Prediction of resting energy expenditure in a large population of obese children

Hélène Derumeaux-Burel, Martine Meyer, Liliane Morin, and Yves Boirie

ABSTRACT

Background: Recommendations for energy intake in obese children rely on accurate methods for measuring energy expenditure that cannot be assessed systematically.

Objective: The aim was to establish and validate new equations for predicting resting energy expenditure (REE), specifically in obese children.

Design: REE (indirect calorimetry) and body composition (bioelectrical impedance analysis) were measured in 752 obese subjects aged 3–18 y. The first cohort (n = 471) was used to establish predictive equations, the second (and independent) cohort (n = 211) was used to validate these equations, and the third cohort, a follow-up group of children who lost weight (n = 70), was used to examine predictive REE in the postobese period. REE values predicted with the use of various published equations and the new established equation were compared with measured REE by using the Bland-Altman method and Student’s t tests.

Results: In cohort 1, significant determinants of the new prediction equations were fat-free mass in boys (model R² = 0.79) and age and fat-free mass in girls (model R² = 0.76). External validation conducted by using the Bland-Altman method and Student’s t tests, in cohort 2, showed no significant difference between measured REE and predicted REE with the new equation. When already published equations were applied, systematical bias appeared with all published equations except for that of the World Health Organization. In cohort 3, the children who lost weight, almost all equations significantly underestimated REE.

Conclusions: These new predictive equations allow clinicians to estimate REE in an obese pediatric population with sufficient and acceptable accuracy. This estimation may be a strong basis for energy recommendations in childhood obesity. Am J Clin Nutr 2004;80:1544–50.

KEY WORDS Resting energy expenditure, body composition, obesity, fat-free mass, predictive equation, children

INTRODUCTION

The prevalence of overweight and obesity in children and adolescents is rapidly increasing in Western societies (1, 2). This alarming situation is a serious public health problem because the obese adolescent has the highest risk among adolescents of becoming an obese adult (3), regardless of parental obesity (4). Recommendations for energy intake should rely on accurate methods for assessing energy expenditure (EE). However, because not all offices have the correct apparatus so that REE can be measured in everyday situations, accurate equations to predict EE are required. It is also necessary to measure changes in lean body mass and EE during weight loss so that weight-reduction programs can be adapted to preserve fat-free mass (FFM) and growth rate. Bioelectrical impedance analysis (BIA) is an appropriate and simple method for assessment of body composition and could be used for the ultimate prediction of EE in humans (5). Predictive equations of resting EE (REE) are usually based on sex, age, and body weight (6–8). This information is particularly relevant because REE contributes 60–70% of daily EE in individuals, although the contribution of physical activity should also be considered (9).

Equations to predict REE in obese subjects, especially in children, have already been established (10). Although FFM explains interindividual variations in REE better than does body weight (11, 12), body composition is rarely considered, particularly in children. Moreover, the applicability of these equations and their accuracy have not been tested in the same population after changes in body composition, eg, weight loss.

Therefore, the aims of the first part of this study were to establish new predictive equations using body composition, on a large sample of French obese children, to validate the equations on a second independent population of obese children, and to evaluate their accuracy in a longitudinal follow-up survey in which body composition and REE were simultaneously measured. Finally, boys and girls with a large age range, 3–18 y old, were included to allow examination of a period of life that is characterized by various changes in growth rate and metabolic changes. In a second part, the accuracy of the newly established equations was compared with that of published equations: a World Health Organization (WHO) equation (6), the Harris-Benedict equation (7), the Schofield weight and height equations (8), and the equation of Tverskaya et al (Tverskaya equation; 10).

SUBJECTS AND METHODS

Subjects

Inclusion and exclusion criteria for the first and second cohorts were the same except for date of inclusion. To take part in this...
study, children aged 3–18 y should have a body mass index (BMI; in kg/m²) z score ≥2 and must be visiting a pediatric nutritionist for the first time. Children and parents must agree to nutritional follow-up with weight control, nutritional and exercise advice, and REE measurement. For cohort 1, the inclusion period was the years 1993 through 1999, and, for cohort 2, it was the period from 1 January 2001 to 1 March 2002.

REE was measured at the Human Nutrition Laboratory (Clermont-Ferrand, France) after exclusion of any evolving disease. A total of 471 children constituted the cohort 1. New equations were established in this population. We validated these equations in cohort 2 (n = 211), which was constituted of other obese children who were referred between 1 January 2001 and 1 March 2002 for an REE measurement.

Some of the cohort 1 children were measured again after the first investigation; 70 children had lost weight (± SD weight loss: 12.08 ± 6.94%). This population, considered cohort 3 in this study, allowed testing of the validity of newly established equations when weight changes occurred.

Methods

Data were compiled by using EXCEL software (version 98; Microsoft, Redmond, WA), and analyses were conducted by using SAS statistical software (version 8.0; SAS Institute, Cary, NC).

The SD score for BMI (z score) was determined by the following formula:

$$Z = (Q/M)^{1/2} - 1/L \times S \quad (1)$$

where Q is the observed BMI. BMI variations in centiles from birth to 87 y in the French population (13) were used to obtain L (skewness variation with age), S (CV), and M (the 50th centile) (13).

Assessment of body composition

The assessment consisted of whole-body BIA and measurements of height and weight, from which BMI was calculated. While wearing their underwear, patients were weighed on a mechanical scale that was precise to within 0.1 kg (709; SECA, Hamburg, Germany). Height was measured to 0.1 cm with a height gauge that was accurate to within 0.2 cm. BIA (101; RJL System, Detroit) was performed in the postabsorptive state, after 10 min of rest in a supine position and while the patients had an empty bladder. The algorithms used were validated in a population of obese children and adolescents by Wabitsch et al (14).

These measurements were always performed by the same investigator (LM).

Energy expenditure measurement

An open-circuit indirect calorimetry procedure was performed for ≥45 min by using a Deltatrac II apparatus (Datex Engström, Helsinki). Before each test, the gas analyzers were calibrated with a reference gas mixture (95.0% O₂ and 5.0% CO₂). REE was measured after an overnight fast. The subjects were monitored during the measurements to prevent any movement or sleeping under the hood. The first 10 min of each study was excluded to account for environmental adjustment by the children and gas adaptation in the hood. Then REE was calculated from oxygen consumption and carbon dioxide production by using the equation of De Weir (15).

Predicted equations

We compared new equations with published equations. Thus, REE values predicted with the use of a new equation and published equations were compared with measured REE. The WHO (6), Harris-Benedict (7), and Schofield (8) equations—which are not specifically dedicated to obese populations—and the Tverskaya equation (10) involving obese children were used in this study. These equations are shown in Table 1 for the sake of clarity.

Statistical analysis

All the results are expressed as means ± SD. Quantitative averages were compared by using analysis of variance (ANOVA). To compare the mean REE predicted by various equations with the mean measured REE, we used a repeated-measures ANOVA. When a significant difference occurred, a multiple comparison that incorporated Dunnett’s test was used. The analysis had 2 parts.

The aim of the first part was to establish and validate new equations in a large cohort of French children. In the first population (cohort 1), statistical analyses were performed by simple linear regression on variables related to measured REE. Multivariate analyses were conducted by using multiple linear regression and integrating all factors for which P value in the simple linear regression was ≤0.20. The threshold for significance was set at 0.05 for all statistical analyses. This multivariate analysis enabled us to obtain our own equation by using a stepwise selection. In each step, R², SE, and likelihood ratio were analyzed. These factors were introduced in a final model to predict REE.

### Table 1

<table>
<thead>
<tr>
<th>Author and year (reference)</th>
<th>Sex</th>
<th>Age (y)</th>
<th>Predictive equation for resting energy expenditure (MJ/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harris and Benedict, 1919 (7)</td>
<td>Male</td>
<td>All</td>
<td>[66.473 + (5.003 \times (H/100)) + (13.752 \times W)−(6.755 \times \text{age})] × 4.18/1000</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>All</td>
<td>[655.096 + [1.85 \times (H/100)] + [9.563 \times W]−[4.676 \times \text{age}]] × 4.18/1000</td>
</tr>
<tr>
<td>World Health Organization, 1985 (6)</td>
<td>Male</td>
<td>3–10</td>
<td>[(95 \times W) + 2071/1000]</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>3–10</td>
<td>[(94 \times W) + 2088/1000]</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>10–18</td>
<td>[(16.6 \times W) + (77 \times H) + 572 \times 4.18/1000]</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>10–18</td>
<td>[(7.4 \times W) + (482 \times H) + 217] × 4.18/1000</td>
</tr>
<tr>
<td>Schofield, 1985 (8)</td>
<td>Male</td>
<td>3–10</td>
<td>[(19.59 \times W) + (130.3 \times H) + 414.9] × 4.18/1000</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>3–10</td>
<td>[(16.969 \times W) + (161.8 \times H) + 371.2] × 4.18/1000</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>10–18</td>
<td>[(16.25 \times W) + (137.2 \times H) + 515.5] × 4.18/1000</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>10–18</td>
<td>[(8.365 \times W) + (465 \times H) + 200] × 4.18/1000</td>
</tr>
<tr>
<td>Tverskaya et al, 1998 (10)</td>
<td>All</td>
<td>6–18</td>
<td>[775 + (28.4 \times \text{FFM})−(37 \times \text{age}) + (3.3 \times \text{FM}) + (\text{sex} \times 82)] × 4.18/1000</td>
</tr>
</tbody>
</table>

W, weight (in kg); H, height (in m); FFM, fat-free mass (in kg). Age is given in years. Sex: male, 1; female, 0.
TABLE 2
Clinical characteristics of all subjects

<table>
<thead>
<tr>
<th></th>
<th>First sample</th>
<th></th>
<th></th>
<th>Second sample</th>
<th></th>
<th></th>
<th>Third sample</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All (n = 471)</td>
<td>Boys (n = 191)</td>
<td>Girls (n = 280)</td>
<td>All (n = 211)</td>
<td>Boys (n = 62)</td>
<td>Girls (n = 149)</td>
<td>All (n = 70)</td>
<td>Boys (n = 24)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>11.50 ± 2.97</td>
<td>11.44 ± 2.69</td>
<td>11.54 ± 3.25</td>
<td>12.79 ± 3.04</td>
<td>12.95 ± 2.75</td>
<td>12.72 ± 3.16</td>
<td>13.93 ± 2.35</td>
<td>13.44 ± 2.34</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.49 ± 0.16</td>
<td>1.50 ± 0.16</td>
<td>1.48 ± 0.16</td>
<td>1.55 ± 0.16</td>
<td>1.58 ± 0.18</td>
<td>1.53 ± 0.13</td>
<td>1.59 ± 0.12</td>
<td>1.61 ± 0.13</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>63.61 ± 21.84</td>
<td>64.52 ± 22.15</td>
<td>62.98 ± 21.65</td>
<td>71.11 ± 23.04</td>
<td>72.72 ± 22.08</td>
<td>70.43 ± 23.47</td>
<td>70.99 ± 17.32</td>
<td>72.02 ± 18.99</td>
</tr>
<tr>
<td>W: H score</td>
<td>3.72 ± 0.97</td>
<td>3.89 ± 1.01</td>
<td>3.62 ± 0.922</td>
<td>3.57 ± 1.02</td>
<td>3.55 ± 0.88</td>
<td>3.59 ± 1.07</td>
<td>2.83 ± 0.91</td>
<td>3.04 ± 0.93</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>27.78 ± 4.95</td>
<td>27.84 ± 4.68</td>
<td>27.74 ± 5.13</td>
<td>28.80 ± 5.71</td>
<td>28.22 ± 4.81</td>
<td>29.04 ± 6.04</td>
<td>27.51 ± 4.23</td>
<td>27.09 ± 4.13</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>35.33 ± 10.87</td>
<td>36.35 ± 11.48</td>
<td>34.50 ± 10.372</td>
<td>39.85 ± 11.79</td>
<td>42.71 ± 12.66</td>
<td>38.66 ± 11.24</td>
<td>41.36 ± 9.03</td>
<td>43.70 ± 11.26</td>
</tr>
<tr>
<td>Measured REE (MJ/d)</td>
<td>6.48 ± 1.30</td>
<td>6.89 ± 1.41</td>
<td>6.19 ± 1.14²</td>
<td>7.15 ± 1.58</td>
<td>8.04 ± 1.63</td>
<td>6.78 ± 1.40²</td>
<td>6.52 ± 1.09</td>
<td>7.24 ± 1.18</td>
</tr>
<tr>
<td>Weight loss (%)</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
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<tr>
<td>Weight loss (kg)</td>
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<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
</tr>
<tr>
<td>BMI variation (kg/m²)</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
<td>— — —</td>
</tr>
</tbody>
</table>

1 All values are ± SD. W: H, waist-to-hip ratio; FFM, fat-free mass; FM, fat mass; REE, resting energy expenditure.
2 Significantly different from boys, P < 0.05 (Student’s t test).

The Bland-Altman method (16) permitted us to plot the difference between measured REE and predicted REE with a new equation, and then Student’s t tests were used to underline a systematical bias. To validate the new equation in cohort 2, the slope and the intercept of simple linear regression between measured REE and predicted REE with new equation were compared with 1 and 0, respectively. Finally, we analyzed the accuracy of the new equation in a population of subjects who lost weight (cohort 3) by comparing that equation with the published equations by using the Bland-Altman plot and Student’s t tests. When a significant difference was found, we applied a multivariate analysis with a stepwise procedure in the population who lost weight to ascertain which factors better explained REE in this population.

The second part of analysis aimed to compare the accuracy of predicting REE with the new equations and the published equations. Multiple comparisons using Dunnett’s test permitted the testing of differences between measured and predicted REE obtained with the Harris-Benedict, WHO, Tverskaya, and Schofield equations. The Bland-Altman plot (16) and Student’s t tests were used to assess agreement between predicting equations.

RESULTS

Descriptive analysis of the 3 cohorts

The main characteristics of the 471 children included in cohort 1 are shown in Table 2. Children were aged 3–18 y with a Gaussian distribution (20%, 35%, 31%, and 14% for age 3–9, 9–12, 12–15, and 15–18 y old, respectively). Finally, 70 of the children in cohort 1 were measured again 6.22 ± 1.44 mo after the first measurement; this group made up cohort 3. During the period between measurements, they had lost 12% of their initial weight and 5% of their initial fat mass. Characteristics of this cohort are summarized in Table 2. This cohort was older than both other cohorts. There was no age significant difference between boys and girls, but boys lost more weight and fat mass than did girls.

Analysis of the first part of the study

Establishment of new equations

FFM and weight were major determinants of measured REE, and they explained 86% and 82%, respectively, of the variance in simple linear regression. Correlation coefficients of height, fat mass, BMI, and age varied from 0.63 to 0.79. In a multivariate analysis, we tested the model by entering only age, weight, height, and BMI. When age and BMI were entered in the model, $R^2$ was 0.67 in boys and 0.58 in girls. When age, weight, and height were entered in the model, $R^2$ was 0.76 in boys and 0.74 in girls. When the body-composition variations (i.e., FM and FFM) were entered in the model, REE was mainly explained by FFM (79% of variation in REE in boys and 72% of variation in REE in girls; Table 3). In girls, age and FFM explained 76% of REE variation (Table 3). Consequently, new prediction equations adapted for an obese pediatric population with age ranging from 3 to 18 y are as follows:

$$REE = 0.1096 \times FFM + 2.8862$$

(2)

$$REE = 0.1371 \times FFM - 0.1644 \times age + 3.3647$$

(3)

Validation in an independent population

Cohort 2 allowed us to perform an external validation in an independent sample with our new equation; the mean of the estimation was 6.99 ± 3.11 MJ/d, which differed significantly ($P = 0.04$) from measured REE (7.15 ± 1.58 MJ/d). Correlation coefficients between REE measured in cohort 2 and REE estimated with new equation were 0.82 ($P < 0.001$) for the whole sample; 0.85 ($P < 0.001$) in boys, and 0.78 ($P < 0.001$) in girls. When the Bland-Altman method and Student’s $t$ tests were used to compare predicted REE with REE from a new equation and
measured REE, no significant difference appeared. Figure 1 showed the Bland-Altman representation of the difference between 2 methods. When a simple linear regression was applied between measured REE and REE predicted by a new equation, the slope was significantly different from 1, and the intercept was not significantly different from 0.

Evaluation of accuracy in a longitudinally surveyed population

When the Bland-Altman method and Student’s t tests (Figure 2) were used to compare predicted REE with REE from a new equation and measured REE in cohort 3, a significant difference appeared. When multiple regression analysis was used on this sample, FFM in girls and FFM and relative FFM loss in boys appeared in the final model (Table 3).

Analysis of the second part of the study

In the second part of the study, we compared measured REE with various published equations. In cohort 1, when girls and boys were combined and only the Harris-Benedict equation was used, predicted REE did not differ significantly from measured REE (Table 4). The WHO (in 3–9 and 15–18 y old groups) and Schofield (in 3–9, 9–12, and 15–18 y old groups) equations significantly overestimated REE, whereas the Tverskaya equation (in 9–12 and 15–18 y old groups) significantly underestimated REE. In girls, the Schofield and Tverskaya equations significantly underestimated REE. REE was significantly higher in boys than in girls with the use of either compilation method (measured or predicted). The Tverskaya equation underestimated measured REE by 3.87% on average (Table 5). Other equations (WHO and Schofield), on average, overestimated REE with a wide range of estimation. The Harris-Benedict equation, on average, best approached measured REE, but there was still a 20% difference between predicted and measured REE in 21 of 471 children.

In cohort 2, all of the predictive equations significantly underestimated measured REE in either sex (Table 4). These underestimations varied from 1.40% with the WHO equation to 7.88% with the Tverskaya equation (Table 5). When the Bland-Altman method and Student’s t tests were used, a significant difference

### Table 3

<table>
<thead>
<tr>
<th>Step number</th>
<th>FFM</th>
<th>Age</th>
<th>RLFFM</th>
<th>Intercept</th>
<th>$R^2$</th>
<th>P</th>
<th>SE</th>
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<tbody>
<tr>
<td>Cohort 1 $^2$ ($n = 471$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>1</td>
<td>0.1096</td>
<td>—</td>
<td>—</td>
<td>2.8862</td>
<td>0.79</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Girls</td>
<td>1</td>
<td>0.0929</td>
<td>—</td>
<td>—</td>
<td>2.9886</td>
<td>0.72</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.1371</td>
<td>-0.1644</td>
<td>—</td>
<td>3.3647</td>
<td>0.76</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Weight-loss cohort $^3$ ($n = 70$)</td>
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<td></td>
</tr>
<tr>
<td>Boys</td>
<td>1</td>
<td>0.0909</td>
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<td>—</td>
<td>3.3058</td>
<td>0.79</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Girls</td>
<td>1</td>
<td>0.0887</td>
<td>—</td>
<td>-0.0714</td>
<td>3.8693</td>
<td>0.84</td>
<td>&lt;0.001</td>
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</tbody>
</table>

$^1$ FFM, fat-free mass; RLFFM, relative loss of fat-free mass.

$^2$ Covariates considered in cohort 1 were FFM (kg) fat mass, age (y), and BMI (kg/m²).

$^3$ Covariates considered in the weight-loss cohort were RLFFM (%), FFM (kg), age (y), and height (cm).

**FIGURE 1.** The Bland-Altman representation of the difference between resting energy expenditure (REE) estimated by using the new equation and measured REE in cohort 2, compared with the single-sample Student’s $t$ test. There was no significant difference between the 2 REE values ($P = 0.57$).
appeared between measured REE and REE predicted with the use of the Harris-Benedict ($P < 0.001$), Schofield ($P < 0.001$), and Tverskaya ($P = 0.007$) equations. No significant difference existed between measured REE and REE predicted by using the WHO equation ($P = 0.33$).

In cohort 3, those subjects who lost weight (12% of initial weight and 5% of initial fat mass), all predictive equations overestimated REE by 0.70% to 7.45% (Table 5). With the use of the Bland-Altman method and Student’s $t$ tests, all predictive equations except the Tverskaya equation misestimated REE ($P = 0.80$).

**DISCUSSION**

In the current study, predictive equations were developed in both girls and boys to predict REE in a large population of obese children (mean W-H $z$ score $= 3.73 \pm 0.97$) ranging from 3 to 18 y of age. In the process of building the equation, we considered, first, a model with sex as the binary variable. FFM, age, and sex were significant, but the accuracy was $<79\%$ and $<76\%$ in boys and girls, respectively, with the use of the newly established equation (Table 3). We considered a second model by age group (3–9, 9–12, 12–15, and 15–18 y old), in which

<table>
<thead>
<tr>
<th>Sex</th>
<th>cohort 1</th>
<th>cohort 2</th>
<th>Measured REE</th>
<th>Predicted REE</th>
</tr>
</thead>
<tbody>
<tr>
<td>All subjects ($n = 471$)</td>
<td>World Health Organization (6)</td>
<td>Harris-Benedict (7)</td>
<td>Schofield (8)</td>
<td>Tverskaya et al (9)</td>
</tr>
<tr>
<td>Age groups</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>3–9 y ($n = 96$)</td>
<td>4.64 ± 1.30</td>
<td>6.71 ± 1.31</td>
<td>6.43 ± 1.24</td>
<td>6.63 ± 1.40</td>
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<tr>
<td>9–12 y ($n = 164$)</td>
<td>6.20 ± 0.90</td>
<td>6.16 ± 0.93</td>
<td>5.05 ± 0.49</td>
<td>5.26 ± 0.73</td>
</tr>
<tr>
<td>12–15 y ($n = 145$)</td>
<td>7.18 ± 1.11</td>
<td>7.15 ± 1.18</td>
<td>7.10 ± 0.95</td>
<td>7.25 ± 1.17</td>
</tr>
<tr>
<td>15–18 y ($n = 66$)</td>
<td>7.56 ± 1.31</td>
<td>7.84 ± 1.65</td>
<td>7.79 ± 1.24</td>
<td>7.96 ± 1.62</td>
</tr>
<tr>
<td>Boys ($n = 191$)</td>
<td>6.89 ± 1.41</td>
<td>7.46 ± 1.54</td>
<td>6.80 ± 1.52</td>
<td>7.44 ± 1.57</td>
</tr>
<tr>
<td>Girls ($n = 280$)</td>
<td>6.19 ± 1.14</td>
<td>6.20 ± 0.79</td>
<td>6.17 ± 0.92</td>
<td>6.08 ± 0.92</td>
</tr>
<tr>
<td>All subjects ($n = 211$)</td>
<td>7.15 ± 1.58</td>
<td>6.93 ± 1.25</td>
<td>6.76 ± 1.24</td>
<td>6.90 ± 1.37</td>
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<tr>
<td>Age groups</td>
<td></td>
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</tr>
<tr>
<td>3–9 y ($n = 32$)</td>
<td>5.23 ± 0.78</td>
<td>5.58 ± 0.70</td>
<td>5.00 ± 0.42</td>
<td>5.12 ± 0.56</td>
</tr>
<tr>
<td>9–12 y ($n = 31$)</td>
<td>6.60 ± 1.18</td>
<td>6.64 ± 0.77</td>
<td>6.03 ± 0.81</td>
<td>6.29 ± 0.79</td>
</tr>
<tr>
<td>12–15 y ($n = 94$)</td>
<td>7.60 ± 1.20</td>
<td>7.19 ± 1.09</td>
<td>7.12 ± 0.89</td>
<td>7.29 ± 1.09</td>
</tr>
<tr>
<td>15–18 y ($n = 54$)</td>
<td>7.84 ± 1.73</td>
<td>7.48 ± 1.39</td>
<td>7.60 ± 1.09</td>
<td>7.62 ± 1.37</td>
</tr>
<tr>
<td>Boys ($n = 62$)</td>
<td>8.04 ± 1.63</td>
<td>7.99 ± 1.53</td>
<td>7.41 ± 1.53</td>
<td>8.02 ± 1.57</td>
</tr>
<tr>
<td>Girls ($n = 149$)</td>
<td>6.78 ± 1.40</td>
<td>6.50 ± 0.77</td>
<td>6.49 ± 0.99</td>
<td>6.43 ± 0.95</td>
</tr>
</tbody>
</table>

1 All values are $\bar{x} \pm SD$. Tverskaya et al equation data were available on children aged 6–18 y, and so means were calculated on 453 children from cohort 1 and 203 children from cohort 2.

2 Significantly different from measured REE, $P < 0.05$ (Dunnett test after repeated-measures ANOVA).
FFM and sex were significant factors in the youngest group, and BMI was a significant factor in the oldest group. $R^2$ in this model varied between 0.5 and 0.66. According to selection criteria adopted in this study ($R^2$, SE, and P value), we did not select these models. Sex was a variable that was always significant in various models, and, therefore, a model by sex finally was adopted. These equations were validated by using an independent sample with the same recruitment in the first part of the study and a longitudinally surveyed subsample in the second part. Differences in REE are known to be related to FFM (17, 18), but genetics also could explain the difference in REE between populations (19). For this reason, predictive equations for REE based on body-composition formulas are generally population specific and thus should be more appropriate.

In the new equations, as expected, FFM was the major determinant of REE; it explained 79% and 76% of REE in boys and girls, respectively. These results are in agreement with other reports (12). In boys, the new equation was the most accurate for use in the obese population, but, in girls, age was also a significant determinant of REE. This finding suggests a greater influence of hormonal factors in girls: our sample included children aged 3–18 y, which included those in the pubertal period. This period is associated with rapid anatomical and physiologic changes, including variations in metabolic rate and energy requirements. REE in obese children and adolescents was significantly higher than that in normal-weight children (20). When REE was adjusted for body-composition differences, no differences persisted between obese and nonobese populations in some reports (21), but they did persist in others (22).

When an external validation was conducted in cohort 2, no significant difference between measured and predicted REE with the newly established equation was found. REE was well predicted by the new equation. The Bland-Altman method allowed us to consider the new equation as a good tool for predicting REE. When we tested the simple linear regression (Figure 1), the slope was significantly different from 1, and the intercept was significantly different from 0. There was effectively a negative bias, which was strongly linked to the $z$ score, and there was more inaccuracy in a high $z$ score. Therefore, we rebuilt the model with consideration of the $z$ score, but $R^2$ was not improved (0.75). This problem was observed recently in extremely obese adult women and reported (23). Indeed, the authors of that report stated that, in studies in the morbidly obese, predictive equations developed for nonobese populations were more accurate (3%) than were the obese-specific equations, because REE can be 40% overpredicted or 21% underpredicted by the equations developed for use in moderately obese populations. Therefore, we recommend caution when using predictive equations in extremely obese children. When a weight loss occurred in these subjects, both new and published equations, except the Tverskaya equation, significantly overestimated REE. With multiple linear regression, relative FFM loss explained 6% of measured REE variability in boys. Thus, we believe that all these equations are to be used only during the weight-stable period and not during the weight-changing period. The equations should be applied in obese children before any weight loss or after weight stabilization in the postobesity state. Maintenance of a reduced body weight is associated with compensatory changes in EE that oppose the maintenance of a body weight that is different from the usual weight (24, 25). Predictive equations must be established in a weight-stable period when energy metabolism has adapted.

All predicted equations used in this study led to significant miscalculations of REE. Individual estimations were markedly underestimated (±31%) or overestimated (57%). Previous studies established various equations to measure REE by using BIA. With restriction to the analysis of obese children, the WHO equation overestimated measured REE in 4 studies (10, 26–28) but not in the fifth study (29). These reports also concluded that differences existed according to sex (26, 27). The question now is to justify the choice of one formula rather than another. Individual underestimations or overestimations might have a deleterious effect on diet prescription and may limit weight loss. These calculations miscalculated REE by 3.76 MJ/d, which is not acceptable in clinical practice. This underestimation could lead to a miscalculation in dietary recommendations. The populations used for validation can explain these large errors. Harris and Benedict derived their equations by using data from healthy nonobese children (7), so these formulas were not specific to obese children. In agreement with literature, all predictive equations underestimated or overestimated REE according to the population (10). Predictive equations were population specific and constituted a population-based REE estimation, which is less valid on an individual scale. So the question remains as to the extent to which such a variation between individual REE measurements and REE from predictive equation should be tolerated. Predictive equations permit a first estimation of REE. When a failure of dietetic intervention occurred, REE measurement was appropriate.

Body composition was estimated by BIA. This is a useful technique for body-composition analysis in healthy persons who are overweight or mildly to moderately obese (30, 31). Among numerous studies, Utter et al (31) compared body composition evaluated by leg-to-leg BIA or underwater weighing before and after a weight-reduction program in obese and normal-weight control subjects. No significant difference was found between underwater weighing and BIA in estimating the FFM at the baseline and after weight loss. However, BIA values are affected

<table>
<thead>
<tr>
<th>TABLE 5</th>
<th>Mean difference between measured resting energy expenditure (REE) and predicted REE calculated from various equations*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prediction equation</td>
<td>Value</td>
</tr>
<tr>
<td><strong>Cohort 1</strong></td>
<td></td>
</tr>
<tr>
<td>Harris-Benedict (7) ($n = 471$)</td>
<td>$-0.09 \pm 9.82$</td>
</tr>
<tr>
<td>WHO (6) ($n = 471$)</td>
<td>$4.57 \pm 12.72$</td>
</tr>
<tr>
<td>Schofield (8) ($n = 471$)</td>
<td>$2.93 \pm 11.20$</td>
</tr>
<tr>
<td>Tverskaya et al (10) ($n = 453$)</td>
<td>$-3.87 \pm 8.64$</td>
</tr>
<tr>
<td><strong>Cohort 2</strong></td>
<td></td>
</tr>
<tr>
<td>Harris-Benedict (7) ($n = 211$)</td>
<td>$-4.24 \pm 10.65$</td>
</tr>
<tr>
<td>WHO (6) ($n = 211$)</td>
<td>$-1.40 \pm 12.87$</td>
</tr>
<tr>
<td>Schofield (8) ($n = 211$)</td>
<td>$-2.51 \pm 10.83$</td>
</tr>
<tr>
<td>Tverskaya et al (10) ($n = 203$)</td>
<td>$-7.88 \pm 8.86$</td>
</tr>
<tr>
<td>New equation ($n = 211$)</td>
<td>$-2.19 \pm 9.81$</td>
</tr>
<tr>
<td><strong>Weight-loss cohort</strong></td>
<td></td>
</tr>
<tr>
<td>Harris-Benedict (7) ($n = 70$)</td>
<td>$5.30 \pm 8.94$</td>
</tr>
<tr>
<td>WHO (6) ($n = 70$)</td>
<td>$5.70 \pm 9.63$</td>
</tr>
<tr>
<td>Schofield (8) ($n = 70$)</td>
<td>$6.72 \pm 9.39$</td>
</tr>
<tr>
<td>Tverskaya et al (10) ($n = 70$)</td>
<td>$0.70 \pm 8.62$</td>
</tr>
<tr>
<td>New equation ($n = 70$)</td>
<td>$7.45 \pm 8.09$</td>
</tr>
</tbody>
</table>

*All values are $\bar{x} \pm SE$. WHO, World Health Organization.
by numerous variables including body position, hydration status, ambient air, skin temperature, and recent physical activity (32). Equations used by various BIA apparatuses are different and not always known with precision. BIA validity has not really been confirmed, particularly in severely obese children (33, 9). A well-defined procedure specifically for performing routine BIA measurements and the equations used for BIA are necessary (30).

In this study, external validation in an independent population of obese children confirmed the validity of the new equation. Relative FFM loss must be taken into account when obese children lose weight, but metabolic adaptation during rapid weight modifications should also be considered (25). In conclusion, new predictive equations for REE calculations in obese children have been validated in a large population with an accuracy sufficient to allow clinicians to better estimate energy balance in pediatric subjects. These equations have been compared with other equations not specifically dedicated to obese subjects of all ages or developed for pediatric populations, particularly obese and formerly obese children. Because body-weight changes are associated with modifications in the relation between lean mass and metabolic rate, it is recommended that these equations are used in a several-week period of body-weight stability. When REE is measured, these equations may be helpful in detecting specific alterations in the regulation of energy balance that lead to severe obesity in children.

We thank the children for their valuable contribution to the study. HDB contributed to the design of the study, data collection, data analysis and interpretation, and manuscript writing. MM enrolled the children in the study and contributed to the manuscript preparation. LM was responsible for all measurements and data collection. YB was responsible for study conception, data interpretation, and manuscript preparation. None of the authors had any financial or personal conflicts of interest.

REFERENCES