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Validity and accuracy of body fat prediction equations using anthropometric measurements in children 7 – 10 years old

Validade e acurácia de equações de predição de gordura corporal usando medidas antropométricas em crianças de 7 a 10 anos

Ravi Marinho dos Santos[1]
https://orcid.org/0000-0002-2404-6738
Isabele Góes Nobre[1]
https://orcid.org/0000-0003-4598-1060
Gabriela Carvalho Jurema Santos[1]
https://orcid.org/0000-0002-7010-5049
Tafnes Laís Pereira Santos de Almeida Oliveira[1]
https://orcid.org/0000-0002-5904-8557
Isabella da Costa Ribeiro[1]
https://orcid.org/0000-0002-3817-2073
Marcos André Moura dos Santos[2]
https://orcid.org/0000-0002-2734-8416
Luciano Pirola[3]
https://orcid.org/0000-0001-6539-5435
Carol Góis Leandro[1]
https://orcid.org/0000-0001-6176-1688

[1] Universidade Federal de Pernambuco. Recife, PE. Brasil.
[2] Universidade de Pernambuco. Escola Superior de Educação Física. Recife, PE. Brasil.
[3] Lyon University. Cardiology, Metabolism and Nutrition Laboratory. Oullins, France.

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Corresponding author
Carol Góis Leandro.
Departamento de Nutrição, Universidade Federal de Pernambuco – CAV-UFPE
Rua Alto do Reservatório, s/n, Bela Vista, Vitória de Santo Antão (PE), Brasil.
E-mail: carol.leandro@ufpe.br

Abstract – Children with a deficit of growth because of perinatal malnutrition present specificities in the percentage of body fat (%BF) that could not be detected by previous fat mass-based equations. This study developed and validated predictive equations of the %BF derived from anthropometric variables in children aged 7 to 10 living in Northeast Brazil, using dual-energy x-ray absorptiometry (DXA) as a reference. Body composition data from 58 children were utilized. DXA was used as a reference. A stepwise (*forward*) multiple regression statistical model was used to develop the new equations. The Bland-Altman analysis (CI: 95%), paired Student's t-test, and the intraclass correlation coefficient (ICC) was used to validate and compare the developed equations. Two new equations were developed for either gender: boys: %BF: 13.642 + (1.527*BMI) + (-0.345*Height) + (0.875*Triceps) + (0.290* Waist Circumference) and girls: %BF: -13.445 + (2.061*Tight). The Bland-Altman analysis showed good agreement, with limits ranging from -1.33 to 1.24% for boys and -3.35 to 4.08% for girls. The paired Student's t-test showed no difference between %BF-DXA and the two new equations (p> 0.05), and the ICC was 0.948 and 0.915, respectively. DXA-based anthropometric equations provide an accurate and noninvasive method to measure changes in the %BF in children.

Key words: Anthropometry; Body composition; Child.

Resumo – *Crianças com déficit de crescimento por desnutrição perinatal apresentam especificidades na distribuição do percentual de gordura corporal (%GC) que não puderam ser detectadas por equações anteriores baseadas no %GC. Este estudo desenvolveu e validou equações preditivas do %GC derivadas de variáveis antropométricas em crianças de 7 a 10 anos residentes no Nordeste do Brasil, utilizando como referência a absorciometria radiológica de dupla energia (DXA). Foram utilizados dados de composição corporal de 58 crianças. O DXA foi usado como modelo de referência. Um modelo estatístico de regressão múltipla stepwise (forward) foi usado para desenvolver as equações. A análise de Bland-Altman (IC: 95%), teste t de Student pareado e o coeficiente de correlação intraclasse (CCI) foram utilizados para validar e comparar as equações. Duas novas equações foram desenvolvidas para ambos os sexos: meninos: %GC: 13,642 + (1,527*IMC) + (-0,345*Altura) + (0,875*Tríceps) + (0,290* Circunferência da cintura) e meninas: %GC: - 13,445 + (2,061*coxa). A análise de Bland-Altman mostrou boa concordância, com limites variando de -1,33 a 1,24% para meninos e -3,35 a 4,08% para meninas. O teste t de Student pareado não mostrou diferença entre %GC-DXA e as duas novas equações (p>0,05), e o CCI foi de 0,948 e 0,915, respectivamente.*

Palavras-chave: *Antropometria; Composição corporal; Criança.*

INTRODUCTION

In children, accurate measurement of body composition during childhood can be a useful strategy to provide information on growth and nutrition[1]. Body mass index (BMI) is currently the most widely used tool to classify childhood overweight/obesity[2]. However, BMI does not distinguish fat and lean tissue, and previous studies have also demonstrated that the relationship between children's BMI and body fat varies with age and between ethnic groups[3]. Thus, to overcome these limitations, more accurate methods to estimate body composition need to be used.

Several methods to assess body composition have been developed for children with varying degrees of accuracy[4]. Laboratory methods, such as dual-energy x-ray absorptiometry (DXA), are widely accepted as reference analysis[5]. However, the high cost and transport infeasibility of the DXA equipment is evident limitations in many field settings[6]. A more practical, quick, and inexpensive alternative, although providing indirect evidence, is the use of equations to predict body fatness using easily measurable anthropometric variables[7].

Many equations based on anthropometric variables have been developed to estimate body fat percentage (%BF) in children[8,9]. Slaughter et al.[10] developed body fat prediction equations for Afro- and Euro-American children using anthropometric variables. In this study, the equations are based on skinfold thickness (%BF boys = 0.735 [Tri + Calf] + 1.0 and %BF girls = 0.610 [Tri + Calf] + 5.1). However, children with growth deficits because of perinatal malnutrition or living in a region of nutrition transition present a relatively particular fatness distribution[11]. Given these limitations, some disagreement is expected among Brazilian children, particularly because the distribution of overweight and obesity is heterogeneous across the country[12].

In the Northeast region of Brazil, the overweight rate of children is one of the highest in the country (28.8%), and obesity increased by 4.5-fold in the last two decades[13]. Vitória de Santo Antão, located in the State of Pernambuco, witnessed a reduction in infant undernutrition rates with a simultaneous increase in the prevalence of children with obesity[14]. This shift is driven by a single cause, the nutritional transition. Recently published data from our research group suggests that Vitória-PE is in an advanced phase of nutritional transition, where 43.7% of the calories consumed are coming from ultra-processed foods[15]. Thus, the goal of this study is to develop and validate predictive equations of the percentage of body fat derived from anthropometric variables in children aged 7 to 10 years old living in Vitoria de Santo Antão-Brazil.

METHODS

Sample

The study was conducted in Vitória de Santo Antão, a city in the Northeastern region of Brazil belonging to the Pernambuco state. The sample size was calculated using the G-Power software (version 3.1.9.4). An effect size of f^2 was assumed: 0.15; a significance level of 0.05%, and the power of the adopted test was 90%. For a multiple regression analysis (two tails; the number of independent variables = 4), a minimum sample size of 58 participants (31 boys and 27 girls) was necessary to identify a medium effect size.

Ethical aspects

Ethical approval was obtained from the Research Ethics Committee with Human Subjects of the institution Federal University of Pernambuco (CAAE 91338718.0.0000.5208), and the protocol was written according to the standards established by the Declaration of Helsinki. All subjects provided written informed consent before the study and their rights were protected.

Anthropometry and body composition

Lohman described standardization as used to measure body weight, height and waist, and hip circumferences[16]. Bodyweight was collected using a digital scale (Omron HBF-214/HBF214-LA, São Paulo, Brazil). Height was assessed using a portable stadiometer (compact MD - HT / 01). Both measurements were performed with the child barefooted. Circumferences were measured using an anthropometric measuring tape (Cescorf, Porto Alegre, Rio Grande do Sul). Body mass index (BMI) was calculated using the formula: body mass (Kg) / height (m^2). Eight skinfolds were collected using a Cescorf Digital caliper (0.1mm, Porto Alegre, Brazil)[16].

Dual-energy X-ray Absorptiometry (DXA)

Total body composition was assessed using the DXA (HOLOGIC QDR WI Bedford, MA, USA software APEX™). The radiation dose received was less than 1.0 mRem, ensuring the assessment was accurate, safe, and valid for the child population[17]. The device was previously calibrated using a phantom manufacturer provided. To avoid the presence of systematic bias and to guarantee reliability between assessments, a single scanner was performed per child[17]. Children were instructed to wear light clothing without metal adornments.

Reliability

The technical error of measurement (TEM) was performed in 10% of the total sample. A total of 6 children were evaluated by two evaluators on a single collection day. Both evaluators had the measurements compared and expressed in values: absolute (mm) and relative (%) (Supplementary Material Table 1).

Statistical analysis

The normality of the data distribution was verified by the Kolmogorov-Smirnov test and by visual inspection of histograms. All analyses were performed separately for both sexes. Mean and Standard Deviation (SD) were used for descriptive statistics. For the development and validation of the equations, 58 children were stratified for both sexes and randomly divided into two groups: development group (n = 14 boys; n = 12 girls) and validation group (n = 17 boys; n = 15 girls). The anthropometric characteristics of the groups were compared using the student's t-test. The % BF derived from DXA measurements was used as a criterion for the development of predictive equations.

The stepwise multiple regression analysis (forward) was used to choose the best predictors. BMI, height, tricipital skinfold, waist circumference (boys;

model R^2: 0.94), and thigh skinfold (girls; model R^2: 0.85) were considered independent variables. The variation inflation factor (VIF) ≤ 10 was adopted to justify the absence of multicollinearity among the predictors. The Durbin-Watson statistic was used to verify the presence of dependence between the residuals of the predictor variables.

The developed equations were used to predict the %BF-DXA in the validation group and compared with equations published in the literature. The choice of previously published equations followed these selection criteria: (i) studies with equations that differed from the age range of the current study were excluded; (ii) equations developed for different populations as athletes or groups of specific diseases were excluded. Thus, only studies that were methodologically similar to the present study were selected, as shown in Supplementary Material Table 2.

The Bland-Altman analysis (CI: 95%), paired Student's t-test, and the Intraclass correlation coefficient (CCI) was used in the set of tests to validate the developed equations[18]. The magnitude of the CCI was weak: 0.10 ≤ 0.30; moderate: 0.30 ≤ 0.50; strong: 0.50 ≤ 0.70; very strong: 0.70 ≤ 0.90; and perfect: 1.0. All analyses were performed in the Statistical Package for the Social Science (SPSS), version 22, the level of significance established p ≤ 0.005.

RESULTS

Table 1 presents descriptive sample characteristics. There were no differences in the anthropometric characteristics between the two groups for both sexes. Two new predictive equations for %BF were developed for children (both sexes) aged 7-10 years from anthropometric variables inserted in the statistical stepwise multiple regression model (forward).

Table 1. Mean and standard deviation of demographic variables and body composition of children (both sexes) aged 7 - 10 years.

Variables	Development group				Validation group				*P Boys*	*P Girls*
	Boys (n=14)		Girls (n=12)		Boys (n=17)		Girls (n=15)			
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD		
%BF-DXA (%)	30.9	9.5	32.6	7.8	31.5	8.6	31.7	6.6	0.633	0.658
Abdominal (mm)	16.6	4.1	15.4	3.2	19.5	1.3	15.3	2.7	0.443	0.795
Axillary (mm)	16.8	3.8	14.9	3.4	12.7	2.6	11.4	2.7	0.190	0.308
Bicipital (mm)	16.3	3.6	15.4	2.9	9.5	1.7	9.9	1.4	0.240	0.207
Waist.C (cm)	61.9	8.4	62.8	7.9	60.1	5.7	54.7	3.9	0.614	0.115
BMC (g)	991.9	227.2	964.3	135.4	950.1	136.2	939.2	190.1	0.733	0.960
Hip.C (cm)	67.0	8.9	72.8	6.7	68.4	5.2	64.0	3.7	0.227	0.428
Thigh (mm)	22.8	7.1	22.3	3.5	19.7	2.6	20.4	2.0	0.342	0.555
BMD (g/cm2)	788.6	89.6	762.3	71.6	762	59.0	733.4	84.0	0.409	0.329
Height (cm)	127.6	8.4	132.9	7.5	137.7	3.9	136.8	3.7	0.130	0.302
Age (y)	9.4	1.9	9.4	1.9	9.2	1.0	9.0	1.0	0.210	0.732
BMI (kg/m2)	19.7	4.4	17.2	3.3	21.2	4.6	20.2	3.0	0.711	0.185
FM (g)	528.3	211.3	1506.7	257	1819.1	542.9	2035	779	0.211	0.117

Note. %BF-DXA: Percentage of body fat estimated by DXA; Waist.C: Waist circumference (cm); Hip.C: Hip circumference (cm); Subcutaneous skinfolds expressed in millimeters (mm); BMI: body mass index; BMC: Bone mineral content (g); BMD: Bone mineral density (g / cm^2); FM: Fat mass (g); LM: Lean mass (g).

Table 1. Continued...

Variables	Development group				Validation group				*P Boys*	*P Girls*
	Boys (n=14)		Girls (n=12)		Boys (n=17)		Girls (n=15)			
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD		
LM (g)	2461.9	553.6	2015.7	446.1	2276.1	474.0	1924	338	0.483	0.607
Calf (mm)	21.1	5.0	19.3	3.4	14.7	2.2	16.8	2.6	0.320	0.513
Weight (kg)	37.6	7.5	31.4	8.4	36.8	4.9	31.3	3.9	0.937	0.898
Subscapular (mm)	15.2	4.6	14.7	3.4	11.5	1.6	12.3	2.4	0.184	0.683
Suprailiac (mm)	20.5	3.6	16.1	17.2	11.0	2.7	11.5	2.4	0.442	0.242
Tricipital (mm)	17.1	4.0	3.0	3.2	12.8	1.4	12.8	1.5	0.238	0.472

Note. %BF-DXA: Percentage of body fat estimated by DXA; Waist.C: Waist circumference (cm); Hip.C: Hip circumference (cm); Subcutaneous skinfolds expressed in millimeters (mm); BMI: body mass index; BMC: Bone mineral content (g); BMD: Bone mineral density (g / cm^2); FM: Fat mass (g); LM: Lean mass (g).

Both models included the variables: BMI, height, tricipital skinfold, waist circumference, and thigh skinfold which explained 94.0%, and 85.0% of the percentage of BF-DXA variance, respectively (Table 2). The values of the Durbin-Watson statistic (1.765 – 1.859) indicated the absence of autocorrelation (dependence) between the residues. The VIF values (1.644 - 4.050; 1,000) between the predictor variables demonstrated the lack of multicollinearity. For both equations, the SEE values were less than 3.20% (Table 2).

Table 2. % BF predictive equations for children of both sexes 7 - 10 years old generated in this study.

	%BF predictive equations	R	R^2	SEE	DW	VIF
Boys (**n** = 14)	%BF: 13.642 + (1.527*BMI) + (-0.345*H) + (0.875*Tri) + (0.290* Waist C.)	97.0	94.0	2.818	1.859	1.644 – 4.050
Girls (**n** = 12)	%BF: -13.445 + (2.061*Thi)	92.2	85.0	3.200	1.765	1.000

Note. %BF = percentage of body fat; BMI = body mass index; H= Height; Tri = tricipital skinfold (mm); Thi = thigh skinfold (mm); Waist.C = Waist circumference; SEE= Standard error of the estimate; DW = Durbin-Watson statistics; VIF= Variance inflation factor.

Figure 1 shows the analysis agreement Bland-Altman method between %BF-DXA and the %BF-new equations developed for both sexes. The central lines did not show significant deviations from zero for both equations (Boys = bias: 0.05; Girls = bias: -0.4; p ≤0.005). The Bland-Altman analysis showed good agreement between both methods, with limits of agreement ranging from -1.33 to 1.24% for boys and -3.35 to 4.08% for girls.

The agreement between %BF-DXA and the eight predictive %BF equations previously published in the literature is shown in Figure 2. Initially, the central lines showed significant deviations from zero for the six equations (Figure 2A to 2F). The biases ranged from -8.71 to - 10.24; p ≤0.005 for boys and from-8.45 to 10.09; p ≤0.005 for girls. Only *Cameron* equations did not show significant deviations from zero between the central lines (Boys = bias: 0.89; Girls = bias: -1.14; p ≤0.005) (Figure 2G and 2H). Six %BF equations (Figure 2A and 2F) previously developed for both sexes showed discordant limits of agreement compared to the reference method. Such limits ranged from -1.97 to 22.44% for boys and from -6.26 to 23.16% for girls (Figure 2A and 2B); -1.42 to 19.62% for boys and -27.73 to 7.54% for girls (Figure 2C and 2D); -6.81 to 24.23% for boys and -2.34 to 23.88% for girls (Figure 2E and 2F). Only *Cameron* equations showed good agreement between both methods. The limits of agreement ranged from -1.33 to 1.24% for boys and from -3.35 to 4.08% for girls (Figure 2G and 2H).

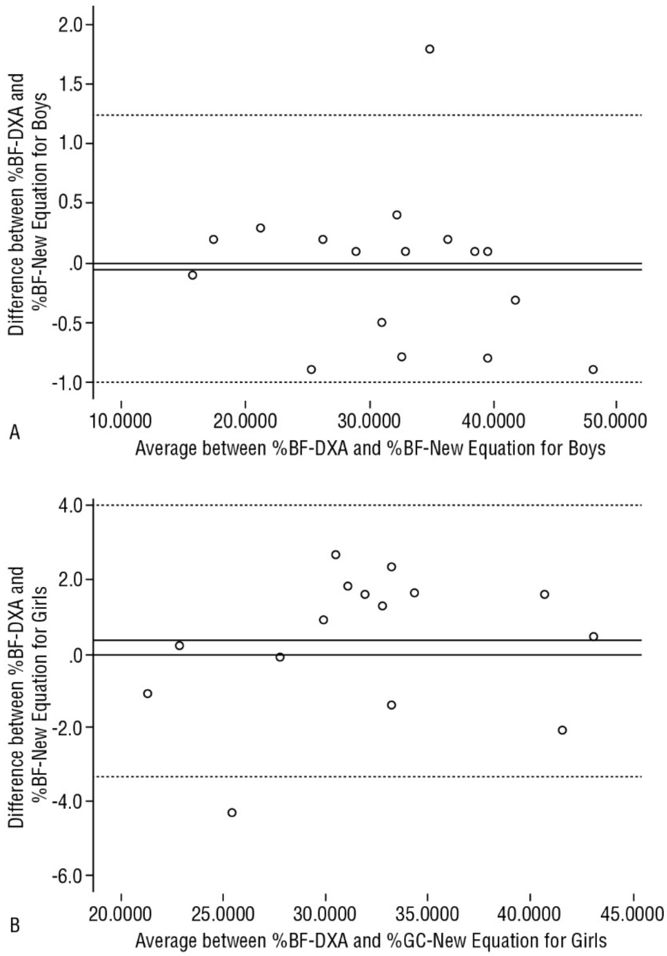

Figure 1. Limits of agreement between %BF-DXA and two new %BF equations in the validation sample (boys n = 17; girls n = 15) to children of both sexes 7-10 years. Boys (A) and Girls (B). Results obtained by Bland-Altman analysis.

Table 3 demonstrates the comparison of %BF-DXA and all predictive equations. There was no difference between %BF-DXA and the two new equations developed for both sexes (p> 0.05). The Intraclass correlation coefficient (ICC) was classified as very strong between DXA, and the two new equations developed for both sexes (ICC = 0.948; 0.915). The ICC was moderate for both *Slaughter* I equations (ICC = 0.558; 0.455). Both *Slaughter* II equations, the ICC varied between moderate (ICC = 0.329) and strong (ICC = 0.655), respectively. *Bray's* equations, the ICC were classified as moderate (ICC = 0.366) and strong (ICC = 0.679). Among *Cameron* equations, ICC was classified as very strong (ICC = 0.700; 0.764). %BF was overestimated in the equations of *Slaughter* I - Boys (10.17; p <0.005) and *Slaughter* I - Girls (8.42; p <0.005); *Slaughter* II - Boys (9.10; p <0.005) *Slaughter* II - Girls (10.06; p <0.005); *Bray*-Boys (8.72; p <0.005) *Bray* - Girls (10.74; p> 0.005). *Cameron's* equations - Boys (-0.65; p <0.005) and *Cameron* - Girls (-1.13; p> 0.005) showed no differences (Table 3).

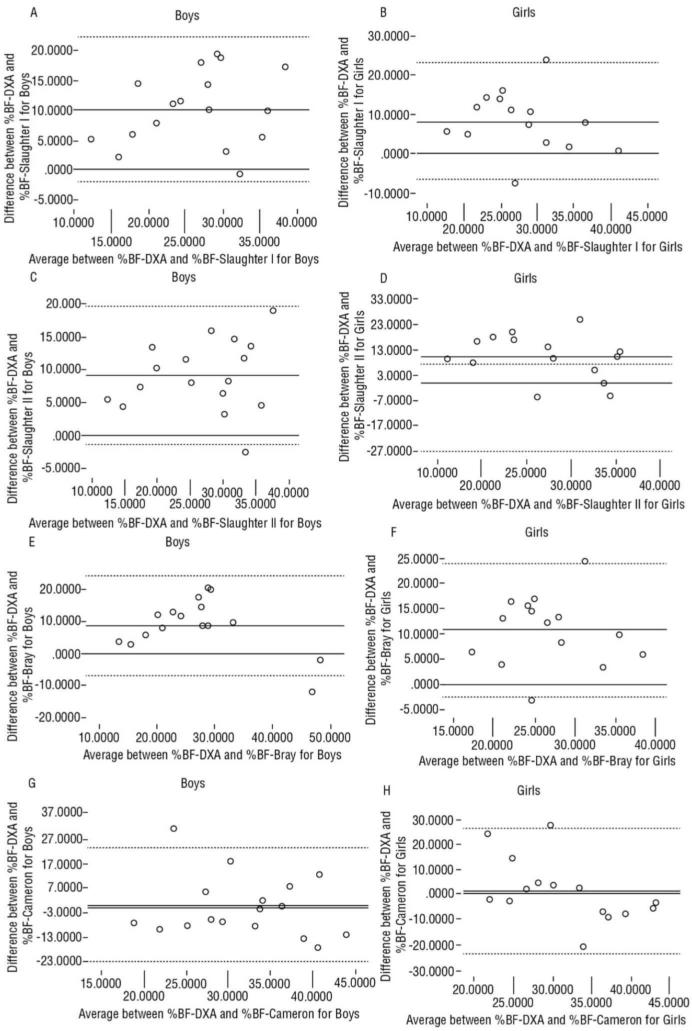

Figure 2. Limits of agreement between %BF-DXA reference values and %BF predicted equations previously published in the validation sample (boys **n**=17; girls **n**=15). Figure 2A and 2B shows the Slaughter I equations agreement. Figure 2C and 2D shows the Slaughter II equations agreement. Figure 2E and 2F shows the Bray equation's agreement. Figure 2G and 2H shows Cameron's equations agreement. Boys (left) Girls (right). Results were obtained through the Bland-Altman analysis.

Table 3. Comparison of the body fat percentage, measured by DXA and the predictive equations.

	Authors	N	BF (%) Equations Mean (±SD)	BF (%) DXA Mean (±SD)	Intraclass correlation coefficient (ICC)	*t*	*p*
1	%BF-New equations (boys)	17	32.29 (9.29)	31.94 (8.72)	0.948	-3.53	0.728
2	%BF-New equations (girls)	15	31.73 (7.95)	32.13 (6.56)	0.915	0.40	0.717
3	%BF-Slaughter I (boys)	17	21.29 (7.38)	31.94 (8.63)	0.558	10.17	0.000
4	%BF-Slaughter I (girls)	15	23.70 (7.93)	32.13 (6.56)	0.455	8.42	0.001
5	%BF-Slaughter II (boys)	17	22.37 (7.66)	31.94 (8.63)	0.655	9.10	0.000
6	%BF-Slaughter II (girls)	15	22.06 (8.90)	32.13 (6.56)	0.329	10.06	0.001
7	%BF-Bray (boys)	17	22.76 (7.44)	31.94 (8.63)	0.679	8.72	0.000
8	%BF-Bray (girls)	15	21.39 (6.77)	32.13 (6.56)	0.366	1.74	0.000
9	%BF-Cameron (boys)	17	31.54 (7.67)	31.94 (8.63)	0.700	-0.65	0.974
10	%BF-Cameron (girls)	15	32.25 (8.89)	32.13 (6.56)	0.764	-1.13	0.951

DISCUSSION

The present study proposed a novel and simple method for estimating %BF in a group of children aged 7-10 years using the DXA as a reference. Our data demonstrated that the %BF calculated by the two new anthropometric equations was highly associated with DXA (97.0 and 92.2), remarked by the high power of explanation (R^2: 94.0 and 85.0) and low errors (SEE: 2.818 and 3.200) (Table 2). The descriptive dataset values from BMC, FM, LM, and BMD assessed by DXA demonstrate valuable information for further studies (Table 1). Another aim of this study was to analyze the validity of previously developed equations. Thus, except for the Cameron equations, none of the previously published equations was valid in our validation sample (Figure 2A to 2H; Table 3). This indicates that specific predictive equations are not universal and must be used in the context of the population characteristics.

This study demonstrated that equations developed for boys included BMI, Height, Triceps, and Waist circumference as independent variables. The inclusion of waist circumference is not surprising in our predicted model because the association between waist circumference and %BF is a phenomenon well recognized. Indeed, it was reported a positive correlation between waist circumference and DXA-%BF in Danish children[19]. In Brazilian children, it was demonstrated that the waist circumference at the midpoint had the best correlation with %BF in boys and girls aged 6 to 9 years[20]. Of all independent predictors, only height had a negative regression coefficient (-0.345), which means the tallest children tend to have lower values of %BF while the smaller children tend to do the inverse. A similar finding was found by Ortiz-Hernández et al.[21], where the equations were developing for Mexican boys containing only height as a negative coefficient. BMI was also included in our regression model. Although BMI does not provide direct information on body composition, as the measured variables are weight and height, the strength of the linear relationship with %BF is well-described[22]. In this sense, studies developed by Costa-Urrutia et al. and Srdić et al.[23,24] demonstrated a stronger correlation between BMI and %BF and children aged 7. The triceps skinfold also was included in our final model, corroborating with previous studies[12,25]. More recently, two prediction equations for healthy children utilizing the triceps skinfold as an independent variable demonstrated a high correlation with %BF-DXA and lower bias[26]. Thus, the final predictive model included an interesting combination of the circumference and skinfold thickness. Investigations about these interactions have suggested good values for calculating the percentage of body fat[27].

This study also demonstrated that the simplest model developed for girls included only one skinfold thickness as an independent variable. In this sense, only thigh skinfold thickness was a better predictor of %BF-DXA than any other anthropometric variable provided in the present study. Other studies have reported a high correlation between the thickness of adipose tissue of the lower limb (e.g., thigh and calf thickness) with %BF in children and adolescents using different criteria methods (e.g., DXA, hydrostatic weighing, and 4C model)[12]. Another study investigated the relations between %BF assessed by DXA with upper body and lower limb skinfold in young healthy. As a result, the lower limb skinfold was more strongly related to %BF than upper body skinfolds[28]. A broad range of studies showed that the inclusion of lower limb sites from the thigh and calf isolated or combined with other sites from the upper body, for example, was significantly related to total body fat[29]. The British Olympic Association (BOA) recognized and recommended that the anterior thigh skinfold thickness should be included in the *Durin and Womersley* equation to increase the estimated capacity of total body fat[30]. Therefore, our equation can provide an advantage in time, accuracy, and clinical practice, as well as facilitate the assessment of % BF in studies with children.

This study suggests that the two newly developed equations, specific for boys and girls, can be appropriate for the assessment of %BF in children living in a region with the nutritional transition. These equations can play a crucial role in monitoring the changes imposed by the environmental impacts of nutritional transition over body composition and may help in predicting illnesses associated with nutrition-related non-communicable diseases.

CONCLUSIONS

The present study provided two new equations developed and validated in children living in a region witnessing a nutritional transition. Also, this study has descriptive body composition data from these children utilizing a reference model (DXA). All six equations except for the Cameron equations used in this study may not be suitable for assessing %BF in children living in Vitória de Santo Antão. Hence, our newly proposed equations provide a better reflection of %BF than any other previously proposed equation and provide a better predictor of excessively high or low levels of percentage body fat. In this context, a further cross-validation study on independent children's cohorts is essential to assess the predictability of developed equations in different samples.

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COMPLIANCE WITH ETHICAL STANDARDS

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Ethical approval

Ethical approval was obtained from the local Human Research Ethics Committee – Federal University of Pernambuco and the protocol (no.

91338718.0.0000.5208) was written following the standards set by the Declaration of Helsinki.

Conflict of interest statement

The authors have no conflict of interest to declare.

Author Contributions

Conceived and designed the experiments: RM, CG; Performed the experiments: RM, IG, GCJ, TL, IC; Analyzed the data: RM, IG, GCJ, TL, IC, MAM, L, CG; Contributed reagents/materials/analysis tools: MAM, L. Wrote the paper: RM, CG.

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SUPPLEMENTARY MATERIAL

Supplementary material accompanies this paper.

Supplementary File 1: Free access in https://osf.io/fgcdb/
Supplementary File 2: Free access in https://osf.io/fgcdb/

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