Prediction of 24-h energy expenditure and its components from physical characteristics and body composition in normal-weight humans

Arne Astrup, Grete Thorbek, John Lind, and Björn Isakson

ABSTRACT The applicability of body composition as estimated by the bioimpedance method to predict energy expenditure (EE) was studied. Ten healthy subjects underwent measurement of body composition and 24-h energy expenditure (24-h EE) twice in a respiration chamber on a fixed program. The 24-h EE and its components, sleeping EE (SEE), basal EE (BEE), and daytime EE, for an individual were very reproducible (coefficient of variation 2.3%, 1.4%, 5.0%, & 3.1%, respectively). The variability of 24-h EE among subjects was 11.4% but only 4.1% when adjusted for differences in lean body mass (LBM). LBM was the best determinant of 24-h EE, BEE, and SEE and accounted for 91–93% of the interindividual variance of EE. The prediction equations were 24EE (kcal/d) = 390 + 33.3 LBM (r² = 0.93, P = 0.000001), SEE (kcal/h) = 9.8 + 1.1 LBM (r² = 0.92, P = 0.000001), and BEE (kcal/h) = −3.1 + 1.35 LBM (r² = 0.91, P = 0.000002). In conclusion, 24EE, BEE, and SEE can be predicted with a high degree of precision from LBM as estimated by bioimpedance in normal-weight subjects. Am J Clin Nutr 1990;52:777–83.

KEY WORDS Body composition, energy expenditure, energy requirement, indirect calorimetry, lean body mass

Introduction

There is a need for information on the energy requirements of individuals because it has direct application to management of obese and postobese patients. Energy requirements for weight maintenance are highly variable from individual to individual but reasonably stable in each subject unless gross overfeeding or prolonged semistarvation occurs. In adult humans energy requirements equal energy expenditure (EE) during weight maintenance and can either be assessed by calorimetry or estimated indirectly by equations using simple physical characteristics. In 1985 an FAO/WHO/UNU report presented equations on how to estimate basal energy expenditure (BEE) from age, sex, and body weight (1). This factorial method has a low predictive value for estimating BEE because these three factors account for < 50% of the variation in BEE (1).

It is now well established that the effects of age, sex, and body weight on BEE are due to variations in lean body mass (LBM), and the correlation coefficient (r) between LBM and BEE may be as high as 0.91 (r² = 0.82), indicating that 82% of the variance in BEE is accounted for by LBM (2). However, such a high figure requires considerable precision in the determination of LBM, which is usually performed by underwater weighing, as well as an accurately and nonstressful measure of BEE, as with the ventilated-hood system (2). Determinations of body composition by techniques such as underwater weighing and tritiated-water space measurements are accessible for scientific purposes, but they are too expensive for clinic and epidemiologic use. The bioimpedance method offers an easy, quick, and inexpensive way to get a precise estimate of LBM and fat mass (3). The method was highly validated against other methods by various conditions (3–5).

The purposes of the present study were 1) to measure 24-h energy expenditure (24-h EE) and its components in a high-precision respiration chamber and determine the day-to-day variation in normal-weight subjects and 2) to develop prediction equations of EE from estimates on body composition obtained from bioimpedance measurements.

Methods

Subjects

Ten healthy, normal-weight subjects of both sexes (six males and four females), aged 22–47 y, participated. The subjects were university students and staff volunteers. None smoked or took medicine during the study. They had normal hemoglobin and thyroid-hormone status.

Experimental design

The study was approved by the Municipal Ethical Committee of Frederiksberg and Copenhagen. All subjects participated

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TABLE 1
Anthropometric data of subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sex</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>Lean body mass</th>
<th>Fat mass</th>
<th>Body mass index</th>
</tr>
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<tr>
<td>1</td>
<td>M</td>
<td>22</td>
<td>1.85</td>
<td>90.0</td>
<td>78.3</td>
<td>11.7</td>
<td>26.3</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>25</td>
<td>1.66</td>
<td>72.6</td>
<td>55.7</td>
<td>16.9</td>
<td>26.3</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>25</td>
<td>1.70</td>
<td>67.2</td>
<td>52.9</td>
<td>14.3</td>
<td>23.3</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>34</td>
<td>1.58</td>
<td>53.3</td>
<td>44.3</td>
<td>9.0</td>
<td>21.4</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>23</td>
<td>1.78</td>
<td>75.8</td>
<td>63.9</td>
<td>11.9</td>
<td>23.9</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>23</td>
<td>1.63</td>
<td>62.5</td>
<td>47.3</td>
<td>15.2</td>
<td>23.5</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>27</td>
<td>1.83</td>
<td>76.4</td>
<td>63.8</td>
<td>12.6</td>
<td>22.8</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>47</td>
<td>1.81</td>
<td>73.8</td>
<td>61.2</td>
<td>12.6</td>
<td>22.5</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>45</td>
<td>1.65</td>
<td>60.4</td>
<td>44.5</td>
<td>15.9</td>
<td>22.2</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>30</td>
<td>1.85</td>
<td>74.8</td>
<td>62.7</td>
<td>12.1</td>
<td>21.9</td>
</tr>
</tbody>
</table>

in measurements of 24-h EE in the respiration chambers on two occasions separated by 4 wk. Consecutive measurements in women were performed at the same time in the menstrual cycle. A typical Danish diet with fixed components (19% protein, 43% fat, 38% carbohydrate) was given for weight maintenance and was served on both occasions. On the basis of national food tables, the gross energy intake was calculated to be 2250–2580 kcal/d for males and 2010–2280 kcal/d for females (Dankost dietetic software, National Food Agency, Seborg, Denmark). Protein intake for males was 75–85 g/d and for females, 64–78 g/d. On study days the subjects entered the respiration chamber at 0830 after ≥ 12 h of fasting and after voiding. Breakfast was served ~0845 and the gas-exchange measurements were started at 1000 and continued for 24 h. The subjects followed a standard daily activity schedule consisting of two 15-min bicycling sessions, at 1030 and 1500, on a stationary bicycle at a speed of 20 km/h with a load of 1.5 kg. Subjects prepared for bed at 2245 and were in bed at 2300. The remainder of the time was occupied with sedentary activities and some spontaneous activities (reading, watching television, sewing, making beds, etc.). Lunch was served at 1230, coffee or tea at 1515, and dinner at 1800. Subjects were awakened the next morning at 0650, and after voiding they went to bed for a 1-h measurement of BEE (basal metabolic rate) during physical rest. Beds were folded away at 0800 and room temperature was raised to 24 °C from a night temperature of 18 °C. Breakfast was served at 0830 followed by sedentary activities until the measurements were finished at 1000.

Anthropometry
Physical characteristics of the subjects are given in Table 1. All measurements were made in the morning after an overnight fast and after voiding. Body weight was measured on a decimal scale (Seca model 707, Copenhagen) and bioimpedance was measured by an Anitimer (HTS-Engineering Inc, Odense, Denmark) as described by Lukas et al (3). LBM was calculated by using the equation reported by Khaled et al (4) and fat mass was determined as body weight minus LBM.

The respiration unit
The respiration unit at the Research Department of Human Nutrition in Copenhagen was built in 1988 to measure 24-EE in humans by indirect calorimetry on the basis of measurements of oxygen consumption, carbon dioxide production, and nitrogen excretion in urine. The unit consists of two respiration chambers built of steel plates (3 mm) welded together, airtight, with a floor area of 6.5 m² (366 × 178 cm) and a volume of 14.7 m³ (height 226 cm). The walls are insulated with plasterboard and painted and the floor is covered with chipboard and vinyl. A false ceiling, built of noise-suppressing plates, hangs 10 cm below the ceiling of the chamber and 5 cm from the walls.

A door (60 × 180 cm high), fitted with a U-shaped frame lined with lists of rubber, can be fixed airtight to the chamber by bolt clamps and can be opened from both sides. Daylight comes through a window (80 × 70 cm high) with curtains, and further lighting is provided by four lamps affixed to the walls. Meals are served through an airtight hatch (50 × 40 × 26 cm high) in the wall. A moveable toilet for separate collection of feces and urine is placed in another airtight hatch (40 × 50 × 36 cm high) on the back wall.

The chamber is furnished with a writing desk that can be lowered, an office chair, an armchair, and a comfortable bed (85 × 200 cm), which can be placed upright when not in use. The chamber is also equipped with a washstand with hot and cold water, a mirror, a telephone, a television set, a radio, and a stationary bicycle.

Atmospheric air is sucked into the respiration chamber by an airtight centrifugal ventilator (CRA-310, Novenco, Copenhagen) working with a constant revolution and a maximum pressure of 13 mm Hg. A constant flow of 2–5 m³/h and a slight negative pressure of ~1 mm Hg in the chamber can be obtained.

The climate in the chamber can be kept constant at any temperature between 15 and 30 °C and at any relative humidity between 40% and 60% by an internal ventilation system. A centrifugal ventilator (D4E 200-CA02, Novenco) with a maximum capacity of 1500 m³/h can be regulated to give comfortable ventilation of the chamber and to secure fast and thorough mixing of the chamber gas. The ingoing air passes a cooling and a heating surface so that the required temperature and humidity are obtained before the air enters the chamber over the false ceiling. A sample of the mixed chamber gas is continuously drawn for measurements of airflow and air composition. The
TABLE 2
Repeated measurements of 24-h energy expenditure (EE) and its components at 4-wk intervals in 10 normal-weight subjects

<table>
<thead>
<tr>
<th></th>
<th>24-h EE</th>
<th>Basal EE (0700–0800)</th>
<th>Daytime EE (1000–2300)</th>
<th>SEE (2300–0700)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement 1*</td>
<td>2317 ± 112</td>
<td>75 ± 4.7</td>
<td>112 ± 4.5</td>
<td>71 ± 3.7</td>
</tr>
<tr>
<td>Measurement 2*</td>
<td>2293 ± 122</td>
<td>74 ± 4.3</td>
<td>110 ± 5.2</td>
<td>71 ± 3.6</td>
</tr>
<tr>
<td>Index (%)†</td>
<td>—</td>
<td>104 ± 1.3</td>
<td>156 ± 1.4</td>
<td>100 ± 0</td>
</tr>
<tr>
<td>Within-subject CV (%)‡</td>
<td>2.3</td>
<td>5.0</td>
<td>3.1</td>
<td>1.4</td>
</tr>
<tr>
<td>Between-subjects CV (%)</td>
<td>11.4</td>
<td>19.9</td>
<td>15.3</td>
<td>16.7</td>
</tr>
<tr>
<td>Effect of sex§</td>
<td>P &lt; 0.001</td>
<td>P &lt; 0.002</td>
<td>P &lt; 0.01</td>
<td>P &lt; 0.01</td>
</tr>
<tr>
<td>Effect of time</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

* 24-h EE measured in kcal/d; basal, daytime, and sleeping EE measured in kcal/h. x ± SEM.
† Index refers to EE relative to sleeping EE (%).
‡ Coefficient of variation.
§ Statistical effect of sex on mean values of EE.

The climate of the chamber is controlled continuously by temperature and humidity sensors connected with a corresponding thermostat and hygrostat (Landis and Gyr, Copenhagen). The temperature and humidity are kept within ±0.5 °C and ±1% relative humidity, respectively, and readings of the actual climate in the chamber are registered by a recorder.

The total volume of the outgoing air is determined by measuring the differential pressure over an orifice in the pipe from the chamber. The metering system (Hartmann and Braun, Frankfurt, FRG) involves measurements of the differential pressure, the actual pressure, and the temperature in the pipe. The electrical signals from the instruments are transmitted to a state corrector, which standardizes the actual volume to standard temperature and pressure (STP) conditions (760 mm Hg, 0 °C), and are displayed by a pulse counter and a recorder and transmitted to a computer.

To obtain representative samples of outgoing air a side pipe leads air through a system where two subsequent side pipes branch out in order to reduce the sample airstream to 30 L/h. The air flow into the side pipes is controlled by airtight valves and diaphragm pumps. Unrepresentative samples created by stratification in the main pipes are thus avoided. For financial reasons only one set of gas analyzers is used for both chambers; therefore, it is necessary to alternate between the gases from the chambers. The shift is controlled automatically by means of solenoid valves with intervals of 2 min, by which the composition of the gas from each chamber is measured 15 times/h.

Before being analyzed, the air sample passes through small CaCl₂ towers (for drying), a dust filter, and a flowmeter. The concentration of carbon dioxide is measured by infrared absorption (Uras 3 G, Hartmann and Braun) with an output from 0 to 20 mA corresponding to 0–1.5% CO₂. The concentration of oxygen is measured by paramagnetism (Magnos 4 G, Hartmann and Braun), with an output from 0 to 20 mA corresponding to 21–19% O₂. Both gas analyzers operate with an accuracy of ±0.5%. The air composition for the two chambers are alternately registered on a recorder; the electrical signals are transmitted to an analog-digital converter and transmitted to the computer and printer. With the program developed all measurements of airflow and gas composition can be printed and the mean for 24 h, or any time interval chosen, can be calculated and printed.

Calculation of gas exchange and energy expenditure

The volumes of oxygen and carbon dioxide leaving the chamber are calculated from the measured total volume of outgoing air (Vₒ) and the mean fractions of oxygen and carbon dioxide (Fₒ_CO₂ and Fₒ_N₂), whereas the volume of nitrogen is calculated as Vₒ × (1 – Fₒ_CO₂ – Fₒ_N₂). With the assumption that the composition of the ingoing atmospheric air is 0.20946 O₂ (Fₒ_CO₂), 0.00034 CO₂ (Fₒ_CO₂), and 0.79020 N₂ (Fₒ_N₂), the volume of ingoing oxygen (Vₒ/O₂) is Vₒ × Fₒ_N₂ × 0.20946/0.79020 and the volume of ingoing carbon dioxide (Vₒ/CO₂) is Vₒ × Fₒ_N₂ × 0.00034/0.79020. Before calculation of EE, the amounts of oxygen consumed (Vₒ/O₂) and carbon dioxide produced (Vₒ/CO₂) by burning cigarettes are subtracted.

Twenty-four-hour urine collections were made commencing after the first voiding and including the first voiding of the next day. Volume was read and a sample was stored at −20 °C and analyzed for nitrogen with an analyzer (NA 1500, Carlo Erba Strumentazione, Milan, Italy).

EE was calculated by use of the following equation used for determination of EE in mammals, assuming the contribution of methane production to EE to be negligible (6):

\[
EE \text{ (kcal)} = 3.87 \times Vₒ \times \text{L} + 1.20 \times V₉₇ \times \text{V}_\text{CO₂} \times \text{L} - 1.43 \times Uₙ \times \text{g}
\]

where Uₙ is urine nitrogen.

The gas analyzers were adjusted before and after each experiment but not during measurement because no tendency to drift was found. The whole unit was regularly calibrated by comparing a known volume of carbon dioxide entering the chamber with the volume of carbon dioxide measured by the unit. The amount of carbon dioxide entering the chamber was measured by weight with an electronic precision platform scale (F150S, Sartorius, GmbH, Goettingen, FRG) with an accuracy of ±1 g at a maximum weight of 150 kg. A gas cylinder with 100% CO₂ was placed on the scale and 600–800 g CO₂, corresponding to a 24-h production from humans was released into the chamber over a period of 16–18 h and measured by the unit, all values being corrected to STP. Comparing the values of ingoing and outgoing carbon dioxide showed that a high degree of accuracy was obtained from 10 calibration experiments in each chamber, with mean values (±SD) of 1.016 ± 0.0069 and 0.993 ± 0.0042 for chambers A and B, respectively.
Statistical analysis

A multifactor analysis of variance with age and gender as covariates was performed to test differences between experimental periods, and two means were compared by post-hoc testing. Linear and step-wise regression analyses were performed with Statgraphics software (Graphic Software Systems, Inc., Rockville, MD). EE was adjusted for differences in LBM as described by Bogardus et al (2). Unless otherwise stated all results are expressed as mean ± SEM.

Results

The results of the 24-h EE and its components were very similar when duplicate measurements were made (Table 2). There were no significant differences between the duplicate measurements (effect of time). 24-h EE and its components varied considerably from subject to subject (Table 2). All components of 24-h EE were significantly lower in females than in males (Table 2). EE was lowest during sleep, and when expressed relative to SEE, BEE was 104 ± 6% (CV 5.5%) and daytime EE was 156 ± 6% (CV 4.1%).

When EE was expressed in relation to LBM, the assumed metabolically active tissue, the within-subject variation was unchanged but between subjects the variation was reduced (Table 3). After adjustment for differences in LBM, the CVs were further reduced and no significant effect of sex remained (Table 3).

Physical characteristics such as body weight, height, metabolic live weight (kg⁰.⁷⁵), and BMI were found to be significantly related to 24-h EE (Table 4). According to a step-wise regression analysis, these factors exerted their effect on EE only through covariation with LBM. Consequently, 24-h EE, BEE, and SEE were best predicted by LBM without any statistically significant effect being added by sex, age, fat mass, or energy intake. LBM was highly correlated to SEE as shown in Figure 1 [SEE (kcal/h) = 9.8 + 1.1 LBM, r² = 0.92, P = 0.000001]. Similar high correlations were found between LBM and BEE [BEE (kcal/h) = -3.1 + 1.35 LBM, r² = 0.91, P = 0.000002] and LBM and 24-h EE [24-h EE (kcal/d) = 390 + 33.3 LBM, r² = 0.93, P = 0.000001]. The intercepts of the regression equations for 24-h EE and for SEE were significantly different from zero (P = 0.006 and P = 0.04, respectively) whereas the intercept for the BEE equation was nonsignificant (P = 0.60). In these correlations duplicate measurements of EE were included as shown in Figure 1 and Figure 2. However, an assessment of the correlations separately for the first and second measurement did not reduce the coefficient of correlation, and no difference was observed between the duplicate measures.

The validity of other prediction algorithms for the present individuals is shown in Table 5. Generally, the mean difference between predicted and observed BEE was small and the relative maximum error was of the order of 10–20% (Table 5). An exception was the FAO/WHO factorial method, which yielded a maximum predictive error of 25% and r² between predicted and observed BEE of 77%.

TABLE 3
Repeated measurements of 24-h EE and its components, expressed in relation to lean body mass

<table>
<thead>
<tr>
<th></th>
<th>24-h EE</th>
<th>Basal EE</th>
<th>Daytime EE</th>
<th>Sleeping EE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement 1*</td>
<td>40.6 ± 0.7</td>
<td>1.33 ± 0.01</td>
<td>2.03 ± 0.01</td>
<td>1.23 ± 0.01</td>
</tr>
<tr>
<td>Measurement 2*</td>
<td>40.1 ± 0.7</td>
<td>1.34 ± 0.01</td>
<td>1.97 ± 0.01</td>
<td>1.19 ± 0.01</td>
</tr>
<tr>
<td>Within-subjects CV (%)</td>
<td>2.5</td>
<td>5.0</td>
<td>2.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Between-subjects CV (%)</td>
<td>4.8</td>
<td>5.6</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Adjusted CV (%)#</td>
<td>4.1</td>
<td>6.0</td>
<td>5.8</td>
<td>4.7</td>
</tr>
<tr>
<td>Effect of sex‡</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Effect of time‡</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

* 24-h EE measured in kcal·d⁻¹·kg LBM⁻¹; basal, daytime, and sleeping EE measured in kcal·h⁻¹·kg LBM⁻¹. x ± SEM.
† CV after adjustment for differences in lean body mass (2).
‡ Statistical effect of sex on mean values of EE.

TABLE 4
Squared Pearson correlation coefficients between EE and body characteristics

<table>
<thead>
<tr>
<th></th>
<th>24-h EE</th>
<th>Basal EE</th>
<th>Sleeping EE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>0.72*</td>
<td>0.69*</td>
<td>0.67*</td>
</tr>
<tr>
<td>Body weight</td>
<td>0.89*</td>
<td>0.82*</td>
<td>0.85*</td>
</tr>
<tr>
<td>Lean body mass</td>
<td>0.93*</td>
<td>0.91*</td>
<td>0.92*</td>
</tr>
<tr>
<td>Body mass index</td>
<td>0.28†</td>
<td>0.22†</td>
<td>0.27†</td>
</tr>
<tr>
<td>Body weight⁰.⁷⁵</td>
<td>0.88*</td>
<td>0.81*</td>
<td>0.84*</td>
</tr>
<tr>
<td>FAO/WHO</td>
<td>0.82*</td>
<td>0.77*</td>
<td>0.79*</td>
</tr>
</tbody>
</table>

* P < 0.00001.
† P < 0.05.

FIG 1. Correlation between lean body mass (LBM) as measured by the bioimpedance technique and duplicate measurements of sleeping energy expenditure (SEE) in six males and four females. For duplicate measures of SEE, the CV is 1.4%.
24-hour Energy Expenditure (kcal)

FIG 2. Correlations between LBM and 24-h EE and basal EE (BEE) in six males and four females. For duplicate measurements of 24-h EE and BEE, CVs are 2.3% and 5.0%, respectively.

Discussion

The present study confirms previous reports indicating that measurements in a respiration chamber are very reproducible (11–13). 24-h EE within-individual variation was only 2.3% and the lowest variation was found to be 1.4% during sleep. These figures are similar to those reported for duplicate measures in other chamber studies (11–13). BEE varied more than did SEE and 24-h EE, which was expected because BEE was only measured for 1 h.

The variation of EE is composed of a biological variation and a variability of the method. According to the calibration studies, the day-to-day variation of respiration chamber measurements is 0.5%, which leaves a biological within-individual variation of 1% on SEE and of 2% on 24-h EE. In our protocol a fixed standardized schedule was followed for all activities in the chambers, including physical activity in the form of bicycling. To ensure optimal adherence to the protocol, the subjects were kept under intermittent surveillance by a medical student except for the time they spent on personal hygiene.

The low day-to-day variation in 24-h EE and the finding that there was no trend toward a decline from the first to the second measurement suggests that the subjects were totally unstressed even at the first occasion. However, the participants of this study were students and staff members who were familiar with the setting and respiration chambers. Patients and other non-professionals may become slightly stressed during the first stay, which may reduce the EE in repeated measurements (14). In addition, to avoid variation due to the impact of menstrual cycle on EE (15), repeated measurements in women were carried out at the same time in their menstrual cycles.

Between subjects there was a more pronounced variation in 24-h EE and its components (CV 11–20%), females having significantly lower figures than did males (Table 2). By contrast and agreeing with other studies, the effect of sex disappears when the EEs are standardized on the basis of LBM, which is an estimate of metabolically active tissue (7). When expressed as relative to LBM or adjusted for differences in LBM, the between-subject variations of 24-h EE, BEE, and SEE were reduced to 4.1–6.0% (Table 3). Furthermore, LBM represents the best predictor of EE compared with other physical characteristics and indexes (Table 4). In our study differences in LBM account for 91–93% of the variation in EE between people. This figure is better than the 81% reported by Ravussin et al (7) and the 55–64% reported by other groups (9, 16–18). An exception was Owen et al (17) who found that 92% of the variation in BEE could be accounted for by differences in LBM but only in athletic women. The corresponding figures in nonathletic women and in men were 55–59% (16, 17). Bogardus et al (2) found that 82% of the variance could be accounted for by LBM and inclusion of age and sex increased the figure to 83%. However, family membership accounted for an additional 11%, so 94% of the variability of BEE was explained (2).

Obviously, our high value of variation explained by LBM (91%, $r = 0.96$) seems to be partly because we only included lean subjects whereas most reported studies also included overweight and obese subjects. It is well established that some overweight and obese subjects have lower BEE expressed in relation to LBM (19) whereas others have normal values (18). Consequently, when overweight subjects are included, the relation between LBM and EE cannot display total linearity and this results in lower coefficients of correlation. Thus, with increasing overweight, total LBM may become less metabolically active. It is well known that ~25% of the excessive body weight
of obesity is lean body tissue. It is not fully elucidated how this excessive LBM is composed, but a relative lower contribution of body cell mass and a larger contribution of body fluids may explain a lower metabolic activity per unit LBM. Garby et al (10) showed that the relation between LBM and EE cannot be linear because the fat mass also contributes to EE. This finding should be considered when EE is assessed in obese individuals. It is also possible that individuals predisposed to obesity have lower BEE per kilogram LBM as indicated by studies of pre-obese (2) and postobese subjects (20).

In addition, differences in the methods for estimating fat-free mass or LBM may contribute to the residual variation on EE not explained by LBM, although any attempt to validate methods of body composition is hampered by the lack of a suitable “gold standard.” The bioimpedance method used in the present study may have a lower methodologic error than does underwater weighing, which recently was shown to overestimate LBM compared with estimates based on measurements of total body potassium and deuterium dilution of body water (21). In addition, in obese subjects LBM from density was found to be ~5 kg smaller than LBM from impedance (22).

In conclusion, the factorial method using simple physical characteristics as age, sex, and body weight for prediction of EE (1) has a low predictive value compared with the more precise equations using the strong relation between LBM and EE. The present study suggests that the easy, quick, and inexpensive bioimpedance technique is appropriate for this purpose in normal-weight subjects. However, the results should be confirmed in a cross-validation study in another group of subjects.

References


