Accuracy of Dietary Reference Intakes for determining energy requirements in girls1–3

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ABSTRACT
Background: The most recent Dietary Reference Intakes (DRIs) (2002) for energy were based on pooled data from convenience samples of individuals with energy expenditure determined by using doubly labeled water (DLW). To our knowledge, the accuracy of these intake estimates has not been assessed in children.

Objective: We assessed the accuracy of DRI prediction equations for determining daily energy needs in girls by comparing the individual-level prediction of estimated energy requirements with the measured value of total energy expenditure (TEE) from DLW, which is considered the gold standard.

Design: In this cross-sectional analysis, we measured the resting metabolic rate (RMR) by using indirect calorimetry and TEE by using DLW in 161 nonobese premenarcheal girls aged 8–12 y. The activity factor TEE/RMR was used to categorize the physical activity level used in DRI equations.

Results: We observed a strong linear relation between TEE by using DLW and estimated energy requirements predicted from DRI equations. (Pearson’s r = 0.78, P < 0.0001, R² = 0.61). The DRI-predicted energy requirements underestimated measured TEE by ~120 kcal on average. The overall mean (±SD) error in the sample was −121.3 ± 163.9 kcal. The average (±SD) percentage error in the sample was −5.8 ± 7.9%. Seventy percent of participants had predicted TEE values ≤10% of measured TEE.

Conclusions: DRI equations for girls predict well for the group. The use of these equations for individuals may result in the underestimation of energy requirements for a significant percentage of girls. Am J Clin Nutr doi: 10.3945/ajcn.112.052233.

INTRODUCTION
The Food and Nutrition Board of the Institute of Medicine (IOM)4 provides Dietary Reference Intakes (DRIs) (1), including energy, for healthy persons in the United States and Canada. In adults, the estimated energy requirement is defined as the “average dietary energy intake that is predicted to maintain energy balance in a healthy adult of a defined age, sex, weight, height and level of physical activity consistent with good health” (1). In children, this definition is extended to include an estimate for the energy associated with the tissue deposition related to growth and development.

The most recent DRI (1) for energy was based on a large database of energy expenditure data determined by using doubly labeled water (DLW), which is considered the gold standard for measuring energy expenditure. Investigative teams in the United States and Canada who had measured energy expenditure data contributed to the database used to develop DRIs.Datasets included convenience samples of subjects with individually measured total energy expenditure (TEE), age, sex, height, weight, and measured or predicted basal energy expenditure (BEE). These samples were pooled, and DRIs for each life-stage group were determined. To our knowledge, no previous studies have been conducted to validate these predictive equations in children.

In this report, we compared total energy expenditure measured by using doubly labeled water (TEEDLW) at the baseline visit in a large cohort of girls (n = 161) aged 8–12 y with the estimated energy requirement determined by using Dietary Reference Intake equations (EERDRI). We undertook an analysis to examine how well the EERDRI predicted TEEDLW. We compared measured energy expenditure to that predicted from the current DRI equations for girls aged 3–18 y of age. Data from 358 girls who were living in the United States whose BMI (kg/m²) was greater than the third and <85th percentiles were included in the development of prediction equations. Girls included in our cohort were considered of normal weight on the basis of a triceps skinfold <85th percentile at baseline.

SUBJECTS AND METHODS
Participants
Between September 1990 and June 1993, we enrolled 196 girls in the Massachusetts Institute of Technology (MIT) Growth and Development Study. These samples were pooled, and DRIs for each life-stage group were determined. To our knowledge, no previous studies have been conducted to validate these predictive equations in children.

In this report, we compared total energy expenditure measured by using doubly labeled water (TEEDLW) at the baseline visit in a large cohort of girls (n = 161) aged 8–12 y with the estimated energy requirement determined by using Dietary Reference Intake equations (EERDRI). We undertook an analysis to examine how well the EERDRI predicted TEEDLW. We compared measured energy expenditure to that predicted from the current DRI equations for girls aged 3–18 y of age. Data from 358 girls who were living in the United States whose BMI (kg/m²) was greater than the third and <85th percentiles were included in the development of prediction equations. Girls included in our cohort were considered of normal weight on the basis of a triceps skinfold <85th percentile at baseline.

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4Abbreviations used: BEE, basal energy expenditure; DLW, doubly labeled water; DRI, Dietary Reference Intake; EERDRI, estimated energy requirement determined by using Dietary Reference Intake equations; IOM, Institute of Medicine; MIT, Massachusetts Institute of Technology; PA, physical activity; PAL, physical activity level; RMR, resting metabolic rate; TEE, total energy expenditure; TEEDLW, total energy expenditure measured by using doubly labeled water.

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Development Study. The criteria for enrollment were premenarchal status and a triceps skinfold <85th percentile for age and sex (2). Premenarchal girls aged 8–12 y were recruited from the Cambridge and Somerville public schools in Massachusetts, the MIT summer day camp, and friends and siblings of enrolled subjects. All participants were healthy, free of disease, and were not taking any medication that affected body composition or energy expenditure. The study protocol was approved by both the Committee on the Use of Humans as Experimental Subjects at MIT and the Institutional Review Board of the Tufts New England Medical Center. In all, 196 girls completed the protocol. To make the sample comparable to that used to develop DRIs, we excluded subjects who were below the third percentile for BMI ($n = 7$) or above the 85th percentile ($n = 9$). In addition, we excluded girls who either had missing resting metabolic rates (RMRs) ($n = 6$) or total energy expenditure data ($n = 12$) and one identical twin chosen at random. A total of 161 participants were included in the analysis.

**Study visit**

Details of the study visit are described elsewhere (3). Girls were admitted to the Clinical Research Center at MIT for an overnight visit that included the measurement of body composition and TEE DLW.

RMR was measured by using indirect calorimetry after an overnight fast and a 30-min rest period as previously described (3, 4), and daily RMR was calculated by using Weir’s equation (5). Subjects, while wearing a hospital gown and slippers, were weighed on a scale (Seca) that was accurate to 0.1 kg. Height was measured to 0.1 cm by using a wall-mounted stadiometer. BMI was calculated from measures of height and weight and referenced against the sex- and age-specific CDC childhood growth reference (6). On baseline questionnaires, participants were asked to indicate their race-ethnicity (white, black, Hispanic, Asian, or other). At study entry, none of the subjects reported taking any medications. We classified girls as prepubertal (Tanner stage 1) or pubertal (Tanner stage 2, 3 or 4) as previously described (3).

**Body composition and total energy expenditure**

Isotopic analyses for the assessment of body composition (fat-free mass and fat mass) and energy expenditure were conducted at the USDA Human Nutrition Research Center on Aging at Tufts University on two Isotope Ratio Mass Spectrometers (Hydra Gas; PDZ Europa LTD and SIRA 10; Micromass) as detailed previously (3). For consistency with the IOM approach, we added to the energy cost allotted for the deposition of tissue stores to TEE DLW as follows: 20 kcal/d for girls <9 y old and 25 kcal/d for girls ≥9 y old (1).

The physical activity level (PAL) was determined from TEE DLW and RMR by using indirect calorimetry. We used this quotient to categorize participants as sedentary, low active, active, and very active according to the IOM guidelines (1) as follows: if TEE/RMR was <1.4, PA (physical activity) = 1.00 (sedentary); if TEE/RMR was ≥1.4 but <1.6, PA = 1.16 (low active); if TEE/RMR was ≥1.6 but <1.9, PA = 1.31 (active); and if TEE/RMR was ≥1.9 but <2.5, PA = 1.56 (very active).

Estimated energy requirements (EER DRI) were calculated by using the following equations (1):

For girls <9 y old,

$$EER_{DRI} = 135.3 - [30.8 \times \text{age(y)}] + \text{PA} \{[10.0 \times \text{weight(kg)}] + [934 \times \text{height(m)}]\} + 20 \quad (I)$$

For girls ≥9 y old,

$$EER_{DRI} = 135.3 - [30.8 \times \text{age(y)}] + \text{PA} \{[10.0 \times \text{weight(kg)}] + [934 \times \text{height(m)}]\} + 25 \quad (2)$$

**Statistical analysis**

Exploratory data analysis and graphic displays were used to test assumptions of linear regression and examine associations between puberty, race-ethnicity, physical activity category, fat, fat-free mass, and TEE DLW. Correlations between continuous variables were evaluated by using Pearson’s correlation coefficients. Independent-sample t tests or ANOVA were used to formally test differences in continuous variables, and the chi-square or Fisher’s exact tests were used to examine the homogeneity of proportions of categorical variables.

We calculated error by subtracting the measured TEE DLW from EER DRI. This variable was used as the outcome in multiple linear regression analyses to examine the influence of race-ethnicity, body composition (fat-free mass and fat mass), and physical activity category on the error in estimation. The percentage error was calculated by dividing the error by TEE DLW ($\times 100\%$). This variable was used to determine how many subjects had prediction errors <10%.

Because there were only 15 girls who were classified as sedentary (PAL <1.4) and only one girl who was classified as very active (PAL ≥1.9), the sedentary and low-active groups were combined, and the active and very active groups were combined in this analysis; thus, the physical activity category was examined as a binary variable.

All analyses were performed with SAS software (version 9.2; SAS Institute Inc). Statistical significance was declared at $P < 0.05$.

**RESULTS**

Participant characteristics are presented in **Table 1** overall and by age (<9 or ≥9 y). Fourteen percent of participants were classified as <9 y of age, and 73% of participants were white. The mean age in the sample was 10.0 ± 0.95 y. As expected, there were significant differences between age groups for height and weight (Table 1), and TEE DLW was higher in the active/very active group (**Table 2**). A scatter plot of TEE DLW compared with EER DRI is shown in **Figure 1**. There was a strong linear relation between TEE DLW and EER DRI (Pearson’s $r = 0.78$, $P < 0.0001$, $R^2 = 0.61$).

The EER DRI underestimated TEE DLW by ~120 kcal on average (overall mean ± SD error in the sample was −121.3 ± 163.9 kcal). Results of the multivariate analysis of error are shown in **Table 3**. The physical activity category, black race, fat
mass, and fat-free mass were significant predictors of the error in estimation. Pubertal status was not related to the error after adjustment for fat and fat-free mass. The mean difference in error between the sedentary/low-active and active/very active subjects was 135 kcal after adjustment for fat mass, fat-free mass, and race. After adjustment for fat mass, fat-free mass, and physical activity category, the mean difference in error between black and white subjects was 104 kcal. For each kilogram increase in fat-free mass, error decreased by 13 kcal on average (after adjustment for fat-free mass, race, and physical activity category). For each kilogram increase in fat-free mass, error decreased by ~20 kcal on average. The adjusted $R^2$ for the model was 0.29, and the SEE was 138 kcal.

The average (± SD) percentage error in the sample was $-5.8 \pm 7.9\%$. At the individual level, seventy percent of study participants had EER$_{DRI}$ values ±10% of TEE$_{DLW}$. In 4 participants (2.5%), EER$_{DRI}$ was overestimated by >10%, and in 45 participants (28%), EER$_{DRI}$ was underestimated by >10%. In subjects in the sedentary/low active group, 63% ($n = 57$) had EER$_{DRI}$ values ±10% of TEE$_{DLW}$, 78% of subjects ($n = 55$) in the active/very active group had EER$_{DRI}$ values ±10% of TEE$_{DLW}$.

**DISCUSSION**

For this report, to examine the direction and extent of the error in prediction and explore its sources, we compared TEE$_{DLW}$ with TEE predicted by using DRI equations for energy in nonobese premenarchal girls 8–12 y of age. At the group level, our findings suggested that the DRI predictive equation performs well overall in this age-sex group. As expected, TEE$_{DLW}$ and EER$_{DRI}$ were highly correlated. The average (± SD) percentage error was $-5.8 \pm 7.9\%$. At the individual level, estimated energy requirements differed by >10% from those predicted for almost one-third of participants. The negative mean percentage error further suggested that the use of these equations for individuals may underestimate energy requirements for a substantial proportion of girls. The low $R^2$ suggested that factors other than age, race-ethnicity, and activity level influenced the error of estimation. The discrepancy observed between TEE$_{DLW}$ and EER$_{DRI}$ may have been due in part to the use of a predictive equation for BEE in the DRIs and measured BEE in our sample. Empirically, had the predictive BEE equation been used to estimate EER$_{DRI}$, the mean PAL would have increased from 1.58 to 1.68, and EER$_{DRI}$ would have increased from 1838 to 1951 kcal/d, in agreement with TEE$_{DLW}$ (1959 kcal/d). In the case of normal-weight girls, the equation was based on 71% of the girls aged 3–18 y ($n = 256$ of 358) in the DLW database for whom measured BEE was available (1). Because the $R^2$ of the predictive equation is 0.75, the possibility that some error arises from estimated BEE values cannot be excluded.

We are not aware of any other studies that have evaluated the DRI for energy in this age group. Our findings are similar to those reported in the Observing Protein and Energy Nutrition study of girls aged 3–18 y ($n = 256$ of 358) in the DLW database for whom measured BEE was available (1). Because the $R^2$ of the predictive equation is 0.75, the possibility that some error arises from estimated BEE values cannot be excluded.

**TABLE 1**

<table>
<thead>
<tr>
<th>Participant characteristics$^1$</th>
<th>Total ($n = 161$)</th>
<th>Age &lt;9 y ($n = 22$)</th>
<th>Age ≥9 y ($n = 139$)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>10.0 ± 0.95$^2$</td>
<td>8.7 ± 0.19</td>
<td>10.2 ± 0.84</td>
<td>—</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>140.3 ± 8.3</td>
<td>134.2 ± 5.7</td>
<td>141.2 ± 8.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>32.8 ± 5.5</td>
<td>28.8 ± 3.9</td>
<td>33.4 ± 5.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BMI percentile</td>
<td>42.2 ± 23.4</td>
<td>43.2 ± 26.3</td>
<td>42.0 ± 23.0</td>
<td>0.83</td>
</tr>
<tr>
<td>BMI z score</td>
<td>−0.25 ± 0.70</td>
<td>−0.22 ± 0.79</td>
<td>−0.25 ± 0.69</td>
<td>0.86</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>7.6 ± 2.4</td>
<td>6.7 ± 2.3</td>
<td>7.7 ± 2.5</td>
<td>0.08</td>
</tr>
<tr>
<td>Fat-free mass (kg)</td>
<td>25.2 ± 4.1</td>
<td>22.1 ± 2.5</td>
<td>25.7 ± 4.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Race-ethnicity [$n (%)$]</td>
<td></td>
<td></td>
<td></td>
<td>0.58</td>
</tr>
<tr>
<td>White</td>
<td>117 (73)</td>
<td>18 (82)</td>
<td>99 (71)</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>23 (14)</td>
<td>2 (9)</td>
<td>21 (15)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>21 (13)</td>
<td>2 (9)</td>
<td>19 (14)</td>
<td></td>
</tr>
<tr>
<td>PA$^4$ category [$n (%)$]</td>
<td></td>
<td></td>
<td></td>
<td>0.09</td>
</tr>
<tr>
<td>Sedentary/low active</td>
<td>90 (56)</td>
<td>16 (73)</td>
<td>74 (53)</td>
<td></td>
</tr>
<tr>
<td>Active/very active</td>
<td>71 (44)</td>
<td>6 (27)</td>
<td>65 (47)</td>
<td></td>
</tr>
</tbody>
</table>

$^1$ $P$ values for differences between age groups were determined by using an independent samples $t$ test for continuous variables and a chi-square test for categorical variables.

$^2$ Mean ± SD (all such values).

$^4$ PA, physical activity.

**TABLE 2**

<table>
<thead>
<tr>
<th>Measures of energy expenditure overall and by physical activity category$^7$</th>
<th>Total ($n = 161$)</th>
<th>Sedentary/low active ($n = 90$)</th>
<th>Active/very active ($n = 71$)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEE$_{DLW}$ (kcal/d)</td>
<td>1959 ± 260</td>
<td>1851 ± 213</td>
<td>2097 ± 249</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>EER$_{DRI}$ (kcal/d)</td>
<td>1838 ± 229</td>
<td>1689 ± 150</td>
<td>2028 ± 161</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>RMR (kcal/d)</td>
<td>1225 ± 136</td>
<td>1231 ± 136</td>
<td>1216 ± 137</td>
<td>0.48</td>
</tr>
</tbody>
</table>

$^7$ All values are means ± SDs. $P$ values for differences between physical activity category groups were determined by using an independent samples $t$ test. EER$_{DRI}$ estimated energy requirement determined by using Dietary Reference Intake equations; RMR, resting metabolic rate; TEE$_{DLW}$ total energy expenditure measured by using doubly labeled water.
adults in which TEE_{DLW} was highly correlated with TEE predicted by using DRI estimates ($r = 0.93$) in a large sample of men and women between the ages of 40 and 69 y (7). In the OPEN study, the average ($\pm$SD) percentage of difference of TEE_{DLW} and EER_{DRI} was 5.6% $\pm$ 0.6%, and 68% of men and 64% of women had predicted TEE $\leq$10% of measured values. In contrast to our study in which the predictive equations underestimated TEE, predictive equations overestimated TEE in the OPEN study.

Our approach had both strengths and limitations. One notable strength was that both RMR and TEE were measured. We also had an objective measure of the PAL. Thus, error introduced in determining the physical activity factor for the DRI equation was minimized. In addition, our sample size was adequate to examine whether differences existed by pubertal status, activity levels, and race-ethnicity and body composition. However, our study group was a convenience sample and, thus, was not representative of the US population of girls. The prediction equations we used were developed for girls ages 3–18 y. The girls in our study only represented the age range of 8–12 y, which limits the generalizability of our findings. Furthermore, all girls in our study were nonobese, and thus, we could not evaluate the equations for obese girls within this age range. Woodruff et al (8) have suggested the need for a reevaluation of equations for obese children and adolescents. Nonetheless, these findings present data to validate the accuracy of the DRI for nonobese premenarcheal girls.

In conclusion, to our knowledge, this is the first study that has examined the validity of DRI equations in non-overweight/obese preadolescent girls. Our findings suggest that, on a group level, the equations perform well. Our study was a convenience sample limited to preadolescent girls of normal weight; thus, more studies are needed to confirm our findings and to validate these equations in other groups including boys, younger and older children, and obese children and adolescents. Because we observed a >10% error in the prediction of daily energy needs in 30% of the population, caution is urged in the use of these equations for individual assessment.

We thank William Dietz who was the principal investigator of the study from 1990 to 1997.

The authors’ responsibilities were as follows—LGB and AM: designed the research, guided the analysis, interpreted results, and drafted the manuscript; SMP and KL: performed statistical analyses and assisted in writing the manuscript; and all authors: read and approved the final manuscript. None of the authors had a conflict of interest.

TABLE 3

<table>
<thead>
<tr>
<th></th>
<th>$\beta \pm SE$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary/low active compared with active/very active</td>
<td>134.9 $\pm$ 23.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Black race-ethnicity*</td>
<td>103.7 $\pm$ 31.8</td>
<td>0.001</td>
</tr>
<tr>
<td>Other race-ethnicity*</td>
<td>$-55.8 \pm 32.8$</td>
<td>0.091</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>12.9 $\pm$ 4.9</td>
<td>0.01</td>
</tr>
<tr>
<td>Fat-free mass (kg)</td>
<td>$-20.0 \pm 3.0$</td>
<td>0.01</td>
</tr>
</tbody>
</table>

*Error = estimated energy requirement determined by using Dietary Reference Intake equations — total energy expenditure measured by using doubly labeled water.

*White race was the reference category.

FIGURE 1. TEE_{DLW} compared with EER_{DRI}. Correlation between measured energy expenditure (TEE_{DLW}) and predicted energy requirements (EER_{DRI}). EER_{DRI}, estimated energy requirement determined by using Dietary Reference Intake equations; TEE_{DLW}, total energy expenditure measured by using doubly labeled water.
REFERENCES