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# Validation of Dietary Reference Intakes for predicting energy requirements in elementary school-age children

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**BACKGROUND/OBJECTIVES:** Dietary Reference Intakes (DRI) for energy are derived from total energy expenditure (TEE) measured using the doubly labelled water (DLW) method. The objective of this study was to assess the validity of DRI for predicting the energy requirements of elementary school-age children.
**SUBJECTS/METHODS:** The present study involved 25 elementary school-age children aged between 9 and 11 years. TEE was assessed by the DLW method, and the results were compared with the TEE predicted by the DRI equations in order to evaluate accuracy.
**RESULTS:** The subjects' TEE measured by the DLW method was 1,925.2 ± 380.9 kcal/day in boys and 1,930.0 ± 279.4 kcal/day in girls, whereas resting energy expenditure was 1,220.2 ± 176.9 kcal/day in boys and 1,245.9 ± 171.3 kcal/day for girls. The physical activity level was 1.58 ± 0.20 in boys and 1.55 ± 0.13 in girls. The mean bias between the predicted and measured TEE was 12.6% in boys and -1.6% in girls, and the percentage of accurate predictions was 28.6% and 63.6%, respectively. In boys, the equation resulted in underprediction of TEE among the subjects having low TEE values, whereas there was overprediction among subjects having high TEE values as shown by the Bland-Altman plot. On the contrary, this proportional bias was not observed in girls.
**CONCLUSIONS:** The findings of this study suggest that the DRI equation for energy could result in the overestimation of energy requirements in elementary school-age boys. In the case of girls, the equations could be accurate at the group level. However, the DRI appears to be invalid for individual girls, as more than one third of girls had their TEE inaccurately predicted. We recommend more studies for confirmation of these results.

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## INTRODUCTION

Recently, paediatric obesity has become one of the most important public health concerns worldwide [1-4]. Therefore, it has become increasingly vital to develop a method for accurately measuring the energy requirements of children in the context of obesity prevention and management. In children, energy requirements are estimated by measuring total energy expenditure (TEE) and then adding the energy cost of growth to allow for tissue growth and maturation [5,6]. Currently, the doubly labelled water (DLW) method is the reference for TEE assessment [7]. However, this method is expensive and requires high analytical expertise [7-8]. Therefore, various studies have applied it for the development and validation of other more affordable methods, including Dietary Reference Intake (DRI) equations for energy estimation [9-13].

The Institute of Medicine (IOM) in its 2002 report published DRIs for Americans and Canadians focusing on energy, carbohydrates, fibre, fat, fatty acids, cholesterol, protein, and amino acids [5]. The DRI equations for energy were established based on TEE data measured by the DLW method obtained from previous studies conducted in different age groups such as infants and children up to 2 years of age, children from 3 to 9 years, children from 9 to 18 years, and adults aged 19 years and above. These equations are based on the individual's gender, age, height, weight, and physical activity level (PAL) [5]. However, these pooled data from large age groups may not be representative of smaller sub-groups, as shown in one study

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in which the DRI equation was found to be inaccurate in children aged 4-5 years [14]. A study by Harrell *et al.* [15] involving children 8-18 years of age found that energy expenditure ($kcal \cdot kg^{-1} \cdot h^{-1}$) at rest or during exercise was significantly greater in younger children than in those of higher pubertal stage.

Studies on the accuracy of these DRI equations in estimating the energy requirements of elementary school-age children are still limited. To the best of our knowledge, only one study by Bandini *et al.* [16] was conducted on girls between 8 and 12 years of age. Therefore, a study involving both boys and girls in this age group is required. The objective of this study was to evaluate the validity of the DRI equations in predicting the energy requirements of elementary school-age children.

## SUBJECTS AND METHODS

*Subjects*

Twenty-five children (14 boys and 11 girls) between 9 and 11 years of age from Gangneung and Pohang, Korea were included in this study. For the subjects to be included in the study, the following criteria were considered: (a) being in good health, (b) having normal weight, (c) not involved in extreme physical activity such as athletics, (d) living in the study province for at least 2 weeks before and during the study. Initially, 74 subjects (25 girls and 49 boys) were recruited for this study. After excluding obese subjects and those who had missing or insufficient data, the final number of subjects came to 25 (14 boys and 11 girls). Obese children were excluded from this study because the evaluated DRI equations were developed based on data from normal weight children [5].

*Study design*

The present study was conducted in two cities in South Korea: Pohang city (Pohang study) and Gangneung city (Gangneung study). The measurement of TEE was conducted within a period of 8 days for each participant. Before starting the measurements, the study was approved by the Ethical Committee of the National Institute of Health and Nutrition in Japan and the Institutional Review Board (IRB) of Gangnwung-Wonju National University (approval number: GWNU-IRB-2013-19).

*Anthropometric measurements*

Anthropometric measurements included the subjects' weights and heights, and the body mass index (BMI) was obtained by dividing body weight (kg) by height squared ($m^2$). During anthropometric measurements, subjects wore the lightest possible clothes to minimise error.

*Resting energy expenditure (REE)*

In the Pohang study, REE was measured using the Douglas bag, whereas in the Gangneung study, it was measured using a ventilated hood system (TrueOne2400 Parvo Medics, USA). In their study, Crouter *et al.* [18] compared these two methods in the measurement of gas exchange variables at rest and during different work rates. The findings showed that there was no significant difference between the two methods concerning the measured VE, $VO_2$, or $VCO_2$ ($P \geq 0.05$). Details on the principles and procedures of the measurements are given elsewhere [18,19].

*Dietary intake assessment*

During the 8 days of DLW measurement, the dietary record method was used to measure the children's dietary intake. For each child, dietary intake data were collected on 3 days (2 weekdays and 1 weekend day), with the assistance of his or her parents. The completed dietary records were checked by well-trained dieticians, and incomplete or unclear records were clarified through an interview with each participant. The nutrient intakes were calculated using a computer-aided nutritional analysis program (CANpro 4.0, Korean Nutrition Society, Seoul, Korea).

*Measurement of TEE*

The subjects' TEE was measured for 8 days using the DLW method. After collecting the subjects' baseline urine samples, their body weight and height were measured. Each participant then ingested a dose made of approximately 0.06 g/kg body weight of $^2H_2O$ at 99.8 atom% (Cambridge Isotope Laboratories, MA, USA) and 1.4 g/kg body weight of $H_2{}^{18}O$ at 10.0 atom% (Taiyo Nippon Sanso, Tokyo, Japan). After DLW dose consumption, five more urine samples were collected from each participant during the measurement period. In order to minimize risk of bias, the subjects were instructed to collect all samples at a similar time of day. TEE was calculated using the modified Weir's formula [7,20]: TEE (kcal/day) = 1.1 $rCO_2$ + 3.9 $rCO_2$ / FQ, with $rCO_2$ (L/day) as the rate of $CO_2$ production and FQ as the food quotient, which was obtained by using a dietary record method involving the equation of Black *et al.* [21]. PAL was calculated as the TEE measured by the DLW method ($TEE_{DLW}$) divided by the REE.

*DRI predictive equations for TEE*

To derive estimated energy requirements (EER) for children, the IOM used DLW data to develop predictive equations for TEE based on each child's gender, age, height, weight, and PAL category and then added 25 kcal/day as an estimate of energy deposition [5]. These equations have also been adopted during the development of Dietary Reference Intakes for Koreans 2015 [22]. The present study assessed the validity of the DRI predictive equations for energy in both boys and girls by comparing predicted TEE ($TEE_{DRI}$) with $TEE_{DLW}$. The equations are shown below:

TEE for boys 9 through 18 years:
TEE = 88.5 - [61.9 × age (years) + physical activity coefficient (PA)] × [26.7 × weight (kg) + 903 × height (m)]

Where PA is the physical activity coefficient:
PA = 1.00 if it is estimated that $1.0 \leq PAL < 1.4$ (sedentary)
PA = 1.13 if it is estimated that $1.4 \leq PAL < 1.6$ (low active)
PA = 1.26 if it is estimated that $1.6 \leq PAL < 1.9$ (active)
PA = 1.42 if it is estimated that $1.9 \leq PAL < 2.5$ (very active)

TEE for girls 9 through 18 years:
TEE = 135.3 - [30.8 × age (years)] + PA × [10.0 × weight (kg) + 934 × height (m)]

Where PA is the physical activity coefficient:
PA = 1.00 if it is estimated that $1.0 \leq PAL < 1.4$ (sedentary)
PA = 1.16 if it is estimated that $1.4 \leq PAL < 1.6$ (low active)
PA = 1.31 if it is estimated that $1.6 \leq PAL < 1.9$ (active)
PA = 1.56 if it is estimated that $1.9 \leq PAL < 2.5$ (very active)

*Statistical analysis*

Statistical analysis was performed with SPSS software version 23 (IBM Corp., NY, USA), and the data are presented as the means with standard deviations (SD). Normality was assessed by using the Shapiro-Wilk test. For the normally distributed variables, comparison between girls and boys was done using the independent samples t-test. For subjects' age, which was not normally distributed, gender group comparison was performed using the Mann-Whitney U Test. The mean percentage error between $TEE_{DRI}$ and $TEE_{DLW}$, the root mean squared prediction error (RMSE), and the percentage of accurate predictions were computed to evaluate the accuracy of the DRI equation against the DLW method for assessment of TEE. Pearson's correlation analysis was used to assess the association between $TEE_{DLW}$ and $TEE_{DRI}$. In all tests, statistical significance was set at $P < 0.05$.

## RESULTS

*Characteristics of subjects*

Subjects' characteristics are displayed in Table 1. The study involved 25 children, including 11 girls and 14 boys. The subjects' mean age was 10.1 ± 0.8 years in boys and 10.7 ± 0.4 years in girls. For the rest of the assessed variables (height, weight and BMI), there was no significant difference between the genders. Mean height was 1.42 ± 0.1 m in boys and 1.47 ± 0.1 m in girls, and mean weight was 36.9 ± 6.8 kg in boys and 39.0 ± 6.3 kg in girls. BMI was 18.2 ± 2.1 kg/m$^2$ in boys and 18.3 ± 1.4 kg/m$^2$ in girls.

**Table 1.** Characteristics of the subjects

| | Boys (n = 14) | Girls (n = 11) | *P*-value[1)] |
|---|---|---|---|
| Age (yrs) | 10.1 ± 0.8 | 10.7 ± 0.4 | 0.049[b)] |
| Height (m) | 1.42 ± 0.1 | 1.47 ± 0.1 | 0.131[a)] |
| Weight (kg) | 36.9 ± 6.8 | 39.0 ± 6.3 | 0.451[a)] |
| BMI (kg/m$^2$) | 18.2 ± 2.1 | 18.3 ± 1.4 | 0.831[a)] |

BMI, body mass index
[1)] *P*-value obtained by using [a)] independent t-test or [b)] Mann-Whitney U test

**Table 2.** Subjects' energy expenditure

| | Boys (n = 14) | Girls (n = 11) | *P*-value[1)] |
|---|---|---|---|
| REE (kcal/day) | 1,220.2 ± 176.9 | 1,245.9 ± 171.3 | 0.718 |
| REE/BW (kcal/kg/day) | 33.6 ± 5.8 | 32.3 ± 4.7 | 0.549 |
| $TEE_{DLW}$ (kcal/day) | 1,925.2 ± 380.9 | 1,930.0 ± 279.4 | 0.972 |
| $TEE_{DLW}$/BW (kcal/kg/day) | 52.4 ± 7.5 | 49.8 ± 4.7 | 0.297 |
| PAL ($TEE_{DLW}$/REE) | 1.58 ± 0.20 | 1.55 ± 0.13 | 0.743 |

REE, resting energy expenditure; REE/BW, resting energy expenditure adjusted for body weight; $TEE_{DLW}$, total energy expenditure measured by the DLW method; $TEE_{DLW}$/BW, total energy expenditure measured by the DLW method, adjusted for body weight; PAL, physical activity level.
[1)] *P*-value obtained by using independent t-test

**Table 3.** Evaluation of the DRI predictive equation for TEE in 25 elementary school-age children based on bias, root-mean-square prediction error (RMSE), and percentage accurate prediction

| N | $TEE_{DLW}$ (kcal/day) | $TEE_{DRI}$ (kcal/day) | Difference $TEE_{DRI}$ - $TEE_{DLW}$ (kcal/day) | Bias[1)] (%) | Maximum negative error[2)] (%) | Maximum positive error[3)] (%) | RMSE (kcal/day) | Accurate Prediction[4)] (%) | Under Prediction[5)] (%) | Over Prediction[6)] (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Boys 14 | 1,925.2 ± 380.9 | 2,167.9 ± 510.9 | 242.7 ± 298.9 | 12.6 | -11.0 | 43.0 | 376.7 | 28.6 | 7.1 | 64.3 |
| Girls 11 | 1,930.0 ± 279.4 | 1,898.8 ± 241.6 | -31.2 ± 225.1 | -1.6 | -14.8 | 30.8 | 216.8 | 63.6 | 27.3 | 9.1 |

$TEE_{DLW}$, total energy expenditure measured by the DLW method; $TEE_{DRI}$, total energy expenditure calculated by the DRI predictive equation.
[1)] Mean percentage error between predictive equation and measured value
[2)] The largest underprediction that was found with this predictive equation as a percentage of the measured value.
[3)] The largest overprediction that was found with this predictive equation as a percentage of the measured value.
[4)] Percentage of subjects that have $TEE_{DRI}$ predicted by equation within 90% to 110% of $TEE_{DLW}$ measured
[5)] Percentage of subjects that have $TEE_{DRI}$ predicted by equation within < 90% of $TEE_{DLW}$ measured
[6)] Percentage of subjects that have $TEE_{DRI}$ predicted by equation within > 110% of $TEE_{DLW}$ measured

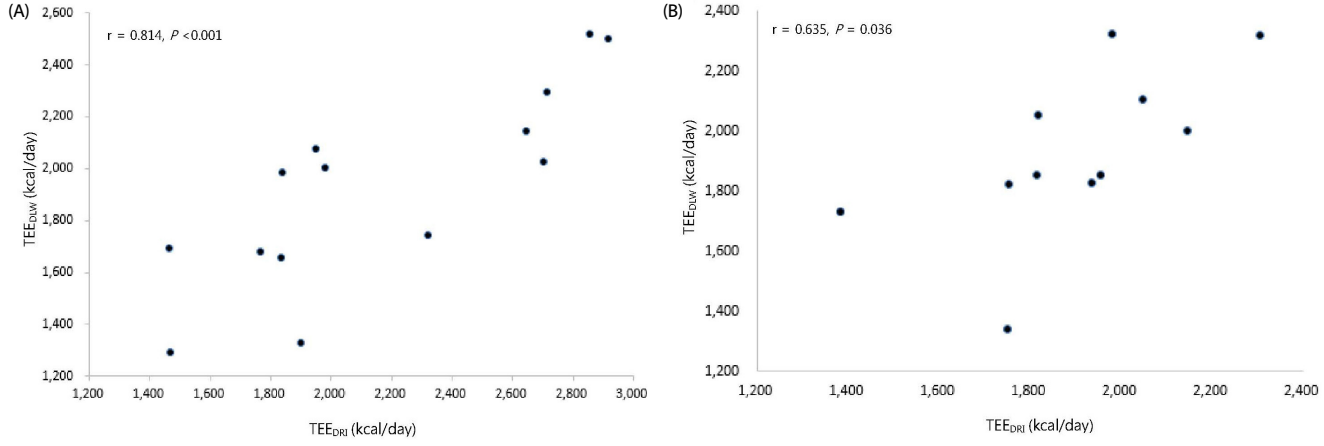


**Fig. 1.** Correlation between $TEE_{DRI}$ and $TEE_{DLW}$ in boys (A) and girls (B). $TEE_{DLW}$, total energy expenditure measured by the DLW method; $TEE_{DRI}$, total energy expenditure calculated by the DRI predictive equation.

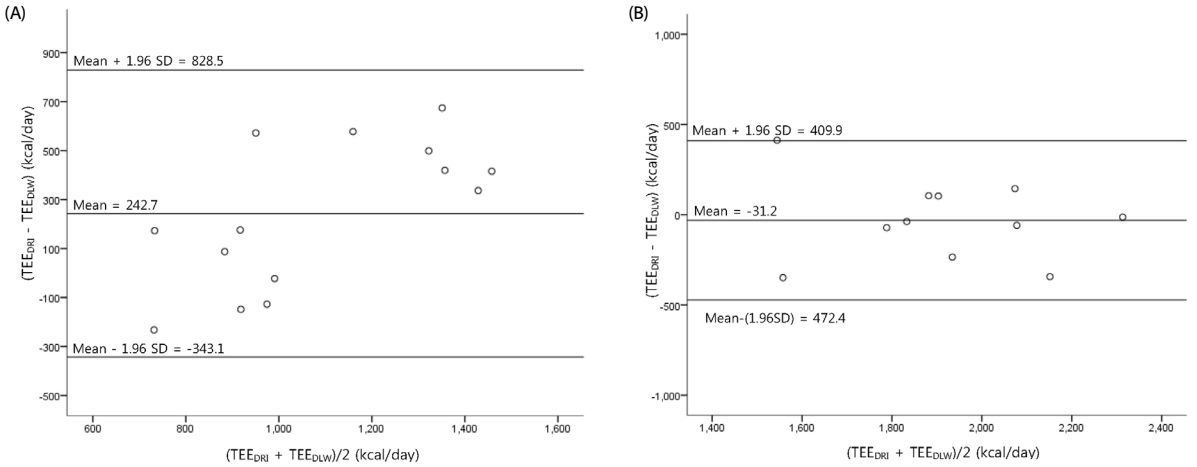


**Fig. 2.** Bland-Altman plot of differences between $TEE_{DRI}$ and $TEE_{DLW}$ in boys (A) and girls (B). SD, standard deviation; $TEE_{DLW}$, total energy expenditure measured by the DLW method; $TEE_{DRI}$, total energy expenditure calculated by the DRI predictive equation.

*Subjects' energy expenditure*

Table 2 presents the variables relating to the subjects' energy expenditure. No significant differences were observed between boys and girls for all measured energy expenditure variables. The $TEE_{DLW}$ was 1,925.2 ± 380.9 kcal/day in boys and 1,930.0 ± 279.4 kcal/day in girls, whereas REE was 1,220.2 ± 176.9 kcal/day in boys and 1,245.9 ± 171.3 kcal/day in girls. PAL was 1.58 ± 0.20 in boys and 1.55 ± 0.13 in girls.

*Accuracy of DRI predictive equation for TEE*

In boys, $TEE_{DRI}$ significantly overestimated $TEE_{DLW}$ by 242.7 ± 298.9 kcal/day ($P < 0.05$), as shown in Table 3. In the case of girls, $TEE_{DLW}$ was underestimated by 31.2 ± 225.1 kcal/day, but this difference was not significant. The mean percentage error was 12.6% for boys and -1.6% in girls, whereas RMSE was 376.7 kcal/day and 216.8 kcal/day, respectively. The DRI equation accurately predicted TEE in only 28.6% of boys, whereas the rate of accurate predictions was 63.6% in girls.

A scatter plot assessing the correlation between $TEE_{DLW}$ and $TEE_{DRI}$ is presented in Fig. 1. There was a good linear correlation between the two methods in both boys (Pearson's $r = 0.814$, $P < 0.001$) and girls (Pearson's $r = 0.635$, $P < 0.05$).

Fig. 2 presents the Bland-Altman plot of differences between $TEE_{DRI}$ and $TEE_{DLW}$. In the case of boys, the plot shows a proportional bias with a tendency towards underestimation in subjects with low TEE and overestimation in those with high TEE. On the contrary, a proportional bias was not observed in girls. In addition, wider limits of agreements were present in boys than in girls.

## DISCUSSION

In the present study, we used the DLW method to evaluate the validity of the DRI predictive equations for TEE in normal-weight elementary school-age children aged 9-11 years. To the best of our knowledge, this was the first study to assess the validity of DRI equations for predicting energy requirements in both school-age boys and girls. There was no significant difference between boys and girls regarding all measured variables for energy expenditure, namely REE, REE/BW, $TEE_{DLW}$, $TEE_{DLW}$/BW, and PAL. REE was 1,220.2 ± 176.9 kcal/day in boys and 1,245.9 ± 171.3 kcal/day in girls, whereas $TEE_{DLW}$ was 1,925.2 ± 380.9 kcal/day and 1,930.0 ± 279.4 kcal/day, respectively.

Our findings on children's REE and $TEE_{DLW}$ are comparable to the results from similar studies on energy expenditure in elementary school-age children. In one study, Kaneko *et al*. [23] measured REE in 221 Japanese children and adolescents aged 6-17 years by using a ventilated indirect calorimeter. Among the study subjects, 32 (20 boys and 12 girls) were aged between 10 and 11 years, and in this age group, REE was 1,296 ± 184 kcal/day in boys and 1,182 ± 115 kcal/day in girls. In another study conducted by Hoffman *et al*. [24], the DLW method was used to measure the TEE in Brazilian children of elementary school age. The study included 30 non-stunted children aged 8-11 years, including 15 boys and 15 girls. In their study, REE was 1,244.3 ± 34.2 kcal/day in boys and 1,113.5 ± 38.5 kcal/day in girls, whereas $TEE_{DLW}$ was 2,158.0 ± 88.0 kcal/day in boys and 1,930.927 ± 95.8413 kcal/day in girls. The DLW method was also used by Bandini *et al*. [16] to assess TEE in a large study of 161 American non-obese pre-menarcheal girls aged 8-12 years. According to their study results, girls' REE was 1,225 ± 136 kcal/day while $TEE_{DLW}$ was 1,959 kcal/ day. To the best of our knowledge, no previous study has assessed TEE in Korean elementary school-age children using DLW or any other method.

The PAL of our study subjects was 1.58 in boys and 1.55 in girls, which corresponds to the low-active category. This confirms the findings of previous studies that have assessed PAL in Koreans using the physical activity diary method [25-30]. Based on these and other similar studies, the Korean population is considered as low-active on average, and corresponding physical activity coefficients (PA) have been applied in the DRI equations for Koreans to predict their energy requirements.

The results of the present study suggest that in elementary school-age boys, the DRI prediction equation could overestimate TEE. In this group, the mean percentage error was 12.6%, and only 28.6% of boys had their TEE accurately predicted. In addition, the Bland-Altman plot of the differences between $TEE_{DRI}$ and $TEE_{DLW}$ showed large limits of agreement, and there

was a proportional bias with a tendency towards underprediction in boys having a low TEE and overprediction in those having a high TEE. Similar to our findings in elementary school-age boys, a study by Butte *et al*. [14] involving a sample of 97 normal-weight preschool-age children (mean age = 4.5 years) found that the DRI equations for energy overestimated the energy requirements of preschool-age children. The inaccuracy of the DRI equation for TEE in elementary school-age boys could negatively impact the problem of obesity in this group, given that rates of childhood obesity in Korea have been increasing in recent decades [31,32].

Contrary to the observations in boys, the study findings show that the DRI equation could accurately predict TEE in elementary school-age girls at the group level. The mean percentage error in this group was -1.6%, and 63.6% of the girls had their TEE accurately predicted. The observed negative mean percentage error suggests that the DRI equation may have underestimated the energy requirements in a considerable portion of girls. The Bland-Altman plot demonstrated narrow limits of agreement, and no proportional bias was observed in girls. Our results in girls are in agreement with the findings of a study by Bandini *et al*. [16], in which the mean percentage error was -5.8% and the percentage of accurate predictions was 70%. Based on these results, they reported that the DRI equation performs well for predicting energy expenditure in girls at the group level, but their application of the DRI equation to individuals may have resulted in the underestimation of energy requirements in a substantial proportion of girls.

To the best of our knowledge, this is the first study to assess the accuracy of DRI equations in estimating energy requirements in both elementary school boys and girls. A few studies have investigated the validity of DRI predictive equations for energy requirements in other age groups. In the Observing Protein and Energy Nutrition study carried out by Toose *et al*. [33], the DRI equations were found to be accurate in a sample of 450 men and women aged 40-69 years, with a mean percentage error of -7.5% in men and -5.9% in women. In addition, 68% of men and 64% of women showed $TEE_{DRI}$ values within 10% of the $TEE_{DLW}$. In another study conducted by Kim *et al*. [34], the accuracy of the DRI equation was assessed in 71 Korean adults (35 men and 36 women) aged between 20-49 years. According to the study findings, the DRI equation was accurate in this group with a bias of -1.3% in men and -4.9 in women as well as an accuracy rate of 77.1% in men and 62.9% in women.

Our study was limited by the small sample size and especially the high cost of the DLW and analytical expenses. In addition, the study focused only on normal-weight elementary school-age children. Therefore, our findings may not be representative of all elementary school-age children. Further studies with larger samples are required to confirm our findings. On the other hand, the strength of our study is that both TEE and REE were measured with highly accurate methods, namely the DLW and indirect calorimetry methods, respectively [7,9].

In conclusion, the findings of this study suggest that the DRI equation for energy could result in the overestimation of energy requirements in elementary school-age boys. In this case, application of this equation could have a negative impact on achieving energy balance in this group. In the case of girls, the equation could be accurate at the group level. However, caution should be taken while applying the DRI equation for energy to individual girls, as more than one third of girls had their TEE inaccurately predicted. The present study suggests the need to develop new equations to estimate TEE in elementary-school age children using a larger sample.

## CONFLICT OF INTEREST

The authors declare no potential conflicts of interests.

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