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Total Daily Energy Expenditure is Overestimated by Dietary References Intake Equations Compared with Doubly Labeled Water in A Sample of Brazilian Adolescents

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Abstract

Objective: This report aimed to compare the total daily energy expenditure (TDEE) of adolescents measured by doubly labeled water (DLW) with the 2005 and 2023 dietary reference intake (DRI) equations proposed by the Institute of Medicine (IOM) in a sample of Brazilian adolescents. Methodology: This is a cross-sectional and observational study with a convenience sample of 15 obese and eutrophic adolescents, aged between 11 and 14 years, from public schools and the obesity outpatient clinic of the Clinics Hospital of the Ribeirão Preto Medical School – University of São Paulo (HC FMRP-USP) in Brazil. Were obtained stature and weight by conventional methods and used to calculate the body mass index (BMI) to determine the nutritional status. Fat-free mass (FFM) was measured using dual-energy X-ray absorptiometry. Energy expenditure was determined by DLW and estimated by the 2005 and 2023 DRI equations. The level of physical activity was measured with the ActivPAL™ accelerometer to classify adolescents within the equations. Results: Forty-seven percent of the sample were eutrophic and 53% were obese. The adolescents were classified as somewhat active according to the average number of daily steps. The DLW-derived TDEE and the TDEE derived from the 2005 and the 2023 predictive equations are presented as means, standard deviations, and 95% confidence intervals (CI). The 2005 and 2023 DRI equations produced significantly higher values than the DLW-determined TDEE (56.2% and 57.2%, respectively). Conclusion: Additional studies with Brazilian adolescents should be conducted to propose more accurate and specific predictive TDEE equations.

Introduction

One of the greatest challenges in clinical practice is to measure energy intake and expenditure accurately. Total daily energy expenditure (TDEE) is comprised of three components: resting (or basal) metabolic rate, the thermic effect of food, and activity energy expenditure [1].

The doubly labeled water (DLW) method has become the gold standard for assessing TDEE [2, 3], but it is an expensive method and not available for all professionals. In 2005, the Institute of Medicine (IOM) [4] published equations to estimate the energy requirement for Americans of all sexes, ages, and stages of life, which were based on energy expenditure measured in previous studies using DLW.

Recently, the IOM updated the energy expenditure equations based on two factors [5]. The first is the continuous rise in the body mass index (BMI) of the population, which leads to an increasing prevalence of overweight and obesity. Secondly, new scientific evidence has advanced the knowledge about the energy requirements of individuals to balance energy expenditure and to promote normal weight status, reducing the risk of chronic diseases.

The most significant difference between 2005 and 2023 DRIs is the narrowing of the differences in energy requirements across physical activity level (PAL) categories. In general, the energy expenditure requirement (EER) of those in the least active PAL category is higher in 2023 than in 2005. On the other hand, the EER of those in the highest PAL category is lower in the 2023 version and the increase from "low active to active" or "active to very active" categories tends to be smaller than in the previous EERs.

The accuracy of the 2005 and 2023 equations is still being determined in Brazilian adolescents. In order to facilitate nutritional assessment in clinical practice, the present report compares the TDEE measured by DLW with estimated values from the 2005 and the new 2023 DRI equations in a sample of Brazilian adolescents, aiming to determine which one is closer to reality.

Subjects and Methods

This cross-sectional and observational study includes TDEE that was measured by DLW in a convenience sample of 15 obese and eutrophic adolescents (nine girls and six boys). The adolescents (aged between 11 and 14 years) were recruited from public schools and the obesity outpatient clinic of the Clinics Hospital of the Ribeirão Preto Medical School – University of São Paulo (HC FMRP-USP) in Brazil. Adolescents with physical limitations for daily activities or physical activity were excluded from the study. To participate, the adolescents' parents signed an informed consent form and the adolescents signed an assent form.

Anthropometric measures (stature and body mass) were obtained by conventional methods [6] and used to calculate the body mass index (BMI) to determine the nutritional status. Those between z-scores 0 and + 1 compared to the World Health Organization (WHO) BMI curves were classified as eutrophic, and those with z-scores above + 2 were classified as obese [7]. Fat-free mass (FFM) was measured using dual-energy X-ray absorptiometry (DXA, Hologic 4500W), a widely used imaging technique for the assessment of body composition with high precision and accuracy [8].

After these measurements, the participants ingested an isotope dose. The method for measuring energy expenditure with doubly labeled water involves enriching body water with heavy isotopes of oxygen (^{18}O) and hydrogen (^{2}H) and measuring the difference in the elimination rates of these isotopes. The dose was calculated according to lean body mass (2g of ^{18}O at 10% per kg of body water and 0.12g of deuterium oxide at 99.9% per kg of body water).

Carbon dioxide production was calculated with the formula rCO2(mol)=(N/2)(K18−K2), where rCO_2 is the carbon dioxide production, N is the body water volume in mol, the value 2 is a constant reflecting that 1 mol of CO_2 removes two atoms of oxygen, and K18 and K2 are the elimination rates of oxygen and hydrogen, respectively [2].

Energy expenditure was determined by analyzing a baseline urine sample (before administering the dose) and samples collected on days one, two, three, seven, twelve, thirteen, and fourteen after the dose. The multiple points technique of the DLW method [9, 10, 11] was used to calculate the TDEE by isotopic ratio mass spectrometry (ANCA 20-22, SERCON, United Kingdom) at the Isotope Ratio Mass Spectrometry Laboratory of the Ribeirão Preto Medical School. The difference in concentration of isotopes from the urine baseline samples over the period was used to estimate the carbon dioxide production (CO_2) based on the rate of ^{2}H and ^{18}O elimination [2].

TDEE was also calculated with the specific DRI equations published by the Institute of Medicine (IOM) in 2005 [4] and by the TDEE Equations by Age, Sex, Physical Activity, and Energy Cost of Growth: Children and Adolescents, published in 2023 [5].

In 2005, the calculation of TDEE was proposed to represent the sum of the energy expenditure rate and the energy cost of growth to allow tissue growth and maturation with the addition of the energy cost of physical activity. In the new 2023 equations, the PAL thresholds were used to define the categories at all stages of life except childhood. However, recent evidence indicates that the PAL is not constant but varies significantly across age groups, particularly during the first 20 years of life, limiting its use for all life stages. Therefore, an approach was developed to incorporate the age dependency into PAL categories to develop the predictive equations [4, 5].

The ActivPAL™ activity monitor (PAL TECHNOLOGIES LTD., Glasgow, UK) was used to determine the PAL. The ActivPAL™ summarizes data at 5-second intervals at a sampling frequency of 10 Hz [11]. It measures the duration of sitting/lying, standing, walking, posture transitions, count steps, and fragmentation (breaks of sedentary time).

The participant remained for seven days with the monitor positioned in the midline of the anterior region of the right thigh and fixed with a bandage of transparent film (3M™ Tegaderm™) in the size of 10 x 10 cm to isolate humidity. The physical activity results were summarized as the average of seven days, considering the time from 6 am to 10:30 pm. PAL was determined by the number of steps per day during the week, an estimate of the physical activity index, as done in other studies [12, 13, 14, 15, 16, 17]. Based on this assessment, the comparison was made using the equations for low-active adolescents proposed by the IOM.

The DLW-derived TDEE and the TDEE derived from the 2005 and the 2023 predictive equations are presented as means, standard deviations, and 95% confidence intervals (CI). The Bland & Altman [18] analysis assessed the agreement between the methods, and graphs were plotted for the relationship between measured and DRI-estimated TDEE.

An interview was conducted with the adolescents to obtain the total screen time pattern, which included the use of computers, tablets and cell phone in addition to TV watching.

Statistical analysis

Statistical analyses were conducted using SPSS software, version 25, with a confidence level of 95%. The data for the DRI 2005 and the DRI 2023 and their differences were found to deviate from a normal distribution ($p<0.05$ in the Shapiro-Wilk test), when considering the entire sample.

Further analysis of the sample by segmenting it into eutrophic and obese individuals revealed that the data for the DRI 2005 of eutrophic individuals also did not follow a normal distribution according to the Shapiro-Wilk test ($p<0.05$). Additionally, the data for lean mass did not follow a normal distribution when considering the entire sample.

The Wilcoxon test showed significant differences ($p<0.05$) between the compared methods in the study. Furthermore, the Mann-Whitney test revealed a significant difference ($p<0.05$) between the lean mass of the obese and eutrophic groups.

Results

The demographic and physical characteristics of the study participants are presented in Table 1. All

Table 1. Demographic characteristics of the study participants.

		All (15)
Demographic characteristics		
Gender	Male	9
	Female	6
Education	Public School	15
	Private School	0
Screen time (hours/day)	1-2	2
	2-3	0
	3-4	7
	5-6	1
	>6	5

Table 2. Mean, standard deviation (SD), range, and 95% confidence interval (CI) of age, anthropometric variables, total daily energy expenditure, and energy requirement estimated by the DRI equations (2005 and 2023) in the 15 participants from Ribeirão Preto, São Paulo, Brazil, according to sex.

	All (15)		Eutrophic (7)		Obese (8)	
	Mean (SD)	Range Min Max	Mean (SD)	Range Min Max	Mean (SD)	Range Min Max
Age (years)	12.7 (1.0)	11 14	13.0 (0.8)	12 14	12.5 (1.2)	11 14
Weight (kg)	69.0 (26.2)	41.0 131.9	47.3 (5.3)	41.0 54.0	88.0 (21.6)	66.0 131.9
Stature (cm)	159 (9.1)	148 185	155.7 (7.5)	148 170	161.9 (9.9)	155 185
BMI (kg/m²)	26.9 (8.3)	17.1 40.5	19.6 (2.3)	17.1 23.4	33.3 (5.8)	24.4 40.5
FFM (Kg)	39.1 (12.3)	24.0 71.1	29.8 (3.5)	24.0 35.6	47.3 (11.4)	35.2 71.1
Number of steps	8,795 (2,867)	1,222 13,165	9,680 (2,219)	7,514 13,165	8,020 (3,278)	1,222 11,158
TDEE (kcal/day):	Mean (SD)	IC 95% Lower; Upper	Mean (SD)	IC 95% Lower; Upper	Mean (SD)	IC 95% Lower; Upper
DLW	1,768.3 (565.2)	1,455.4; 2,081.3	1,620.1 (469.7)	1,185.7; 2,054.5	1,898.1 (639.1)	1,363.7; 2,432.4
DRI 2005	2,646.6 (784.1)	2,212.3; 3,080.8	2,149.5 (313.4)	1,856.7; 2,436.4	3,084.1 (822.7)	2,396.3; 3,771.8
Difference[1]	878.2 (644.8)	521.1; 1235.3	526.5 (622.6)	-49.4; 1,102.3	1,186.0 (517.0)	753.8; 1618.2
Percentage difference[2]	56.2 (40.2)	33.9; 78.5	41.7 (41.5)	3.4; 80.1	68.9 (37.0)	37.9; 99.8
DRI 2023	2,642.7 (631.9)	2,292.7; 2,992.6	2,226.7 (250.6)	1,995.0; 2,458.4	3,006.6 (648.3)	2,464.6; 3,548.6
Difference[3]	874.3 (543.9)	573.1; 1175.5	606.6 (591.0)	60.0; 1,153.2	1,108.5 (397.4)	776.3; 1,440.8
Percentage difference[4]	57.2 (38.1)	36.0; 78.3	47.1 (41.3)	8.8; 85.3	66.0 (35.4)	36.4; 95.6
2023 and 2005 DRI Difference	-3.9 (165.2)	-95.4; 87.6	80.2 (73.5)	12.2; 148.1	-77.5 (191.5)	-237.6; 82.7
Percentage difference[5]	1.2 (5.3)	-1.8; 4.1	4.1 (3.5)	0.9; 7.4	-1.4 (5.5)	-6.0; 3.2

FFM: Free fat mass; BMI: Body mass index; TDEE: Total daily energy expenditure; DLW: Doubly-labeled water; DRI: Dietary Reference Intake.[1]: (DRI 2005 – DLW); [2]: ((DRI 2005 – DLW/DLW)*100); [3]: (DRI 2023 – DLW); [4]: ((DRI 2023 – DLW/DLW)*100); [5]: ((DRI 2023 – DRI 2005/DRI 2005)*100).

participants attended public school and most had 3-4 hours a day of screen time.

The physical and physiological characteristics of the participants, number of daily steps, TDEE estimates, and FFM are presented in Table 2.

Forty-seven percent of the sample were eutrophic and 53% were obese. There were more daily steps in the eutrophic group but the difference was not significant. The adolescents were classified as somewhat active according to the average number of daily steps [15, 17].

The group with obesity presented higher measured (DLW) and estimated (DRI 2005 and DRI 2023) TDEE than eutrophics, which could be explained by the fact that adolescents with obesity presented a significantly higher FFM than eutrophic adolescents. TDEE estimated by the 2005 DRI equations was significantly higher than DLW.

TEE predicted by DRI equations agreed with observed TEE (+34 kcal/d or 3%) if the sedentary PAL category was assumed but was overestimated by using the low active (+219 kcal/d or 19%), active (398 kcal/d or 34%), and very active (593 kcal/d or 51%) PAL categories.

Figures A, B, and C present the Bland & Altman graphs of the difference between TDEE using the 2005 DRI [3] (A) and the 2023 DRI [4] (B) equations and the DLW-determined TDEE for the 15 participants. There was disagreement between measured and estimated TDEE. The 2005 and 2023 DRI equations produced significantly higher values than the DLW.

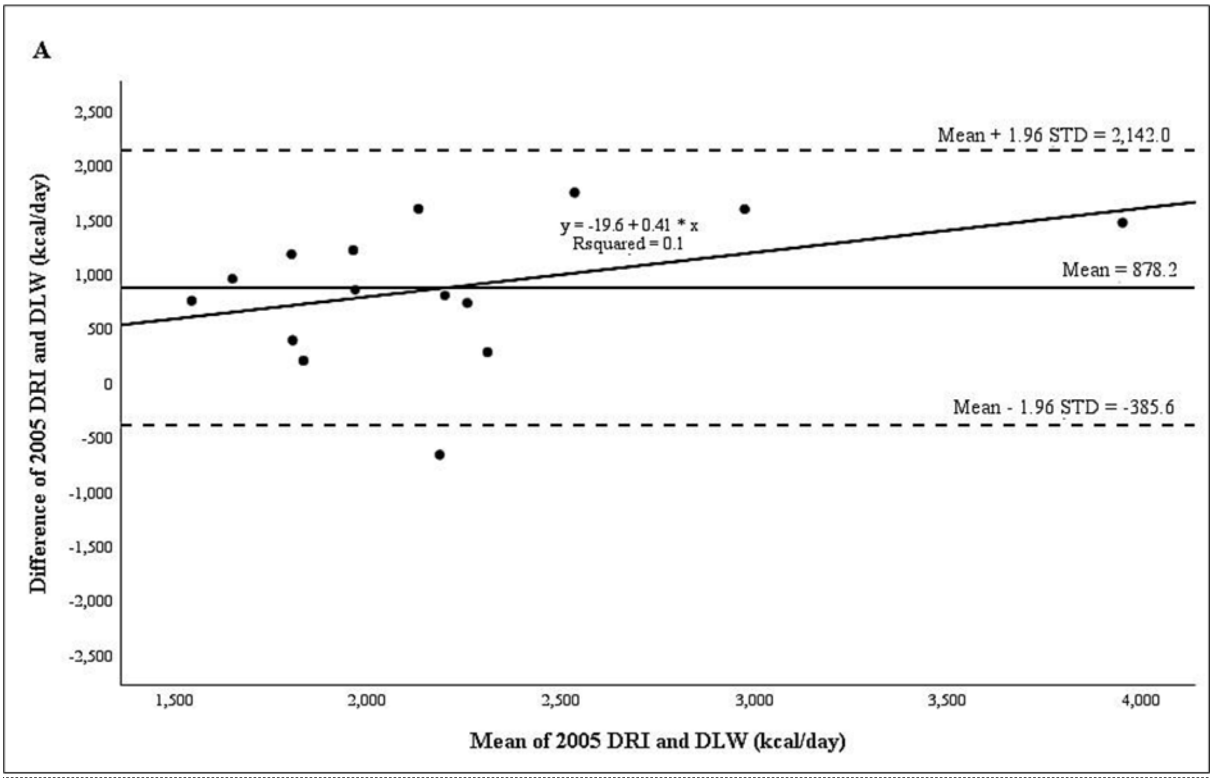

Figure A. Bland & Altman graph of the difference between estimated energy requirement using the 2005 DRI [4] equation and total daily energy expenditure (TDEE) measured by doubly labeled water – DLW (kcal/day) for the 15 participants from Ribeirão Preto, São Paulo, Brazil.

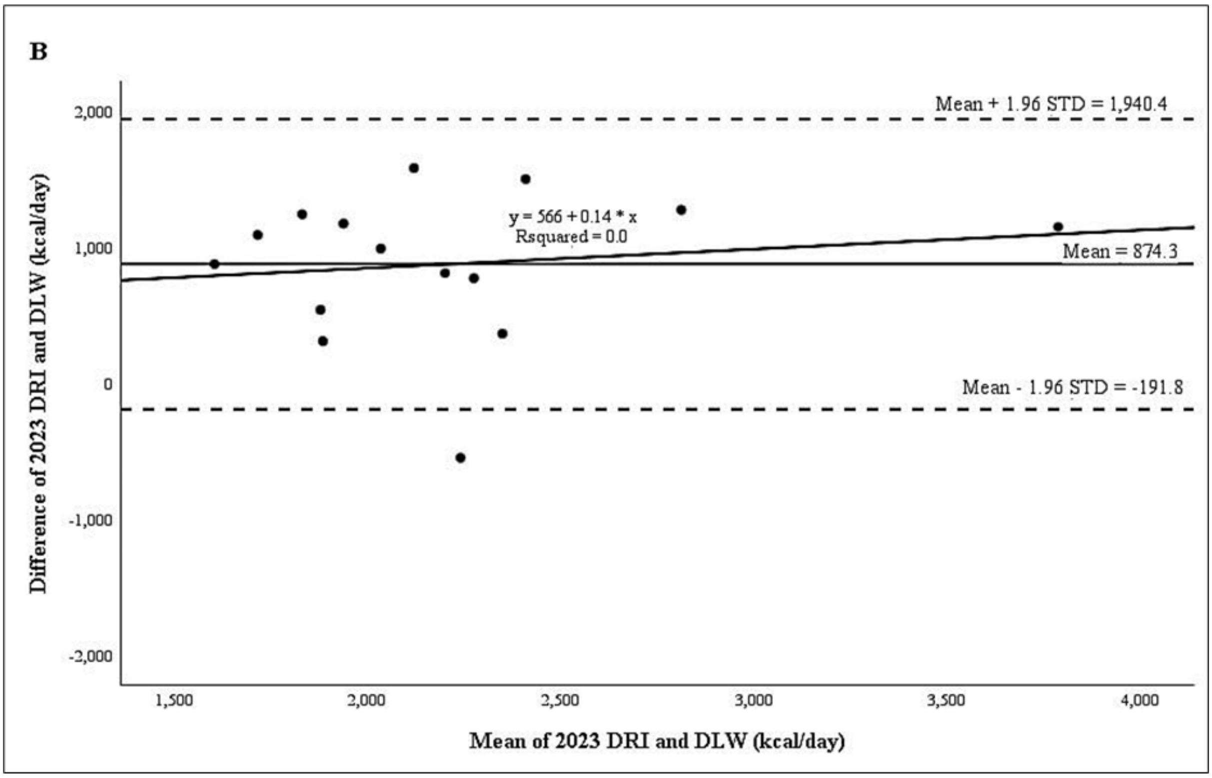

Figure B. Bland & Altman graph of the difference between estimated energy requirement using the 2023 DRI [5] equation and total daily energy expenditure (TDEE) measured by doubly labeled water – DLW (kcal/day) for the 15 participants from Ribeirão Preto, São Paulo, Brazil.

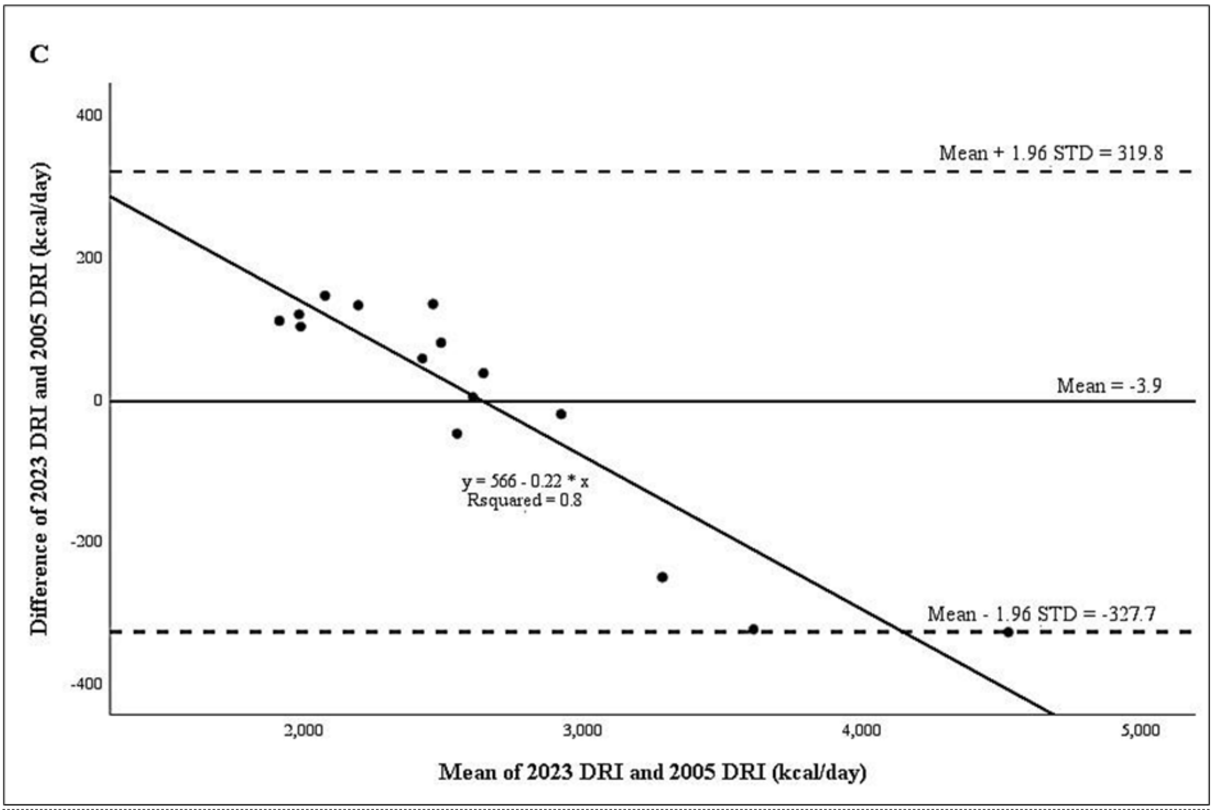

Figure C. Bland & Altman graph of the difference between estimated energy requirement using 2005 [4] and 2023 [5] DRI equations and total daily energy expenditure (TDEE) measured by doubly labeled water – DLW (kcal/day) for the 15 participants from Ribeirão Preto, São Paulo, Brazil.

Discussion

This study used a convenience sample, which introduces some limitations. Although convenience samples are easy to recruit, they do not provide generalized estimates of the general population and specific sociodemographic group. Due to the weak generalizability, such samples often produce biased estimates of the general and sociodemographic subpopulations [19].

The groups with obesity presented higher FFM than the eutrophic groups. The FFM compartment, including skeletal muscle, bone, and other highly active metabolic organs, is the primary determinant of resting energy expenditure (REE). Comparative studies of metabolic rates between obese and nonobese individuals must adjust for the differences in FFM [20].

A study with subjects with severe obesity after bariatric surgery showed that significant changes in muscle mass that occur after surgery may play a crucial role in the evolution of REE [21]. The adipose tissue consumes oxygen at a rate of 0.4 mL per kilogram per minute, which is significantly lower compared to the lean tissue [22] and will determine energy expenditure. Lean body mass (LBM) is more metabolically active than adipose tissue and are determinants of energy requirement [23].

In a study examining the factors influencing the basal metabolic rate (BMR) of obese and overweight children and adolescents (7 to 18 years), Lazzer et al. [24] found that FFM accounted for approximately 60% of the variability in BMR, which further suggests that FFM may play a significant role in determining BMR in both obese and overweight children.

FFM better explains REE than body weight but body composition is generally not considered in the pediatric population [25, 26]. Tverskaya et al. [27] suggested that including DXA-derived LBM to REE estimation in boys (11–15 years old) and girls (4–10 years old) could help prevent systematic error.

Our findings agree with the study in 9 and 11-year-old Korean children [28] and with the study in 10-to -12-year-old Japanese children [29] compared to Japan-DRI estimation, which found the equations overestimated TDEE.

Bandini et al. [30] demonstrated that the equations work well at the group level in eutrophic girls aged 8 to 12 yrs. However, at the individual level, they yield >10% error in the prediction of daily energy needs in 30% of the sample.

In a study with ninety-seven healthy, normal-weight, preschool-age North American children, the 2005 DRI accurately estimated DLW-measured TDEE only when the sedentary PAL category was assumed but was overestimated when the other PAL categories were used [31].

In the present study the adolescents were instructed to maintain their usual lifestyle. This study was conducted in the city of Ribeirão Preto, where temperature variation among seasons is very small (a maximum of 5 degrees). This lack of variation does not influence the subjects's physical activity or dietary pattern. However, wherever temperature variation exists, the time of year should be considered when extrapolating the data.

One of the reasons for the discrepancy between the TDEE measured by DLW and the DRI equations could be the classification of adolescents as low-active. Despite the number of steps, the adolescents did not engage in any physical exercise or sports programs.

The values found with the 2023 DRI equation could be explained, in part, by the exclusion of data from low-income countries in its development despite the attempt to correct the inter-individual variability of TDEE. The standard deviation (SD) mitigates the difference between energy expenditure estimated by DLW and the 2023 DRI equations. Thus, TDEE estimated by the equations needs to be more accurate, and, in clinical practice, it can result in a wide variation when calculated using either DRI equations, significantly overestimating TDEE. It can mislead the attending clinician to give the patient more energy than necessary, which might promote weight gain.

Conclusion

The small number of participants precludes a definitive conclusion on the adequacy of the DRI equations, and more studies are needed to reflect the energy expenditure of a broader range of Brazilian adolescents. Developing cheaper and more accurate methods of measuring TDEE and the level of physical activity in the population is essential for clinical practice. It should be a priority in future studies, but in the present study, total energy expenditure was overestimated by DRI equations compared with doubly labeled water in a sample of Brazilian adolescents.

Abbreviations

BMI - body mass index; BMR - basal metabolic rate; DLW - doubly labeled water; DRI - dietary references intake; DXA - dual-energy X-ray absorptiometry; EER - energy expenditure requirement; FFM - fat-free mass; IOM - Institute of Medicine; LBM - lean body mass; PAL - physical activity level; REE - resting energy expenditure; TBW - total body water; TDEE - total daily energy expenditure.

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Author contributions

LBS and KP: designed research; LBS, KP, EF, and RFM: conducted research; LBS, KP, EF, LAA, MGR: analyzed data or performed statistical analysis; LBS, KP, EF, LAA, MRG, NMCA, RFM: wrote the paper.

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Conflict of interest

The authors declare no conflict of interest.

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