Energy Expenditure Is Very High in Extremely Obese Women

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ABSTRACT To test the hypothesis that total energy expenditure (TEE) and resting energy expenditure (REE) are low in extremely obese individuals, factors that could contribute to maintenance of excess weight, a cross-sectional study was conducted in 30 weight-stable, extremely obese women [BMI (mean ± SEM) 48.9 ± 1.7 kg/m²]. TEE was measured over 14 d using the doubly labeled water method, REE and the thermic effect of feeding (TEF) were measured using indirect calorimetry, and activity energy expenditure (AEE) was calculated as TEE – (REE + TEF). Body composition was determined using a 3-compartment model. Subjects were divided into tertiles of BMI (37.5–45.0; 45.1–52.0; and 52.1–77.0 kg/m²) for data analysis. TEE and REE increased with increasing BMI tertile: TEE, 12.80 ± 0.5, 14.67 ± 0.5, and 16.10 ± 0.9 MJ/d (P < 0.01); REE, 7.87 ± 0.2, 8.78 ± 0.3, and 9.94 ± 0.6 MJ/d (P < 0.001), and these values were 29–38% higher than published means of measured TEE in nonobese individuals. No significant differences were observed among BMI tertiles for AEE, TEF, or physical activity level (PAL = TEE/REE, overall mean 1.64 ± 0.16). The Harris-Benedict and WHO equations provided the closest estimates of REE (within 3%), whereas the obese-specific equations of Irton-Jones overpredicted (40%) and Bernstein underpredicted (21%) REE. Extremely obese individuals have high absolute values for TEE and REE, indicating that excess energy intake contributes to the maintenance of excess weight. Standard equations developed for nonobese populations provided the most accurate estimates of REE for the obese individuals studied here. REE was not accurately predicted by equations developed in obese populations. J. Nutr. 134: 1412–1416, 2004.

KEY WORDS: • extreme obesity • energy expenditure • fat-free mass • prediction equations

The prevalence of extreme obesity, as defined by BMI ≥ 40 kg/m², is now 5% in U.S. adults (1), representing a 3-fold increase over the last 40 years. This previously rare condition is associated with profound adverse health consequences; however, very little is known about factors that promote and maintain extreme obesity. Studies using doubly labeled water indicated that individuals with higher than recommended body weight (BMI ≥ 25 kg/m²) have high absolute total energy expenditure (TEE) compared with individuals of lower BMI (2–4). This implies that a high energy intake is required to maintain the excess weight. However, most of those studies were conducted in overweight or marginally obese individuals, and there is very little information available on the extremely obese individuals who may be more likely to have metabolic abnormalities that could predispose to low energy requirements.

The aim of the present study was to test the hypothesis that the weight maintenance energy expenditure of extremely obese individuals is low relative to both published data for nonobese individuals (3) and TEE predicted by the equations of the U.S. Dietary Reference Intakes (DRIs) (5). In addition, the accuracy of equations for predicting resting energy expenditure (REE) was assessed using prediction equations developed for use with nonobese (5–7) individuals and equations developed for use in obese individuals (8,9).

SUBJECTS AND METHODS

Subjects. The subjects were 30 women who were awaiting gastric bypass (GBP) surgery for weight reduction at the Tufts-New England Medical Center Hospital (Table 1). Individuals were ineligible for the study if they had diabetes, cancer, coronary heart disease, endocrine disorders, other acute or chronic diseases, or medication use known to influence energy expenditure. Measurements were conducted at the Clinical Study Unit (CSU) of the Tufts-New England Medical Center Hospital and at the Jean Mayer USDA Human Nutrition Research Center on Aging at Tufts University. The study was approved by the Human Investigation Review Committee of Tufts-New England Medical Center Hospital. All subjects gave written, informed consent before participating.

Study design. All subjects were monitored for weight stability for 1 mo before the study and only those who were weight stable (defined as body weight maintained within ± 2.3 kg of starting weight) were allowed to participate. Two subjects whose BMI was slightly below 40 kg/m² and who were eligible for GBP surgery were included in the
study population. The study was conducted over a 15-d period. Subjects were free-living except for 2 overnight inpatient stays for measurements of REE and the thermic effect of feeding (TEF), and an additional 36-h period for other testing. Subjects were admitted to the CSU the day before the start of the study. After an overnight fast, measurement of TEE by doubly labeled water was started and REE measurement was conducted on the morning of d 15. Other measurements during the study period included collection of blood samples from fasting subjects and the administration of food frequency and physical activity questionnaires.

**Measurement.** A 15-d doubly labeled water study was conducted to measure TEE, REE and TEF were measured using indirect calorimetry (Deltatrac portable metabolic cart, Sensor Medics). The Siri 3-compartment model was used to estimate the percentage of body fat and body composition, and standard anthropometric measures were also obtained. Biochemical measures such as thyroid function tests and leptin were determined in blood from fasting subjects. Insulin and glucose were also measured in fasting subjects, and the homeostasis model assessment for insulin sensitivity (HOMA) was calculated using these values (10,11). Self-reported leisure time activity during the previous 12-mo period was determined by a structured interview using the Minnesota Leisure Time Physical Activity (LTPA) questionnaire; occupational activity over the previous 12 mo was also assessed using the self-administered Tecumseh Occupational Activity Questionnaire. All of the above methods were detailed and referenced previously (12,13).

**Results.** All subjects were weight stable during the 1-mo period preceding the study [Δ body weight (mean ± SD), 1.46 ± 0.35 kg of starting weight] and were weight stable during the study period (Δ body weight, 4.2 ± 26 g/d). Physical characteristics of the subjects except for body weight after fasting and BMI were similar among the tertiles of BMI in these extremely obese women (Table 1), and values of all biochemical variables were within normal range for all subjects. Glucose was significantly higher in fasting subjects in the highest BMI tertile compared with the middle tertile (P < 0.05), and leptin was elevated in fasting subjects in the middle BMI tertile (P < 0.05) compared with the lowest tertile.

Energy expenditure variables by tertile of BMI are shown unadjusted for body composition (Table 2) and therefore illustrate the effect of increasing BMI on energy expenditure. Both TEE and REE were significantly higher in the highest BMI tertile compared with the lowest tertile. However, when energy expenditure variables such as TEE and REE were adjusted for FFM, there were no significant differences among tertiles. This indicated that the differences in energy expenditure between the highest and lowest tertiles were due to differences in FFM.

**TEE values for all BMI tertiles were significantly higher than the mean TEE (9.51–10.21 MJ/d; P < 0.001) in nonobese women from a published summary (3). Measured TEE was also significantly higher (14.3 MJ/d) than the mean U.S. DRIs estimates of dietary energy needs using the subjects' actual weight in 1) equations developed in normal weight women (11.69 MJ/d; P < 0.001), 2) the combined equation for normal, overweight and obese women (12.42 MJ/d; P < 0.001), or 3) the equation for overweight and obese women (12.77 MJ/d; P < 0.001) (5).**

No significant differences were observed among BMI tertiles for AEE, TEF, physical activity level (PAL), or food quotient (FQ). In addition, the respiratory quotient (RQ) in fasting subjects was significantly higher in the lowest BMI tertile, but postprandial RQ (averaged over the 4 h TEF) did not differ significantly.
In our own data set, mean TEE in the highest BMI tertile was significantly higher than the current U.S. DRI (5) for nonobese persons, $P < 0.001$.

Regression analyses (Table 3) showed that TEE was best predicted by FFM ($R^2 = 0.56; P < 0.001$). Although FFM alone significantly predicted REE ($R^2 = 0.63; P < 0.001$), the addition of fat mass to the regression model substantially improved the prediction for REE ($R^2 = 0.71; P < 0.001$). AEE was also significantly predicted by FFM ($R^2 = 0.12; P < 0.05$).

Comparison of measured REE with predicted REE for several published equations, i.e., the Harris–Benedict equation (6), the WHO prediction equation (8,9), and 2 equations developed for use in the obese (37.5–52) (8,9) (Fig. 2). The WHO equation ($-0.12$ MJ/d; adjusted $P = 0.97$) and the Harris–Benedict equation ($0.23$ MJ/d; adjusted $P = 0.79$) showed nonsignificant mean differences from measured REE. The Harris–Benedict equation underpredicted, and the WHO equation overpredicted REE by only $0.05$.

![FIGURE 1](https://academic.oup.com/jn/article-abstract/134/6/1412/4688758)

**TABLE 2**

Summary of energy expenditure data by tertiles of BMI in 30 weight stable, extremely obese women

<table>
<thead>
<tr>
<th></th>
<th>(37.5–45)</th>
<th>(45.1–52)</th>
<th>(52.1–77)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n$</td>
<td>12</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>TEE† MJ/d</td>
<td>12.80 ± 0.5a</td>
<td>14.7 ± 0.5ab</td>
<td>16.1 ± 0.9b</td>
</tr>
<tr>
<td>REE* MJ/d</td>
<td>7.87 ± 0.2a</td>
<td>8.78 ± 0.3ab</td>
<td>9.94 ± 0.6b</td>
</tr>
<tr>
<td>AEE MJ/d</td>
<td>3.7 ± 0.4</td>
<td>4.7 ± 0.3</td>
<td>4.9 ± 0.6</td>
</tr>
<tr>
<td>TEF, % of test meal energy</td>
<td>6.85 ± 0.71</td>
<td>8.18 ± 1.0</td>
<td>10.46 ± 2.2</td>
</tr>
<tr>
<td>PAL</td>
<td>1.61 ± 0.06</td>
<td>1.67 ± 0.04</td>
<td>1.62 ± 0.05</td>
</tr>
<tr>
<td>Fasting RQ#</td>
<td>0.79 ± 0.01a</td>
<td>0.77 ± 0.01b</td>
<td>0.77 ± 0.01b</td>
</tr>
<tr>
<td>Postprandial RQ</td>
<td>0.81 ± 0.01</td>
<td>0.80 ± 0.01</td>
<td>0.80 ± 0.01</td>
</tr>
<tr>
<td>FQ</td>
<td>0.85 ± 0.01</td>
<td>0.84 ± 0.01</td>
<td>0.84 ± 0.01</td>
</tr>
<tr>
<td>Self-reported physical activity, min/d</td>
<td>299 ± 59</td>
<td>344 ± 63</td>
<td>225 ± 62</td>
</tr>
</tbody>
</table>

$^1$ Values are means ± SEM. Means in a row with superscripts without a common letter differ, $P < 0.05$. Symbols indicate significant main effects of BMI, *$P < 0.001$, †$P < 0.01$, and # $P = 0.01$. TEE values in all tertiles were also significantly higher than the current U.S. DRI (5) for nonobese persons, $P < 0.001$.

**TABLE 3**

Regression models showing predictors of TEE, REE, and AEE in 30 weight stable, extremely obese women

<table>
<thead>
<tr>
<th></th>
<th>$\beta$-Coefficient ± SEE$^2$</th>
<th>$P$-value</th>
<th>Adjusted $R^2$ ($P$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEE</td>
<td>Constant 3.364 ± 1.806</td>
<td>0.073</td>
<td>0.56 ($&lt;0.001$)</td>
</tr>
<tr>
<td></td>
<td>FFM 0.177 ± 0.029</td>
<td>$&lt;0.001$</td>
<td></td>
</tr>
<tr>
<td>REE</td>
<td>Model 1 Constant 2.183 ± 0.930</td>
<td>0.026</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FFM 0.106 ± 0.015</td>
<td>$&lt;0.001$</td>
<td>0.63 ($&lt;0.001$)</td>
</tr>
<tr>
<td></td>
<td>Model 2 Constant 2.872 ± 0.856</td>
<td>0.026</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FFM 0.029 ± 0.01</td>
<td>0.004</td>
<td>0.71 ($&lt;0.001$)</td>
</tr>
<tr>
<td></td>
<td>Fat Mass 0.062 ± 0.020</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>AEE</td>
<td>Model 1 Constant -0.032 ± 1.505</td>
<td>0.983</td>
<td>0.21 (0.006)</td>
</tr>
<tr>
<td></td>
<td>FFM 0.071 ± 0.024</td>
<td>0.006</td>
<td></td>
</tr>
</tbody>
</table>

![FIGURE 1](https://academic.oup.com/jn/article-abstract/134/6/1412/4688758)
with numerous reports of low energy intake in obese individuals and the obese-specific Bernstein (8) and Ireton-Jones (9) equations.

3%. The sum of squared differences between measured and predicted REE was larger for the WHO equation (69 vs. 53) than for the Harris-Benedict equation, indicating that the Harris-Benedict equation was more precise. When equations developed in obese populations were used, measured REE was significantly different from that predicted using the Ireton-Jones equation (−3.30 MJ/d; adjusted P < 0.001) and the Bernstein equation (1.87 MJ/d; adjusted P < 0.001). The Ireton-Jones equation overpredicted REE by 40% and the Bernstein equation underpredicted REE by 18%. In addition, the sum of squared differences between measured and predicted REE was very large for both equations (122, for the Bernstein equation and 458, for the Ireton-Jones equation), indicating that the obese-specific equations were poor predictors of REE.

**DISCUSSION**

The major finding of this study was that the TEE of our extremely obese subjects was very high and increased with increasing BMI from (mean ± SEE) 12.79 ± 0.5 MJ/d in the lowest BMI tertile ([mean ± SD], BMI, 20.8 ± 2.1 kg/m²) to 16.61 ± 0.76 MJ/d in the highest BMI tertile (mean BMI, 61.2 ± 8.8 kg/m²). We chose to examine and present data using BMI tertiles because we wanted to determine whether energy expenditure increased with increasing body mass over the wide range of BMI in our study. The TEE value for the highest BMI tertile was 41% higher on average than the mean TEE of nonobese women (10), but is entirely consistent with previous TEE data from smaller studies of extremely obese persons (34 subjects total) (19–26). There are several aspects of our study design that deserve mention. The use of doubly labeled water to measure TEE and a multicompartment model for the measurement of body composition was important. Doubly labeled water is the only recognized accurate method for estimation of TEE in free-living subjects (27,28) and is the only method that is relatively independent of inaccurate dietary reporting (15–18). Although previous study that compared TEE measured in a calorimetric chamber with that of TEE from doubly labeled water measurements indicated that doubly labeled water may underestimate TEE in obese subjects (20), the degree of underestimation in that study was small (mean ± SD, −4.4 ± 5.2%). Furthermore, an underestimation of TEE in obese individuals would only strengthen our findings of high TEE in our population.

In conclusion, absolute values for TEE and REE in extremely obese individuals are high and increase with increasing body mass. In addition, TEE and REE in our extremely obese subjects were higher than published values for nonobese individuals (3), and also higher than the U.S. DRI estimates of dietary energy requirements in nonobese individuals (5,29). These observations strongly suggest that high energy intakes contribute to the maintenance of excess weight in extremely obese individuals. Finally, the most widely used Harris-Benedict equations and WHO equations provided the closest estimate for predicted REE, and the obese-specific equations were inaccurate for use in our extremely obese individuals.

**ACKNOWLEDGMENTS**

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**LITERATURE CITED**
