Prediction of daily energy expenditure during a feeding trial using measurements of resting energy expenditure, fat-free mass, or Harris-Benedict equations1–3

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ABSTRACT

Background: During feeding trials, it is useful to predict daily energy expenditure (DEE) to estimate energy requirements and to assess subject compliance.

Objective: We examined predictors of DEE during a feeding trial conducted in a clinical research center.

Design: During a 28-d period, all food consumed by 26 healthy, nonobese, young adults was provided by the investigators. Energy intake was adjusted to maintain constant body weight. Before and after this period, fat-free mass (FFM) and fat mass were assessed by using dual-energy X-ray absorptiometry, and DEE was estimated from the change (after – before) in body energy (ΔBE) and in observed energy intake (EI): DEE = EI – ΔBE. We examined the relation of DEE to pretrial resting energy expenditure (REE), FFM, REE derived from the average of REE and calculated from FFM [REE = (21.2 × FFM) + 415], and an estimate of DEE based on the Harris-Benedict equation (HB estimate) (DEE = 1.6 REE).

Results: DEE correlated ($p < 0.001$) with FFM ($r = 0.78$), REE ($r = 0.73$), average REE ($r = 0.82$), and the HB estimate ($r = 0.81$). In a multiple regression model containing all these variables, $R^2$ was 0.70. The mean (±SEM) ratios of DEE to REE, to average REE, and to the HB estimate were 1.86 ± 0.06, 1.79 ± 0.04, and 1.02 ± 0.02, respectively.

Conclusions: Although a slightly improved prediction of DEE is possible with multiple measurements, each of these measurements suggests that DEE equals 1.60–1.86 × REE. The findings are similar to those of previous studies that describe the relation of REE to DEE measured directly. Am J Clin Nutr 2004;80:876–80.

KEY WORDS Daily energy expenditure, resting energy expenditure, energy balance, dual-energy X-ray absorptiometry, feeding trials

INTRODUCTION

During feeding trials in which energy balance is a goal, it is of great value to be able to predict the daily energy expenditure (DEE) of the subjects to estimate goals for initial energy intake for weight maintenance and nitrogen balance and perhaps to detect outliers because of noncompliance or exceptional degrees of physical activity. Because resting energy expenditure (REE) is an important determinant of DEE (1), the measurement or prediction of REE is generally the first step in trying to then predict DEE. Previous studies have examined the relation between REE and DEE estimated with the use of the Harris-Benedict equation (HB estimate), in which weight, height, sex, and age are used to estimate REE. In general, the prediction of group means is fairly good with this approach, but individual estimates are quite variable (2, 3). Others have shown that fat-free mass (FFM) correlates with REE (4, 5). There also are published data correlating REE with total DEE measured by using the doubly labeled water (DLW) technique (6, 7). The accuracy and precision of the DLW technique makes this the “gold standard” for estimating the DEE of persons who are free-living and not confined, eg, to a room calorimeter (1). The DLW technique is an expensive method with relatively complicated sample preparation and analysis (8–13). This technique can provide very important insights into how diets or pharmacologic treatments may affect DEE, but the analytic procedures are generally too time consuming to be used at the inception of a study to determine energy requirements (as opposed to providing a post hoc interpretation of subject compliance with reports of energy intake).

We are conducting a series of dietary trials in a General Clinical Research Center (GCRC) to determine the effect of dietary fatty acid composition on fat oxidation. To limit the effects of fat or FFM gain or loss on the outcome variables, our aim is to maintain our subjects in zero energy balance on the basis of post hoc measurements of body composition and daily proxy measurements of body energy, namely body weight. However, although our subjects are prohibited from engaging in actual exercise training during the studies, considerable variation in physical activity exists among subjects. Despite this factor, we have found that body weight, fat mass, and FFM remain remarkably constant during the diet periods, with relatively little manipulation of energy intake once each diet period has begun. This finding suggests that the technique used by dietitians to predict energy requirements, namely a variation of the Harris-Benedict

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equation, has practical utility. The objective of this study was to evaluate this hypothesis.

SUBJECTS AND METHODS

Experimental design

This study was conducted primarily at the GCRCs of The Ohio State University (n = 3) and The University of Texas Medical Branch (n = 23). The study protocol was approved by the Institutional Review Board for human subjects at our institution, and all subjects gave written informed consent. The 26 subjects of this study participated in the control, 28-d run-in phase of an ongoing study examining the effects of substituting oleic acid for palmitic acid on fat oxidation and energy expenditure, which is based on previous data from our laboratory and suggests that oleic acid was preferentially oxidized compared with palmitic acid (14). As part of this trial, subjects are given all the food and drink (except water) that they need to maintain body weight and (in retrospect) body composition for 28-d periods of each diet. The subjects all ate breakfast every day under supervision, and some subjects ate additional meals in the GCRC, especially during the week.

Using the techniques described below, FFM was measured before beginning and after the run-in diet ended, and REE was measured at the beginning of the trial. DEE was also estimated at the onset of the trial with the use of the Harris-Benedict equation to predict REE. Energy intake and body weight were monitored before beginning and after the run-in diet ended, and REE was estimated from the average energy intake (EI), which was based on what the subjects were given each day to eat and the change in body energy (ΔBE) estimated from the DXA measurements:

\[
\text{DEE} = \text{EI} - \Delta \text{BE}
\]

REE was also estimated from FFM measured before the diet began. The equation used was provided courtesy of the consultant for this study, S Heymsfield (Columbia University, New York) and was based on 12 published studies correlating FFM with REE:

\[
\text{REE} = (21.2 \times \text{FFM}) + 415
\]

This equation is similar to what others have published (ie, REE = 21.6 × FFM + 370; 4). We calculated the average REE from the mean for each subject of the measured REE and that estimated from FFM by using the above equation.

Our GCRC dietitian initially estimated energy needs by using the following Harris-Benedict equations and an increment for physical activity (DEE = 1.6 REE) (HB method):

Males: \(\text{REE} = 66 + (\text{weight, kg} \times 13.7) + (\text{height, cm} \times 5) - (\text{age, y} \times 6.8)\) (3)

Females: \(\text{REE} = 655 + (\text{weight, kg} \times 9.6) + (\text{height, cm} \times 1.7) - (\text{age, y} \times 4.7)\) (4)

For each subject, we also computed the ratio of DEE to the measured REE, to the average REE, and to the HB estimate of daily energy requirement and then compared these ratios to a ratio of DEE to REE (1.7) derived from meta-analyses of a large number of DLW studies (6, 7).

Finally, for each subject, we computed a ratio of DEE to an estimate of DEE (total energy expenditure; TEE), which was taken from a recent report of the Institute of Medicine, National Academy of Science, on macronutrient requirements (16). This report provided equations for predicting DEE on the basis of sex, age, weight, height, and activity factors:

\[
\text{TEE} \text{ (males aged } \geq 19 \text{ y) } = 662 - 9.53 (\text{age, y}) + \text{ PA } [((15.9 \times \text{weight, kg}) + (540 \times \text{height, m})]}
\]

\[
\text{TEE} \text{ (females aged } \geq 19 \text{ y) } = 354 - 6.91 (\text{age, y}) + \text{ PA } [((9.36 \times \text{weight, kg}) + (726 \times \text{height, m})]}
\]

Where, PA, an estimate of physical activity as a ratio to REE, was assumed to be 1.6 based on our analysis of the HB estimate. Also, for this comparison, we used the body weight at the end of the 28-d solid food diet period.

Statistics

Simple and multiple linear regression analyses were used to compare DEE with various estimates of REE. In addition, for

Body composition was assessed by using dual-energy X-ray absorptiometry (DXA) (Hologic Delphi QDR 4500A Bone Densitometer Model DPX- IQ, software version 4.6b; Lunar Corp, Madison, WI) (15). Body energy was estimated by using Atwater conversion values for body fat (9.3 kcal/g) and body protein (assuming 0.2 g protein/g FFM and 4.1 kcal/g protein). DEE was estimated from the average energy intake (EI), which was based on what the subjects were given each day to eat and the change in body energy (ΔBE) estimated from the DXA measurements:

\[
\text{DEE} = \text{EI} - \Delta \text{BE}
\]

Measurement techniques and calculations

Measurements of REE were made in the early morning while the subjects were in a fasting state and after they had rested in bed for 30 min. Specifically, oxygen consumption, and carbon dioxide production, were measured via indirect calorimetry with the use of a metabolic cart with a canopy (Vmax 29; Sensor Medics Corp, Yorba Linda, CA). This measurement was only used before the study to estimate energy intakes; the subjects did not sleep overnight in the GCRC but were asked not to exercise vigorously before arriving at the GCRC, usually at 0630. For this reason, energy expenditure was estimated by using the software that assumes a rate of protein oxidation.
each subject we computed the ratio of DEE to REE, to average REE, and to the estimate of DEE provided by the HB method used by the GCRC dietitian. The mean for each of these ratios was then multiplied by each of the individual estimates of REE, average REE, and the HB estimate. Each of these products then represented estimates of DEE for each subject. We generally used the approach of Bland and Altman (17) to assess how well these various estimates of DEE compared with DEE assessed by using the energy balance approach. In doing so, we followed the specific approach and terminology of Coss-Bu et al (2). Thus, although we did not have a cross-comparison group, we estimated the differences (Δ) between each of these estimates of DEE and “actual” DEE based on energy intake and measurement of energy accretion (2). We then computed the mean difference between each of these 3 estimates of DEE and DEE (ΔDEE) (2). The bias (mean Δ) was equated to the mean difference between each estimate of DEE and actual DEE (2). In the process of carrying out paired t tests comparing each estimate of DEE with the actual DEE, we then also computed the SD of the difference between each of the 3 methods and actual DEE (SDmean Δ) (2). Limits of agreement were then equated to mean Δ ± 2SDmean Δ (2, 17). In the results section, we also present a methods comparison table and figure as described by Coss-Bu et al (2) and originally described by Bland and Altman (17). The results were generally expressed as means ± SEMs, except as otherwise indicated.

RESULTS

Group means (± SEM) for DEE, the HB estimate, measured REE, and REE based on FFM and average REE. DEE correlated (P < 0.001) with FFM (r = 0.78), measured REE (r = 0.73), average REE (r = 0.82), and the HB estimate (r = 0.81) (Table 1). In a multiple regression model containing the first 3 of these variables, R² was 0.70:

\[
\text{DEE (kcal/d) = 1.29 FFM (kg)} + 0.54 \text{measured REE (kcal/d)} + 0.71 \text{HB-estimated DEE (kcal/d)} - 55.17
\]

The ratio of DEE to measured REE, to average REE, or to the HB estimate was 1.86 ± 0.06, 1.79 ± 0.04, and 1.02 ± 0.02, respectively (Figure 1). The mean of these various ratios is 1.82. These estimates also can be compared with an average of estimates of the ratio of DEE to REE (1.7) derived from a meta-analyses of a large number of DLW studies (6, 7). The ratio of DEE to the estimate of TEE provided by the Institute of Medicine report was 0.76 ± 0.02.

The comparisons between estimates of DEE and actual DEE are presented in Table 2. Although the mean bias was small, which indicated that each group estimate of DEE was similar to the actual DEE, the limits of agreement were poor, which suggested that none of the estimates of DEE provided an accurate prediction of individual measurements of DEE. However, it is also relevant to note that when the estimate of DEE derived from REE (13 of 26 subjects) and the average REE or the HB estimate (12 of 26 subjects) were used, the estimate of DEE was within ±200 kcal of the actual DEE. This cutoff was examined because this is the usual point of change in energy intake we make with our diet (ie, the increment in meal size we use in our study, although we sometimes use a 100-kcal unit food). A Bland-Altman plot (17) of the bias (corrected HB estimate minus DEE) as a function of the mean DEE and the corrected HB estimate of DEE is shown in Figure 2.

<table>
<thead>
<tr>
<th>Estimate</th>
<th>kcal/d</th>
</tr>
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<tbody>
<tr>
<td>DEE</td>
<td>2508 ± 98</td>
</tr>
<tr>
<td>HB</td>
<td>2468 ± 79</td>
</tr>
<tr>
<td>Measured REE</td>
<td>1364 ± 51</td>
</tr>
<tr>
<td>REE FFM</td>
<td>1441 ± 45</td>
</tr>
<tr>
<td>Average REE</td>
<td>1403 ± 45</td>
</tr>
</tbody>
</table>

1 All values are x ± SEM; n = 26. DEE was derived from the energy balance calculation shown in the text; HB, estimate of DEE derived from the Harris-Benedict equation estimate of REE and an allowance of 1.6 for physical activity; REE was measured with indirect calorimetry; REE FFM, REE estimated from fat-free mass (see text for equation used); average REE, average of estimates of REE from actual measurements and REE FFM.

### Table 2

<table>
<thead>
<tr>
<th>Estimate</th>
<th>x ± SD Bias</th>
<th>Limits of agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>REE</td>
<td>26.4 ± 363</td>
<td>(−700, 752)</td>
</tr>
<tr>
<td>Average REE</td>
<td>−0.4 ± 289</td>
<td>(−578, 577)</td>
</tr>
<tr>
<td>HB</td>
<td>−1.0 ± 292</td>
<td>(−584, 582)</td>
</tr>
</tbody>
</table>

1 HB, estimate of DEE derived from the Harris-Benedict equation estimate of REE and an allowance of 1.6 for physical activity; REE, resting energy expenditure measured with indirect calorimetry; average REE, average of estimates of REE from actual measurements and REE derived from the measurement of fat-free mass (see text for equation used). Bias was estimated for each subject by subtracting DEE from the estimate of DEE derived from REE, average REE, and HB. Each estimate of DEE was calculated by multiplying each individual estimate of REE, average REE, and HB by the average ratio of DEE to each (1.86, 1.79, and 1.02, respectively). There was no significant difference between any of the 3 estimates of DEE and actual DEE (paired t test). Limits of agreement were equal to x bias ± 2 SD bias.
the actual DEE for such subjects is not accurate. We were heart-ened to find that the average ratios of DEE to our estimates of REE were very similar to those reported in the literature (Figure 1) (6, 7). This finding implies that for the group of subjects studied, compliance with the diet was probably reasonably good because the energy intake for the subjects used in our estimate of DEE was derived from what the subjects were given to eat by the GCRC. Because most trials are ultimately based on group means and variance, this is important and relevant information. Moreover, we suggest that if one cannot perform DLW studies to check the accuracy of energy intake (20–22), assessment of DEE as we have done in our study with a comparison to REE may be useful to those conducting dietary trials with or without the provision of all the food that the subjects eat.

We thank our subjects for their thoughtful participation in this study. We are especially grateful to Steven Heymsfield, a Consultant on our grant, for his overall guidance and advice and specifically for providing us with the equation used to estimate REE from FFM. We thank Diane Habash (The Ohio State University GCRC) and J Ann Livengood (University of Texas Medical Branch GCRC) and their respective staffs for their assistance with the dietary aspects of the study. We are thankful to the nursing staffs at both institutions for their assistance with the clinical aspects of the study, including the performance of the indirect calorimetry, and to Travis Solley, Mary Schmitz-Brown, and Regina Minton for assistance with data management in general and with the indirect calorimetry. Finally, we are grateful to the body composition staff at the University of Texas Medical Branch GCRC and Shriners Hospital for Children.

REFERENCES


DISCUSSION

Numerous studies have examined ways to estimate REE in both healthy and sick people (2–5, 18, 19). Also, many studies have examined the relation of REE and DEE, the latter measured with the DLW technique (summarized in references 6, 7). However, these studies have not examined how measurements that can be rapidly completed in human subjects, such as measurements or estimates of REE or FFM, predict the energy cost of weight maintenance or DEE as defined in this study. Our results suggest that any of the estimates examined in this study provide a good indication of the behavior of a group of subjects, but a relatively poor estimate, on average, for individuals. In this way, our study is similar to what other investigators have found in relatively poor estimate, on average, for individuals. In this way, a good indication of the behavior of a group of subjects, but a suggest that any of the estimates examined in this study provide

![Image](https://academic.oup.com/ajcn/article-abstract/80/4/876/4690390/53x53 to 293x735)

**FIGURE 2.** Plot of the bias in estimating daily energy expenditure (DEE) from the value derived by using the Harris-Benedict equation (HB) versus the average of DEE and the corrected HB estimate of DEE (17). Corrected HB estimates were derived by multiplying individual values for the HB estimate of DEE by the average ratio of DEE to the HB value. Bias is equal to the corrected estimate of DEE from HB minus the measured DEE value.


