. Introduction

Research involving human metabolism requires that subjects be tested in a weight-stable state in order to obtain accurate measurements. Therefore, study subjects should be maintained in a eucaloric state prior to metabolic testing. To accomplish this aim, basal energy requirements, or resting energy expenditure (REE), often are estimated using prediction formulas such as the Harris-Benedict (HB) formula [1]. This prediction formula takes into account gender, body weight, height, and age. The calculated REE must then be modified by an activity factor to predict total, free-living energy requirements. Activity factor adjustments for healthy adults often range from 1.2 (sedentary lifestyle) to 1.5 (moderately active), and are even further increased for very active subjects. Unfortunately, neither the HB formula nor other common formulas, such as the FAO/WHO [2] or the Mifflin equation [3], consider weight history status (i.e., overweight, weight-reduced) or ethnicity, factors that are known to affect REE. Therefore, we felt it was crucial to re-evaluate the validity of the HB formula in predicting REE and in estimating energy needs within a female healthy population with differing weight histories and ethnicities. This information is critical to nutrition research in understanding limitations in the accuracy of the HB formula and other predictive equations that do not take weight history status or ethnicity into account.

Body composition influences energy expenditure and, subsequently, may affect the predictive ability of the HB formula. Fat-free mass (FFM) is the largest determinant of basal energy expenditure. However, obese individuals have a lower REE than would be predicted using a formula simply containing weight, height, age, and gender, due to a greater proportion of fat mass vs metabolically-active fat-free mass. Conversely, weight loss may result in a disproportionate loss of FFM, thereby resulting in an overestimation of REE for weight-reduced individuals. FFM can be largely maintained during weight loss if physical activity is included in the weight loss program [4]. However, subjects undergoing weight loss without exercise experience a loss of FFM as well as fat mass [5]. Therefore, the HB formula may not possess equal predictive ability among normal-weight individuals as compared to overweight individuals or those with differing histories of weight loss.

Ethnicity also influences REE and therefore may affect the predictive ability of the HB formula. REE has been shown to be lower among African American (AA) vs Caucasian (C) women [6,7], in part due to a lower amount of highly metabolically-active, trunk lean tissue mass [3, 8]. However, REE among AA remained lower than among C by an average of 135 kilocalorie (kcal/d) even after adjusting for differences in lean body mass [9], suggesting that ethnicity is associated with an unidentified factor that affects REE. These findings suggest that the HB formula, which was validated in a study population largely comprised of C individuals, may overestimate REE in AA.

The objective of this study was to assess the effects of weight history status and ethnicity on the ability of the HB formula to: 1) predict measured REE, and, 2) accurately estimate energy needs over a 2-week test period among never-overweight, overweight, and weight-reduced healthy, adult C and AA women. We hypothesized that the HB formula would overestimate REE in overweight and weight-reduced subjects relative to normal-weight subjects; that the HB formula would overestimate REE in AA relative to C subjects; and that, over 2 weeks of controlled feeding based on the HB formula, overweight and weight-reduced subjects, and AA subjects, would gain more weight than normal-weight subjects and C subjects, respectively.

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2. Methods and Materials

2.1. Subjects

Data were collected from 217 women who participated in two research studies at the University of Alabama at Birmingham (UAB). Enrollment criteria included AA or C ethnicity by self-report, premenopausal status, aged 20-47 years, and a BMI ranging from 21-25 or 27-30 kg/m^2. Subjects were non-smokers, sedentary (defined as exercising <1 time/wk for the past year), not using any medications that affected fatty acid or glucose metabolism, and reported normal menses. The use of multi-phasic oral contraceptives was permitted. Recruitment efforts were targeted to achieve equal representation of AA and C subjects. Subjects attended at least two informational meetings designed to explain the study parameters before enrollment, and gave informed consent to participate. Studies were approved by the UAB Institutional Review Board for Human Use.

2.2. Study Design

Of the 217 subjects, 47 were never-overweight, and 170 were originally evaluated in an overweight state. Of those overweight subjects, 51 were evaluated later, in a weight-reduced state. Subjects were therefore classified as never-overweight (BMI 21-25 kg/m^2), overweight (BMI 27-30 kg/m^2), or weight-reduced (BMI 21-25 kg/m^2). Never-overweight subjects were evaluated at baseline. The overweight group was evaluated prior to weight loss, and immediately after successfully completing a weight loss of at least 12 kilograms, placing them just below a BMI of 25 kg/m^2. Data represent 2 weeks during which meals and snacks were provided by the General Clinical Research Center (GCRC) metabolic kitchen. Subjects were instructed to only consume the foods provided and to consume all foods. Timing of the feeding protocol was planned such that subjects ended their 2 week feeding period and admitted to the GCRC for body composition and REE assessment during the follicular phase of their menstrual cycle (within 10 days of the first day of their menstrual cycle).

2.3. Diet

The weight maintenance diet administered to subjects was planned by the GCRC Research Dietitian according to a 5-day cycle menu, and contained only commonly-consumed foods consistent with the typical American diet. The macronutrient content of the diet was comprised of 16% energy from protein, 20% energy from fat, and 64% energy from carbohydrate. A lower-fat diet was chosen to ensure that, even during the weight-reduction phase, subjects would receive ample amounts of food, thereby decreasing hunger and potentially minimizing cheating. Subjects received a standard baseline diet of 1700 kcals, with additional unit foods that met the requisite macronutrient proportions added as necessary to meet individual calculated weight maintenance needs. Subjects received between 1700-2300 kcals/day. Individual caloric requirements for weight maintenance were calculated using the HB formula [1] multiplied by an activity factor of 1.35.

The caloric and macronutrient contents of diets were calculated using the Nutrition Data System for Research (NDS-R), developed by the Nutrition Coordination Center, University of Minnesota, Minneapolis, MN [10]. Foods were prepared and packaged in the UAB GCRC metabolic kitchen. During each weight-maintenance period, subjects were required to pick up food at the GCRC 2 days/week. Meals and snacks were consumed under free-living conditions except during the hospital admission, which took place during the last 2-4 days of the weight maintenance period.

2.4. Weight Maintenance

Subjects were weighed (Scale-tronix 6702W; Scale-tronix, Carol Stream, IL) wearing minimal clothing (i.e. in shirt sleeves and pants or dress, but without shoes or heavy coats), twice per week by the GCRC metabolic kitchen staff in conjunction with food pick-up. Weight was recorded to the nearest 0.1 kg. Weight maintenance was defined as ± 2 kg [11] of baseline weight. Baseline weight was defined as the weight on the third day of the diet, to allow for acclimation to the diet. Subjects were weighed at approximately the same time of day for each visit to minimize intra-individual variation. Height was recorded at the beginning of each weight maintenance period using a digital stadiometer (Heightronic 235; Measurement Concepts, Snoqualmie, WA).

2.5. Body Composition

Total and regional (arm, leg, and trunk) lean tissue and fat mass, were measured by dual-energy x-ray absorptiometry (DXA; Lunar DPX-L and Prodigy DXA; GE-Lunar Corp, Madison, WI). Measurements obtained with these instruments are similar (generally within 4%) [12]. Arm and leg lean tissue were combined to form limb lean tissue. Lean tissue excluded the measurement of bone mineral. Total body fat was comprised of limb and trunk fat mass. The Lunar DPX-L scans were analyzed using ADULT, version 1.33. The Prodigy DXA scans were analyzed using enCORE 2002, version 6.10.029.

2.6. Resting Energy Expenditure

REE was measured under inpatient conditions upon awakening by indirect calorimetry using a Deltatrac metabolic monitor (Deltratrac II; SensorMedics, Yorba Linda, CA). Prior to REE measurements, subjects were fasted for 10-12 hours. Oxygen consumption (VO2) and carbon dioxide production (VCO2) were measured for 30 minutes using a thermoplastic ventilated-hood canopy system [13]. Per instructions of the manufacturer, calibrations were performed prior to each test. Energy expenditure was calculated using equation 12 of de Weir [14].

2.7. Statistical Methods

Quantitative variables are expressed as mean ± SD, while qualitative variables are expressed as frequency and percentage. Two-way analysis of variance (ANOVA) was used to perform comparisons between the never-overweight, overweight, and weight-reduced groups for age, body composition variables, BMI, REE, mean difference between estimated and measured REE, and mean weight change with weight history group and ethnicity as the main effects [15,16]. The Tukey post hoc test was then used to determine which specific pairs of means were significantly different. Ethnicity, and interaction terms including ethnicity, were included. Since no interaction terms involving ethnicity were statistically significant or approached statistical significance, these terms were dropped from all subsequent ANOVA models and were not considered further. Statistical tests were two-sided and were performed at a 5% significance level (i.e., $\alpha = 0.05$). Statistical analyses were performed with the use of SAS software (version 9.1; SAS Institute, Inc., Cary, NC).

3. Results

The characteristics of the study population, according to weight status are displayed in Table 1. Never-overweight and weight-reduced women were similar with respect to weight, BMI, and total fat (%), and were significantly different from the overweight group ($P < 0.05$ for all). The never-overweight and overweight women were significantly different with respect to total lean mass and limb lean mass ($P<0.05$ for both), but neither group was significantly different from the weight-reduced group. C women had significantly more trunk lean mass and higher REE than their AA counterparts ($P < 0.001$), and AA women had significantly more limb lean mass than their C counterparts (P<0.001). Additionally, there were differences in total body fat (%) and body fat (kg) that approached significance (P=0.088 and P=0.078, respectively) such that C had higher body fat than their AA counterparts.

The HB formula significantly overestimated REE within each weight history group and both ethnicities (P < 0.05 for all; Table 2). The greatest difference between predicted and measured REE was observed within the overweight group, with a difference of nearly 300 kcals. The difference in the predicted and measured REE was greater for the AA subjects than for the C subjects (P<0.001).

Weight history group was associated with mean weight change. Mean weight change of the never-overweight and overweight groups were significantly less than that of the weight-reduced group (P<0.05; Table 3). However, ethnicity was not significantly associated with mean weight change.

4. Discussion

The results of this study indicated that the ability of the HB formula to estimate REE differed with weight history status and ethnicity, such that it was less accurate among overweight women and AA women. Additionally, the accuracy of the HB formula to predict free-living dietary energy needs, as reflected in weight change over 2 weeks, was affected by weight history status, such that it was less accurate among previously-overweight women, regardless of ethnicity. These results suggest that metabolic differences based on weight history and ethnicity must be considered when estimating energy requirements for studies involving weight stabilization.

We found that the HB formula significantly overestimated REE. However, the HB formula predicted REE with more accuracy among normal-weight and weight-reduced women, and among C women, than among either overweight women or AA women. The largest difference in predicted and measured REE was observed in the overweight group (nearly 300 kcals); the discrepancy for the never-overweight and weight-reduced groups was of a lesser magnitude. The discrepancy between the predicted and measured REE values may be partially explained by body composition. FFM is the largest determinant of REE, explaining approximately 62-73% of the variability of REE [17,18]. The lower proportion of body weight as FFM among the overweight subjects may explain the overestimation of REE by the HB formula in this group.

Regardless of weight history, the HB formula overestimated REE of AA women by a greater amount than that of C women. This result is not unexpected because numerous studies have shown that REE among AA is lower than among C [9,19,20]. Furthermore, the validity of the Harris Benedict formula was determined in a population composed largely of C subjects. The larger difference observed between predicted and measured REE in the AA subjects may have been due in part to the ethnic differences in body composition. AA subjects had more limb lean mass and less trunk lean mass [5,19] than C subjects suggesting that C subjects had a relatively greater amount of organ mass. Mass-specific metabolic rate is higher in organs vs skeletal muscle [19,21]. Thus, a greater proportion of lean mass as organ mass may explain the higher REE among C vs AA.

Change in weight over the 2-week intervention period was affected by weight history status such that weight change was greater in the weight-reduced group relative to the never-overweight and overweight groups (which did not differ from each other.) The relatively greater amount of weight gain observed among the weight-reduced subjects may have been due to behavioral factors, such as failure to comply with the intervention. However, it is also possible that following diet-induced weight loss, a residual effect of prior energy restriction resulted in a depression in REE [22] that continued into the 2-week study period.

Energy balance status affects REE, such that a state of negative energy balance decreases REE [22]. It is therefore critical to accurately predict energy requirements, and ensure weight stability, prior to metabolic testing. Use of an accurate, easily-generated formula to ensure weight maintenance would negate the need for use of other, more expensive and complicated methods for predicting weight maintenance energy requirements, such as doubly labeled water and indirect calorimetry. Aside from the HB formula, other common equations for estimating energy needs include the Food and Agriculture Organization/World Health Organization (WHO) equation [2], the Mifflin equation [3], the Owen equation [23] and, most recently, the Dietary Reference Intakes [24]. Only the latter two account for gender, weight, height, and age; none consider weight history or ethnicity. A need exists for the development of new prediction equations, or adjustment factors for existing equations, that take into account weight history and ethnicity.

Strengths of this study included use of a large sample of AA and C women with differing weight histories; the provision of a carefully controlled diet; the use of indirect calorimetry; and the use of strong measures of body composition. The major limitation of this study was the relatively short (2-week) intervention period.

In conclusion, these results suggest that metabolic differences in energy needs associated with weight history status and ethnicity affect the ability of the HB formula to estimate REE. Weight history status likewise affects the accuracy of the HB formula to predict free-living dietary energy needs. These results suggest that formulas used to calculate energy needs, especially when used for studies requiring weight stabilization, should take into account weight history status and ethnicity.

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Table 1

Characteristics of the subjects by weight history group[1,2]

	Never-overweight[3]	Overweight[3]	Weight-reduced[3]	*P* Group	*P* Ethnicity
Age (y)	30.9 ± 4.9[a]	33.7 ± 6.1[b]	34.9 ± 5.3[b]	0.002	0.663
Weight (kg)	62.3 ± 5.5[a]	78.2 ± 7.3[b]	65.2 ± 6.2[a]	< 0.001	0.234
Body mass index (kg/m^2)	23.5 ± 1.9[a]	29.1 ± 1.4[b]	23.8 ± 0.9[a]	< 0.001	0.600
Total fat (%)	33.0 ± 5.3[a]	44.8 ± 4.0[b]	34.6 ± 4.6[a]	< 0.001	0.088
Body fat (kg)	19.2 ± 4.1[a]	33.0 ± 4.5[b]	21.5 ± 4.2[c]	< 0.001	0.078
Trunk lean mass (kg)	17.7 ± 1.8 [a]	18.8 ± 2.4[b]	18.8 ± 2.3[b]	< 0.008	< 0.001[4]
Limb lean mass (kg)	17.8 ± 1.9[a]	18.7 ± 2.4[b]	18.6 ± 2.1[a,b]	0.031	<0.001[5]
Total lean mass (kg)	35.5 ± 3.4[a]	37.5 ± 4.3[b]	37.4 ± 3.8[a,b]	0.009	0.964
Resting energy expenditure (kcal)	1239.1 ± 155.2[a]	1376.3 ± 161.7[b]	1309.5 ± 155.4[a]	<0.001	<0.001[4]

[1] Mean ± SD

[2] Means in a row with different superscript letters are significantly different, $P < 0.05$.

[3] Total group: n = 47 for never-overweight, n = 170 for overweight, n = 51 for weight-reduced

[4] Caucasian mean value>African American mean value

[5] African American mean value>Caucasian mean value

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Table 2

Subject mean difference (predicted — observed) in resting energy expenditure (kcal/day) between that predicted based on the Harris Benedict formula, and that measured using indirect calorimetry, by weight history group and ethnicity[1,2]

	Predicted — observed REE (kcal/day)				
	Never-overweight[3]	**Overweight**[3]	**Weight-reduced**[3]	***P*** **Group**	**Ethnicity**
Total[3,4]	160 ± 125[a]	295 ± 189[b]	105 ± 135[a]	< 0.001	
AA[5]	210 ± 90	344 ± 161	141 ± 132		< 0.001[6]
C[7]	94 ± 136	239 ± 204	66 ± 131		

1. Mean ± SD

2. Means in a row with different superscript letters are significantly different, $P < 0.05$

3. Total group: n = 44 for never-overweight, n = 168 for overweight, n = 48 for weight-reduced

4. 260 observations, 212 subjects

5. African American: n = 25 for never-overweight, n = 89 overweight, n = 25 for weight-Reduced

6. Greater overprediction in African American vs. Caucasian subjects

7. Caucasian: n = 19 for never-overweight, n = 79 for overweight, n = 23 for weight-reduced

Table 3

Subject mean weight change (kg) during controlled 2-week weight-maintenance period by group and ethnicity[1,2]

	Weight change (kg)			*P*	
	Never-overweight[3]	Overweight[3]	Weight-reduced[3]	Group	Ethnicity
Total[3,4]	-0.18 ± 0.31[a]	-0.17 ± 0.37[a]	0.38 ± 0.84[b]	< 0.001	
AA[5]	-0.19 ± 0.31	-0.18 ± 0.38	0.34 ± 0.81		0.595
C[6]	-0.17 ± 0.30	-0.16 ± 0.36	0.42 ± 0.89		

1 Mean ± SD

2 Means in a row with different superscript letters are significantly different, $P < 0.05$

3 Total group: n = 47 for never-overweight, n = 170 for overweight, n = 51 for weight-reduced

4 268 observations, 217 subjects

5 African American: n = 26 for never-overweight, n = 170 overweight, n = 27 for weight-reduced

6 Caucasian: n = 21 for never-overweight, n = 79 for overweight, n = 24 for weight-reduced