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Original Article

AGREEMENT AND VALIDITY BETWEEN BODY FAT ESTIMATED BY SKINFOLD MEASUREMENT AND AIR DISPLACEMENT PLETHYSMOGRAPHY IN ADOLESCENTS

CONCORDÂNCIA E VALIDADE ENTRE A GORDURA CORPORAL ESTIMADA POR MEDIDAS DE DOBRAS CUTÂNEAS E PLETISMOGRAFIA POR DESLOCAMENTO DE AR EM ADOLESCENTES

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RESUMO

Objetivo: Avaliar a concordância e validade entre os percentuais de gordura corporal estimados usando medidas antropométricas e pletismografia por deslocamento de ar (PDA). **Métodos:** Um estudo transversal foi conduzido em 118 adolescentes (60 meninas) com idade entre 10 e 14 anos ($\bar{x}$=12,19, dp=1,18). Os adolescentes foram classificados como eutróficos ou com sobrepeso de acordo com o índice de massa corporal (peso/altura^2) ($\bar{x}$=20,12, dp=3,56). Medidas de dobras cutâneas (tríceps e panturrilha medial) foram coletadas e utilizadas para estimar a gordura corporal relativa pela equação de Slaughter. A PDA foi utilizada como método de referência para a estimativa da gordura corporal relativa. A concordância entre os métodos de medida de gordura corporal (antropometria × PDA) foi analisada pelo método de Bland–Altman. O erro médio (EM) foi calculado subtraindo o percentual de gordura corporal estimado pela equação de Slaughter do percentual de gordura corporal estimado pela PDA. A validade foi testada com o coeficiente de correlação de concordância (CCC). **Resultados:** Não houve concordância entre os métodos, independente do sexo e status de peso. Para meninos com excesso de peso (EM = 4,52; p = 0,007), meninas eutróficas (EM = 6,37; p < 0,001) e meninas com excesso de peso (EM = 5,55; p < 0,001), a equação de Slaughter resultou em superestimação da gordura corporal comparada com PDA. As equações de dobras cutâneas não demonstraram validade quando comparadas ao PDA. **Conclusão:** As equações de dobras cutâneas de Slaughter não demonstraram concordância e validade em comparação com PDA em ambos os sexos ou status de peso. As equações de dobras cutâneas devem ser utilizadas com cautela e, sempre que possível, acompanhada de outros indicadores de composição corporal.
Palavras-chave: Adolescentes. Composição corporal. Gordura corporal. Métodos indiretos. Métodos duplamente indiretos.

ABSTRACT

Objective: Assess the agreement and validity between relative body fat percentages estimated using anthropometric measurements and air displacement plethysmography (ADP). **Methods:** A cross-sectional study was conducted on 118 adolescents (60 females) aged 10 to 14 years ($\bar{x}$=12.19, sd=1.18). Adolescents were classified as eutrophic or with overweight according to body mass index (body weight/height^2) ($\bar{x}$=20,12, sd=3,56). Measurements of skinfold thickness (triceps and medial calf) were collected and used to estimate relative body fat by the Slaughter equation. ADP was used as a reference method for the estimation of relative body fat. Agreement between body fat measurement methods (anthropometry × ADP) was analyzed by the Bland–Altman method. The mean error (ME) was calculated by subtracting the body fat percentage estimated by the Slaughter equation from the body fat percentage estimated by ADP. Validity was tested with the concordance correlation coefficient (CCC). **Results:** There was no agreement between the methods, regardless of sex and weight status. For boys with overweight (ME = 4.52; *p* = 0.007), eutrophic girls (ME = 6.37; *p* < 0.001), and girls with overweight (ME = 5.55; *p* < 0.001), the Slaughter equation resulted in overestimation of body fat compared with ADP. Skinfold equations did not demonstrate validity when compared with ADP. **Conclusion:** Slaughter's skinfold equations did not demonstrate agreement and validity compared with ADP in either sex or weight status. Skinfold equations should be used with caution and, whenever possible, in combination with other body composition indicators.
Keywords: Adolescents. Body composition. Body fat. Indirect methods. Doubly indirect methods.

Introduction

Overweight and obesity are among the world's greatest public health problems, affecting people of all age groups[1]. Trend analyses of the last decades have shown a significant increase in the prevalence of overweight and obesity in children and adolescents worldwide[1]. This is a worrisome scenario, as children and adolescents with obesity are likely to remain with obesity throughout their lives[2] and have an increased risk of developing cardiovascular diseases in adulthood[3]. Furthermore, obesity during childhood is associated with high blood pressure, insulin resistance, altered lipid levels, asthma, obstructive sleep apnea, and psychological problems[4].

Body mass index (BMI) is widely used as a screening indicator for overweight and obesity because it is a simple and practical tool, and shows a satisfactory ability to discriminate body fat in children and adolescents[5]. However, the use of BMI alone may not be sufficient to identify individuals with excess body fat, given that BMI is calculated from body weight and height and does not differentiate fat mass from fat-free mass[6]. Several other methods can be used to estimate body composition, ranging from simple tests, such as waist circumference, waist-to-height ratio[6], and skinfold thickness[7], to highly sophisticated techniques. More sophisticated methods, used in research environments, such as dual-energy X-ray absorptiometry (DXA), air displacement plethysmography (ADP), ultrasound, and computed tomography, have the greatest validity and reproducibility for body composition assessment[7,8], and considering accuracy, precision, cost, duration and ability, the gold-standard method to assess body composition is DXA, especially for the evaluation of body fat[9]. Such techniques may not always be feasible because of their high cost and need for complex procedures and equipment. To circumvent these limitations, researchers have proposed equations based on anthropometric measurements (body weight, height, body perimeter, and skinfold thickness) and developed bioelectric impedance scales that are widely used for the evaluation of body composition[10,11].

Skinfold equations are a viable option for estimating body fat in children and adolescents[7,12,13]. The Slaughter equation, for example, is sex-specific and allows estimating body fat in young people according to the pubertal stage, skin color, and skinfold thickness (triceps, medial calf, and subscapular)[12]. Although it is recommended to use anthropometric measurements to estimate body composition, these parameters may not be suitable for all populations[13,14]. For instance, in some specific groups such as very thin or adolescents with overweight, anthropometric measurements may not provide good reliability, underestimating or overestimating body fat compared with the 4-compartment model (reference method)[10]. Such limitations underscore the need to assess the agreement between anthropometric measurements and sophisticated techniques, because, even though anthropometric methods have good discriminatory power to estimate body fat in children and adolescents[6], they may be biased and not adequately assess body fat percentage[15,16]. Therefore, this study aimed to assess the agreement and validity between relative body fat estimated by the Slaughter equation and ADP in eutrophic adolescents and adolescents with overweight.

Methods

Study design and participants

This is a cross-sectional study using data from a macro project entitled "Bone mineral density in adolescents: what is the relationship with body fat, physical activity, and sedentary behavior?”. The study was conducted in a public primary school (intentionally selected) in the municipality of São José, SC, Brazil, between March and November 2016. The school was selected because it is the largest in the city (in terms of students), including schoolchildren from different economic conditions and regions of the municipality. The school also provides supervised internships to undergraduate students from the university linked to this study. Sampling was by convenience, and all adolescents aged 10 to 14 years were invited to participate in the study.

The sample included only adolescents classified as eutrophic or overweight, according to specific cut-offs for age and sex[17]. Adolescents with underweight, obese, who were pregnant, and/or diagnosed with diseases or health conditions, that could influence body composition were ineligible for the study. Of the 1002 students enrolled in the school in the survey year, 433 were excluded because they were underweight or obese, 440 refused to participate, and 10 did not meet the inclusion criteria. None of the students reported being pregnant. The final sample comprised 118 individuals who met the inclusion criteria, agreed to participate voluntarily, and completed the entire data collection procedure. The sample power was calculated to posteriori using GPower 3.1 software. For this, the mean value (4.20) and standard deviation (7.10) of differences between the Slaughter equation and ADP estimates were used, resulting in an effect size of 0.59 at a significance level of 0.05 and a power greater than 0.90.

Ethical aspects

All adolescents who agreed to participate in the research signed an assent form and provided a consent form signed by their parents or guardians, in agreement with the requirements for research with human beings of the National Health Council (Resolution No. 466/2012) and the Declaration of Helsinki. The study was approved by the Human Research Ethics Committee at Santa Catarina State University (protocol No. 1,468,045/2016).

Study variables

Participants answered a questionnaire informing their sex (male or female) and age (full years). Body weight was measured to the nearest 100 g using a G-Tech Pro® digital scale (Pacific Palisades, USA). Height was measured to the nearest 1 mm using a portable stadiometer Alturexata® (Minas Gerais, Brazil). BMI values were then calculated by dividing body weight (kg) by height squared (m^2) and used to categorize individuals into eutrophic and with overweight according to sex- and age-specific cutoffs[17]. Sexual maturation was evaluated with images of five different stages of development, evaluated from the growth of pubic hair (stage 1: pre-pubertal; stages 2, 3, and 4: pubertal; stage 5: post-pubertal) [18]. After looking at the images, adolescents must indicate the number corresponding to their stages.

Triceps and medial calf skinfold thicknesses were measured to the nearest 0.1 mm using a scientific skinfold caliper (Cescorf®, Porto Alegre, Brazil). Two non-consecutive measurements were taken from each site and mean values were calculated. When the difference between measurements was greater than 5%, a third measurement was performed; in such cases, the median value was used[19]. The skinfold equations proposed by Slaughter et al.[12] for individuals aged 8 to 18 years were used to estimate absolute and relative body fat (Table 1).

Table 1. Skinfold equations proposed by Slaughter et al.[12]

Group	Equation
Boys	$y = 0.735 \times (TST + MCST) + 1.0$
Girls	$y = 0.610 \times (TST + MCST) + 5.1$

Note:TST, triceps skinfold thickness; MCST, medial calf skinfold thickness
Source: Slaughter et al.[12]

Body density was measured in a Bod Pod® apparatus (Life Measurement Instruments, Concord, CA, USA) by ADP, used as a reference method. The room temperature was maintained at 21–24 °C. Evaluations were carried out with adolescents in a motionless sitting position, with the torso upright and hands placed on the knees. The thoracic gas volume was not measured for logistical reasons and to avoid the exclusion of individuals for whom it was not possible to measure the parameter. Thus, we used thoracic gas volumes estimated by Bod Pod according to sex and age. Body fat estimates were calculated by the Bod Pod software using the Lohman[20] equation = [(5.30/Body density) – 4.89] * 100, and results are expressed as absolute (kg) and relative (%) values.

All anthropometric measurements were performed by a single trained evaluator according to standard recommendations[21]. Body fat assessments by ADP were conducted following the manufacturer's instructions. For participation, adolescents were recommended to (i) fast for at least 10 h prior to the assays, (ii) wear adequate clothing for the measurements (swim briefs for boys and tops and form-fitting shorts for girls, as well as swim caps for ADP evaluations), (iii) not carry or wear any metal object, such as earrings, rings, piercings, and chains, (iv) not have performed physical activity in the 48 h prior to assessments, and, (v) for girls, not have their menstrual period.

Statistical procedures

Data was presented as mean, standard deviation, median, interquartile range, and, when applicable, the frequency distribution. Data distribution was tested by the Kolmogorov–Smirnov test. The independent samples *t*-test and the Mann–Whitney *U*-test were used to compare variables between sexes. Agreement between methods was assessed by the Bland–Altman method[22]. The scatter plot comprised the mean error (ME) (mean of the difference between the Slaughter equation and ADP results) and the mean of both measurements [(Slaughter equation + ADP)/2]. The paired *t*-test (systematic bias) was used to assess differences between measurement methods. The Pearson correlation coefficient was used to assess whether ME correlated with the magnitude of measurements (heteroscedasticity). The concordance correlation coefficient (CCC) analysis was used to evaluate whether the skinfold measurements can reproduce ADP results. Analyses were performed at a significance level of $p < 0.05$ using IBM SPSS Statistics version 20.

Results

A total of 118 adolescents (50.8% girls) aged 10 to 14 years participated in the study. The prevalence of eutrophic boys was 55.2% (n = 32) and eutrophic girls was 56.7% (n = 34), and that of boys with overweight was 44.8% (n = 26), and girls with overweight was 43.3% (n = 26). Age and BMI showed normal distribution for both sexes, and TST and absolute body fat showed normal distribution for boys. As shown in Table 2, the mean values of all study variables were similar among boys and girls.

Table 2. Sample characteristics

Variable	**Boys (*n* = 58)**		**Girls (*n* = 60)**		***p*-value**
	Mean (SD)	**Median (IR)**	**Mean (SD)**	**Median (IR)**	
Age (years)	12.2 (1.2)	12.0 (11.0-13.0)	12.2 (1.14)	12.0 (11.0-13.0)	0.756#
Body weight (kg)	49.3 (12.0)	46,9 (41.3-59.1)	50.2 (12.09)	49.1 (40.6-58.8)	0.695
Height (cm)	156.8 (10.8)	156.3 (146.8-164.7)	156.2 (8.82)	156.6 (149.4-161.0)	0.716
BMI (kg/m^2)	19.9 (3.4)	20.7 (16.8-22.5)	20.4 (3.75)	20.4 (17.0-24.0)	0.357#
TST (mm)	14.6 (6.9)	14.9 (8.3-20.4)	17.0 (7.15)	14.6 (12.1-21.1)	0.097#
MCST (mm)	14.6 (6.2)	13.7 (8.8-19.2)	15.9 (5.42)	15.5 (11.6-19.3)	0.242
Slaughter BF (kg)	11.6 (6.3)	12.0 (5.4-16.5)	13.3 (6.67)	12.2 (8.0-17.2)	0.170
Slaughter BF (%)	22.5 (9.3)	22.2 (13.3-29.3)	25.2 (7.36)	23.1 (19.5-29.1)	0.087
ADP BF (kg)	10.2 (5.6)	8.8 (5.6-14.5)	10.6 (7.45)	8.2 (4.7-14.9)	0.834#
ADP BF (%)	20.2 (9.8)	19.2 (11.6-27.1)	19.2 (8.41)	18.7 (11.1-25.0)	0.551
	n (%)		**n (%)**		**Chi-squared**
Sexual Maturation					0.294
Stage 1	6 (10.3)		4 (6.7)		
Stage 2	11 (19.0)		14 (23.3)		
Stage 3	10 (17.2)		19 (31.7)		
Stage 4	27 (46.6)		21 (35.0)		
Stage 5	4 (6.9)		2 (3.3)		

Note: *n*, absolute frequency; SD, standard deviation; IR, interquartile range; BMI, body mass index; TST, triceps skinfold thickness; MCST, medial calf skinfold thickness; BF, body fat; ADP, air displacement plethysmography; #, Mann-Whitney *U*-Test
Source: Authors

For agreement analysis, we generated dispersion graphs for boys (Figure 1) stratified by body weight status. Although no significant bias was observed between Slaughter and ADP for eutrophic boys (ME = 0.55, p= 0.663), the limits of agreement were high, and CCC was poor (CCC = 0.597; 95% confidence interval (CI) = 0.319 – 0.779). However, for boys with overweight, the skinfold equation provided higher values than the ADP method (ME = 4.52, p = 0.007; CCC = 0.540, 95%CI = 0.289 – 0.722). Heteroscedasticity of data was not observed for eutrophic boys (r = 0.059, p = 0.746), unlike for boys with overweight (r = −0.537, p = 0.005), for which ME values tended to increase for lower body fat measurements obtained by ADP. The LOA and CCC indicated that the Slaughter equation did not demonstrate validity for estimating the body fat of eutrophic boys and boys with overweight compared to ADP.

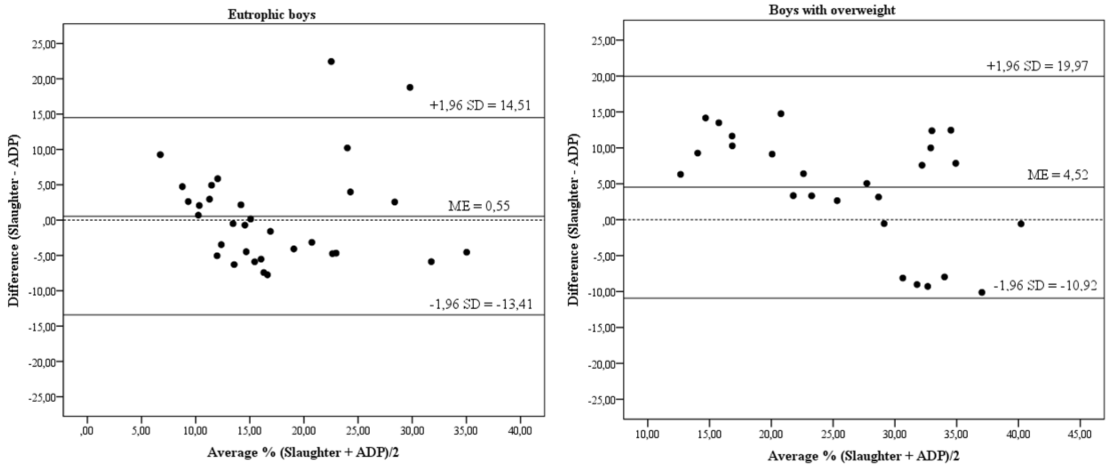

Figure 1. Bland-Altman plots for the concordance limits between values determined by the reference method (ADP) and Slaughter equations to absolute and relative body fat in boys
Source: The authors

For girls (Figure 2), body fat estimated by the Slaughter equation was higher than that estimated by ADP in eutrophic (ME = 6.37, $p < 0.001$; CCC = 0.210; 95%CI = 0.023 – 0.383) and with overweight (ME = 5.55, $p < 0.001$; CCC= 0.462, 95%CI = 0.190 – 0.668) groups. High LOA was observed for both groups, due to the small sample. Heteroscedasticity analysis revealed that, for eutrophic girls, ME tended to increase for lower body fat percentages estimated by ADP ($r = -0.357$, $p = 0.038$). For girls with overweight, heteroscedasticity of data was not observed ($r = -0.068$, $p = 0.742$).

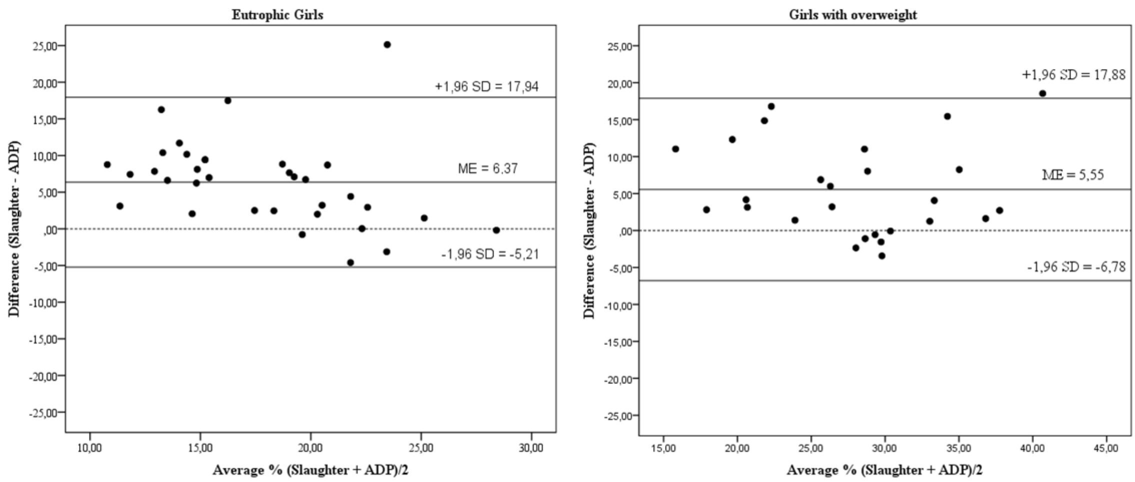

Figure 2. Bland-Altman plots for the concordance limits between values determined by the reference method (ADP) and Slaughter equations to absolute and relative body fat in girls
Source: Authors

Discussion

This study aimed to assess the agreement between two methods for estimating body fat, namely the Slaughter equation and ADP, in eutrophic adolescents and adolescents with overweight. The results indicated that there was no agreement and validity for the Slaughter equations for both sexes, regardless of weight status. The LOA and CCC indicators corroborate that, for adolescents with the characteristics of the present study, the Slaughter equation should be used with caution.

There was no agreement between methods for adolescents with overweight of either sex, corroborating the results of Pelegrini et al.[23], who did not observe agreement between bioelectric impedance analysis (BIA) and ADP for adolescents with overweight. These results suggest that, although skinfold equation are recommended because of their greater simplicity and feasibility when evaluating adolescents with overweight, it is pertinent to consider additional body measures (body perimeters or other indicators, such as waist-to-height ratio and body adiposity index) for better interpretation of body composition. Individuals in this age group undergo hormonal changes related to puberty, generally leading to changes in growth and body composition[24]. The findings reinforce that anthropometric indicators are not accurate for estimating the body composition of children and adolescents with overweight and obesity[7].

One should not rule out the possibility that the differences between methods observed here were due to differences between the study sample and the sample used for the development of the equations (young people from Illinois and Arizona, United States of America)[12]. A study conducted with adolescents from southern Brazil developed skinfold model for estimation of body fat using dual-energy X-ray absorptiometry as the reference method[13]. Although the equations developed by Ripka, Ulbricht, and Gewehr[13] showed normal distribution of residuals but not heteroscedasticity, there was a tendency to overestimate relative body fat in leaner adolescents and underestimate the parameter in obese adolescents compared with dual-energy X-ray absorptiometry. In line with the findings of the current study, these results underscore the difficulty in estimating body fat by skinfold equation in Brazilian adolescents who are very thin or with overweight. Measurement errors may be lower in lean adolescents with low body adiposity, which may facilitate skinfold clamping and measurement. On the other hand, because of the differences in body fat distribution, skinfold thickness, and consistency of subcutaneous adipose tissue in people with overweight, which can make constancy of fat compressibility more difficult, combined with the inability to estimate intra-abdominal fat[14], it's possible that body fat measures are underestimated in adolescents with overweight.

The Slaughter equation, which uses the sum of triceps and medial calf skinfold thicknesses, provided a higher estimation error for adolescents with higher body adiposity compared with an equation that uses the sum of triceps and subscapular skinfold thicknesses[10]. Such a result may be attributed to body fat distribution: triceps and medial calf skinfolds reflect a global distribution of adipose tissue, whereas triceps and subscapular skinfolds represent a more central distribution of body adiposity. These factors may explain the tendency of the Slaughter equation to have lower accuracy in adolescents with more body fat, leading to overestimation of results compared with the 4-compartment model[10]. Although the referred study used a different reference method, the findings support our results, in that the skinfold equation showed no validity to estimate body fat in both sexes compared to ADP.

Heteroscedasticity of data was present in boys with overweight ($r = -0.537$, $p = 0.005$) and for eutrophic girls ($r = -0.357$, $p = 0.038$), showing that ME values tended to increase for lower body fat measurements estimated by ADP. The presence of heteroscedasticity reflects on the Ordinary Least Squares estimators, which no longer have minimum variance and efficiency, and on the bias of the variance of the estimators, which show inconsistency.

Validity between skinfold measurements and ADP results was poor, demonstrating that the Slaughter equation does not reproduce ADP results with precision and accuracy. Although CCC is one of the most used statistical methods for the comparison between different techniques[25], no studies applying Lin's method[26] to confirm the reproducibility of body fat assessed with skinfold thickness in relation to ADP was found. Studies have used

CCC to compare body fat estimated with DXA as the reference method, and the reproducibility of results obtained with BIA[27-29] and anthropometric equations [29,30]. Two equations to estimate body fat in greek adults, considering circumferences, skinfold thicknesses, height, and sex, showed good reproducibility (CCC=0.914 and 0.951)[30], but when comparing Slaughter equation in Colombian children and adolescents with excess of adiposity, reproducibility was poor in boys (CCC=227) and girls (CCC=0,179)[29]. Also, body adiposity index has been used to estimate body fat, compared with BIA as the reference method in adults with overweight and obesity[31], and college students[32]. The only study that used ADP as the reference method, estimated body fat from skinfolds obtained by ultrasound (BodyMetrix) in Brazilian adults, and showed moderate reproducibility in men (CCC=0.853), and good reproducibility in women (CCC=0.903)[33]. In relation to studies with Brazilian adolescents, a study evaluated the fat-free mass with BIA and compared measurements with the DXA, which showed good reproducibility (CCC=0,984)[34]. Given these results, the Slaughter equation does not seem to be the most suitable method for assessing body fat.

Some limitations should be acknowledged. First, the small sample size can be explained by the difficulty in applying ADP to large samples. Second, the study did not use the gold-standard method to assess body fat. On the other hand, the use of ADP as the reference method, which has good validity and reproducibility for estimating body fat[10,35], is a strength of this study. Future research should analyze a representative sample of adolescents with characteristics similar to those of the present study, but with a broader age range and compare different anthropometric techniques with ADP and other reference methods.

Conclusion

There was no agreement between the skinfold equation and ADP for body fat measurement in eutrophic boys, despite the high LOA. For adolescents with overweight of both sexes and eutrophic girls, the Slaughter equation overestimated body fat compared with ADP. Assessment of body fat in adolescents through the Slaughter skinfold equation (using triceps and medial calf skinfold thicknesses) should be performed with caution, and, whenever possible, be accompanied by other methods for assessing body composition. Future studies for the development of new anthropometric equations, considering weight status, may help in estimating body fat measurements.

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