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Fat-free mass in adolescent athletes: Accuracy of bioimpedance equations and identification of new predictive equations

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ABSTRACT

Objectives: The aims of this study were to evaluate the effect of biological maturity on body composition in Brazilian adolescent athletes, to verify the accuracy of previous bioimpedance predictive equations for estimating fat-free mass (FFM), and to develop new predictive equations, considering sexual and skeletal maturity.
Methods: There were 318 Brazilian adolescent athletes (52% male) involved in this study. FFM was determined using single-frequency (50 kHz) bioelectrical impedance analysis (BIA) and dual-energy x-ray absorptiometry (DXA), which was used as the reference method. The adolescents were classified into skeletally mature using bone age (both sexes), and sexually mature using menarche occurrence (female). The effect of maturity on bioelectrical values was tested using bioelectrical impedance vector analysis. Three predictive BIA equations to estimate FFM were selected from the reviewed literature. Lin's concordance correlation coefficient and Bland–Altman test were used to test the concordance and accuracy of BIA equations. Stepwise multiple regression was used to develop new predictive equations, considering BIA vectors, age, skeletal, and sexual maturity.
Results: DXA and BIA results showed wide limits of disagreement for FFM for all the three equations. Two new equation models were developed, including age and skeletal maturity for both sexes and menarche status for females. Both models showed high R^2 (males = 0.92 and females = 0.84).
Conclusions: The assessment of body composition in adolescent athletes should consider sexual (female) or skeletal (male) maturity. The newly proposed equations showed promising results in Brazilian adolescent athletes. A test in different groups and populations is necessary to evaluate the general suitability of the equations in adolescents.

Introduction

The correct assessment of body composition in adolescent athletes is fundamental. It allows the prescription of adequate training and diet and reduces the risk for mistakes that could affect health and athletic performance [1]. Furthermore, the assessment makes it possible to monitor the effects of physical activity and sports practice and to evaluate physical performance. In fact, fat-free mass (FFM) is considered a predictor of muscular strength [2] and physical fitness [3], and it has been demonstrated that vigorous exercise is associated with muscular strength [4] and lean mass [5].

In adolescents, body composition is highly interrelated to biological maturity [1]. In fact, skeletal and sexual maturity are mediated by hormones and growth factors and influence the ontogenesis of FFM, particularly of its primary component, the muscle mass, in addition to bone content, fat mass (FM), and hydration status [6].

Maturity status is commonly assessed using skeletal maturity, secondary sexual development, or both [7]. Menarche occurrence is an accurate indicator of the timing of sexual maturity in female adolescents, whereas male puberty does not have a corresponding physiological event [6]. In both sexes, bone age is recognized as the best isolated indicator and is the most commonly used [6]. The classical method for bone age estimations is based on the recognition of changes in epiphysis space of the hand and wrist by

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comparison with reference atlas Greulich and Pyle method [8]. However, Heppe et al. [9] suggested dual-energy x-ray absorptiometry (DXA) images as a safer method to assess bone age because the exposure to radioactivity is lower.

Various methods are appropriate and can be used to assess the body composition of adolescents; they differ in precision and in the compartment of interest, each one having their own advantages and drawbacks. The most commonly used are based on anthropometric measurements, mainly on body mass index (BMI), a worldwide-recognized indicator of overweight and obesity [10]. However, BMI does not distinguish between FFM and FM, so an excess of FM may conceal FFM deficits or vice versa [11,12]. Indeed, anthropometric measurements and BMI tend to be less accurate than more high-tech methods, like DXA, magnetic resonance imaging, and computed tomography, which are highly expensive and not accessible in many epidemiologic studies, especially in developing countries.

Bioelectrical impedance analysis (BIA) has been used widely as an alternative option to assess body composition because it is safe, noninvasive, and less expensive than other methods [13]. The standard approach of BIA implies the use of predictive equations based on a defined body composition model and assumes that soft tissues hydration for all individuals is a normal condition [14]. Prediction errors can occur when equations are applied to populations with features different from those of the groups in which the predictor was developed. For this reason, several predictive equations have been developed for populations differing in sex, age, ethnicity, physical activity, or sports practice.

Alternative techniques, such as phase-angle analysis or bioelectrical impedance vector analysis (BIVA), have been proposed to overcome BIA limitations because they do not need the use of equations or assumptions on body composition. Piccoli et al. [15] proposed impedance (Z) to be plotted in a Cartesian plane as a bivariate vector originating from R and Xc standardized by height. In the classic BIVA approach, a shortening or lengthening of the vector over the confidence ellipses means a fluid overload or dehydration, respectively. This model also allows bypassing problems of disturbances in fluid distribution in individuals with abnormal hydration, as observed in adolescent athletes [16]. The bioelectrical vector has shown to be related to skeletal maturity in male adolescent athletes [17], sexual maturity in female adolescents [18], and intracellular nutritional status of magnesium [19] and zinc [20] in judo athletes and football players, respectively. However, the recent review on bioelectrical vector analysis in athletes [21] detected a poor efficacy of "classic BIVA" in assessing hydration status and body composition, whereas the "specific BIVA" approach [22,23] is promising.

To our knowledge, there are no BIA equations to determine body composition in adolescent athletes, considering biological maturity. Hence, the aims of this study were to analyze the effect of biological maturity in Brazilian adolescent athletes, to verify the accuracy of previous BIA predictive equations proposed for the assessment of FFM in adolescent nonathletes, and to develop BIA predictive equations for FFM estimation, considering sexual and skeletal maturity.

Material and methods

Participants

The participants consisted of 368 Brazilian athletes (167 boys and 151 girls) ages 11 to 16 y. All the data were collected at a sports-oriented public school located in the central region of the city of Rio de Janeiro, Brazil. It is an elementary, full-time school with classes from grades 6 to 9 that offers five standardized daily meals. Unlike other public schools, all students receive 120 min/d of sports training. Seven sports modalities (swimming, judo, badminton, athletics, soccer,

Table 1
BIA equations found for the prediction of FFM in different groups

Authors [reference number]	Validation methods	Age, y	Equations	n	R^2
Bedogni et al. [28]	DXA	8–12	(0.7 × H²/Z) + 4.8	52	0.95
Cordain et al. [29]	HW	9–14	(0.81 × H²/Z) + 6.86	30	0.69
Deurenberg et al. [24]	**DXA**	**7–25**	**(0.438 × H²/R) + (0.308 × W) + (1.6 × sex) + (0.07 × H) – 8.5 (sex: M = 1; F = 0)**	**246**	**0.99**
Deurenberg et al. [30]	DXA	≥16	(0.438 × H²/R) + (0.36 × W) + (0.56 × sex) + (0.056 × H) – 6.48 (sex: M = 1; F = 0)	166	0.93
Eston et al. [31]	AT	11–17	(0.52 × H²/Z) + (0.28 × W) + 3.25	54	0.93
Horlick et al. [25]	**DXA**	**4–18**	**[(0.459 × H²/R) + (0.064 × W) + 3.474]/ [(0.769 – (0.009 × age) – (0.016 × sex) – 12.44 (sex: M = 1; F = 0)**	**645**	**0.997**
Houtkooper et al. [32]	AT	10–14	(0.58 × H²/R) + (0.24 × W) + 2.69 (only males)	94	0.93
Kim et al. [33]	HW	9–14	(0.56 × H²/R) + (0.20 × W) +1.66	141	0.97
Lewy et al. [34]	DXA	10–11	(0.84 × H²/R) + 1.10	40	0.97
Morrison et al. [35]	AT	6–17	(0.78 × H²/R) + (0.1 × X) + (0.18 × W) – 8.78 (sex F)	65	0.99
Morrison et al. [35]	AT	6–17	(0.56 × H²/R) + (0.06 × X) + (0.34 × W) – 6.41 (sex M)	65	0.99
Nielsen et al. [36]	DXA	9–11	(0.54 × H²/R) + (0.05 × X) + (0.06 × H) + (0.09 × W) + (0.97 × sex) – 5.11 (sex: M = 1; F = 0)	101	0.95
Pietrobelli et al. [26]	**DXA**	**7–14**	**(0.694 × H²/Z) – (0.234 × W) + 1.166 (sex: M = 0; F = 1)**	**172**	**0.96**
Rush et al. [37]	DD	5–14	(0.622 × H²/Z) + (0.234 × W) + 1.166	172	0.96
Schaefer et al. [38]	DD	3.9–19.3	(0.65 × H²/R) + (0.68 × age) + 0.15	112	0.975
Sun et al. [39]	DXA	12–94	(0.65 × H²/R) + (0.26 × W) + (0.02 × R) – 10.68 (sex M)	208	0.90
Sun et al. [39]	DXA	12–94	(0.69 × H²/R) + (0.17 × W) + (0.02 × R) – 9.53 (sex F)	317	0.83
Suprasongsin etal [40]	DD	10–22	(0.524 × H²/R) + (0.415 × W) – 0.32	42	0.96
Tyrrel et al. [41]	DXA	5–10	(0.31 × H²/Z) + (0.17 × H) + (0.11 x × W) + (0.942 × sex) – 14.96 (sex: M = 2; F = 1)	82	0.97

AT, anthropometry; BIA, bioelectrical impedance analysis; DD, total body water by deuterium dilution; DXA, dual-energy x-ray absorptiometry; FFM, fat-free mass; H, height; HW, hydrostatic weighing; R, resistance; W, weight; Z, impedance.
The equations in bold are in accordance with the inclusion criteria of the present study.

Table 2
General characteristics of male adolescent athletes according to skeletally mature

	Skeletally mature (n = 22)	Skeletally immature (n = 145)	*P*-value
Age, y	14.09 ± 0.92	12.62 ± 1.11	0.001
Weight, kg	68.3 ± 16.3	51.5 ± 12.9	0.001
Height, m	1.72 ± 0.07	1.58 ± 0.10	0.001
BMI, kg/m^2	22.7 ± 5.2	19.9 ± 3.5	0.021
Resistance, Ω	516.3 ± 47	586.5 ± 83.8	0.001
Resistance/H, Ω /m	301.3 ± 32.7	373.6 ± 70	0.001
Reactance, Ω	61.7 ± 7.5	63.7 ± 9.6	0.336
Reactance/H, Ω /m	36.1 ± 5.3	40.5 ± 7.6	0.008
Phase angle, °	6.8 ± 0.6	6.3 ± 0.8	0.002
FM_{-DXA}, kg	15.59 ± 10.53	12.68 ± 6.48	0.070
FFM_{-DXA}, kg	49.81 ± 7.22	36.57 ± 9.05	0.001

BMI, body mass index; DXA, dual-energy x-ray absorptiometry; FFM, fat free mass; FM, fat mass; H, height

volleyball, and table tennis) are offered to all students, along with 50 min/wk of physical education. Adolescents with greater preference and ability for sports participate in state and national competitions. To be included in this study, the adolescents had to have ≥6 mo of sport training in the school and ≤3 y of school practice and agreed to participate after a full explanation of the research objectives.

Experimental procedures

This was a dynamic cohort composed of adolescent athletes, in which individual collections of anthropometry, BIA, and DXA data were done on the same day. All the adolescent athletes were classified as skeletally mature or immature according to bone age. Female adolescents also were classified as sexually mature or immature according to menarche occurrence. Then they were analyzed by BIVA to verify the effect of maturity on bioelectrical values. To test whether age exerts influence on the results, body composition characteristics in adolescents of similar age but different biological maturity were compared.

Three BIA equations [24–26] were selected from literature and their results were compared using DXA as a reference method [9]. The FFM values obtained using DXA were applied as a criterion to elaborate new prediction equations through BIA, considering biological maturity.

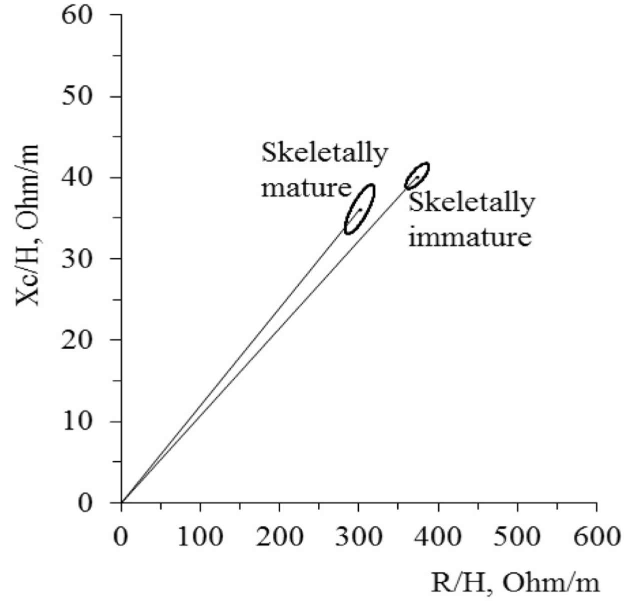
This study was approved by the Ethics Committee of the Pedro Ernesto University Hospital and the Public Secretariat of Education. All guardians and participants agreed to participate after a full explanation of the objectives and signed informed consent forms.

Anthropometric measurements and body composition

Body mass and height were measured using a digital scale and stadiometer (Filizola, Rio de Janeiro, Brazil). BMI was calculated by dividing the weight (kg) by the square of the height (m^2). Body composition was measured using DXA and BIA.

DXA

Body composition, including FM and FFM, was measured using DXA (Lunar iDXA with software enCore 2008 version 12.20, GE Healthcare, Madison, WI, USA), in automatic total body scan mode. For the examination, participants were told to wear light clothing without metal accessories. Participants were placed in dorsal recumbent position and asked to remain motionless until the end of the procedure.



T^2	*F*	*P*	D
25.9	12.9	0.001	1.16

Fig. 1. Mean impedance vectors with 95% confidence ellipses of the male adolescent athletes according to skeletal status. D, Mahalanobis distance; *F*, variance analysis; H, height; *P*, significance level; R, resistance; T^2, Hotelling's *T* test; Xc, reactance.

FM and FFM were expressed in kg. The regions of interest for regional body composition were defined using the software provided by the manufacturer and following its standard quality control procedures. The same operator performed all the scans. Measurements on the calibration block (daily) and on the calibration spine phantom (weekly), supplied by the manufacturer, had coefficients of variation <0.7%.

BIA

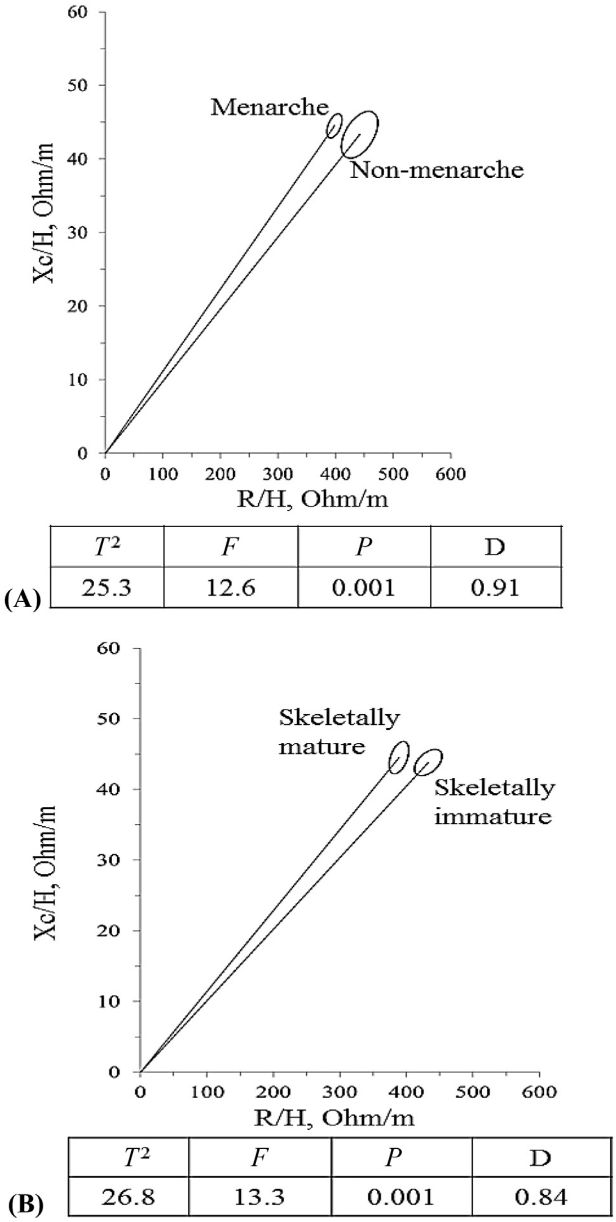
BIA measurements were taken using a BIA 450 Bioimpedance Analyser (Biodynamics), which applies an alternating current of 800 μA at a single frequency of 50 kHz. To measure the whole-body bioelectrical impedance, electrodes were applied on the right wrist and ankle, with the participants in a supine position, in a thermo-neutral environment of 25°C. To avoid disturbances in fluid distribution, participants were instructed to abstain from foods and liquids for ≥4 h, not to drink alcohol for 48 h, and to refrain from caffeine intake and intense physical activity 24 h before the BIA analysis. Female adolescents were instructed not to perform the exam during their menstrual period. Before each testing session, the analyzer was checked with a calibration circuit of known impedance (resistance = 500 ohms; reactance = 0.1 ohms, 0.9% error). Resistance (R) and reactance (Xc) were used to calculate phase-angle values by the following equation [27]:

$$\text{Phase angle } (^\circ) = \text{arctangent } (Xc/R) \times (180^\circ/\pi)$$

Table 3
General characteristics of female adolescent athletes according to sexual and skeletal maturity

	Sexually mature (n = 109)	Sexually immature (n = 42)	*P*-value*	Skeletally mature (n = 78)	Skeletally immature (n = 73)	*P*-value*
Age, y	13.00 ± 1.06	11.85 ± 0.84	0.001	13.29 ± 0.98	12.04 ± 0.90	0.001
Weight, kg	54.5 ± 9.9	45 ± 11.3	0.001	56.45 ± 10.0	46.9 ± 10.1	0.001
Height, m	1.59 ± 0.67	1.52 ± 0.73	0.001	1.60 ± 0.07	1.55 ± 0.07	0.001
BMI, kg/m^2	20.9 ± 3.5	18.9 ± 4.1	0.040	21.67 ± 3.71	19.04 ± 3.35	0.001
Resistance, Ω	634.9 ± 87.6	669.6 ± 97.9	0.001	621.5 ± 81	669.2 ± 96.3	0.001
Resistance/H, Ω/m	397.9 ± 55.4	441.7 ± 80.6	0.002	388.8 ± 50.5	432.8 ± 32	0.001
Reactance, Ω	70.9 ± 10.5	65.9 ± 10.9	0.037	69.9 ± 10.2	69 ± 11.6	0.602
Reactance/H, Ω/m	44.5 ± 6.9	43.3 ± 8.1	0.396	43.8 ± 6.6	44.5 ± 7.9	0.543
Phase angle, °	6.4 ± 0.96	5.6 ± 0.95	0.001	6.5 ± 0.9	5.9 ± 1.0	0.002
FM_{-DXA}, kg	16.6 ± 5.9	13.0 ± 6.8	0.021	17.78 ± 6.38	13.36 ± 5.58	0.001
FFM_{-DXA}, kg	35.1 ± 4.8	29.9 ± 5.9	0.001	35.88 ± 4.62	31.31 ± 5.78	0.001

BMI, body mass index; H, height; FM, fat mass; FFM, fat free mass
**P*-value obtained using independent *t* test



(A)

T^2	F	P	D
25.3	12.6	0.001	0.91

(B)

T^2	F	P	D
26.8	13.3	0.001	0.84

Fig. 2. Mean impedance vectors with 95% confidence ellipses of the female adolescent athletes according to (A) menarche status and (B) skeletal status. D, Mahalanobis distance; *F*, variance analysis; H, height; *P*, significance level; R, resistance; T^2, Hotelling's *T* test; Xc, reactance.

Table 5
Comparison among fat free mass estimates obtained using DXA and different BIA equations

	Male adolescent BIA equations fat free mass (kg)		
DXA (kg)	Deurenberg et al. [24]	Horlick et al. [25]	Pietrobelli et al. [26]
38.8 ± 9.9	39.8 ± 9.4	36.4 ± 7.9	36.1 ± 7.9
P-value*	0.001	0.001	0.001
Female adolescent BIA equations fat free mass (kg)			
34.2 ± 5.6	36.3 ± 6.1	32.3 ± 4.8	31.5 ± 4.7
P-value*	0.001	0.001	0.001

BIA, bioelectrical impedance analysis; DXA, dual-energy x-ray absorptiometry
**P*-values were obtained using paired *t* test.

To identify published BIA equations for calculating FFM, the following inclusion criteria were applied:

1. equations validated using DXA as reference;
2. healthy adolescents with age consistent with the World Health Organization's definition (10–19 y of age);
3. bioelectrical values at a single frequency (50 kHz); and
4. sex as a predictor variable or being sorted out by sex.

Among the 19 BIA equations found (Table 1), only 3 were selected for corresponding to selection criteria: Deurenberg et al. [24], Horlick et al. [25], and Pietrobelli et al. [26].

Bioelectrical impedance vector analysis

BIVA was developed by Piccoli et al. [15]. The technique uses the plot of bioelectrical values R and Xc, normalized per height (H) as a bivariate vector in the RXc graph. The impedance vector distribution can be described by the comparison with reference values (tolerance ellipses) or analyzed in different groups by its associated 95% confidence interval (confidence ellipses). The mean vectors from independent groups of participants could be compared using Hotelling's T^2 test value, with the corresponding *F* test and *P*-values, and the Mahalanobis generalized distance D = distance, and must be represented in parenthesis (D).

In the present study, BIVA results were not compared with a reference population because there are no published data for adolescent athletes.

Skeletal maturity

Skeletal maturity was determined according to Greulich and Pyle [8] from hand and wrist images generated by DXA [9]. All measurements were performed by one experienced and one trained evaluator, with satisfactory reliability (intraclass correlation coefficient, 0.98–0.84). Classification was defined as skeletally mature for those with closed epiphyses and skeletally immature for those with spaces between epiphyses [42].

Age at menarche

Age at menarche was established based on an individual's recall and participants were sorted into menarche or nonmenarche groups, accordingly.

Table 4
Pattern of bioelectrical and body composition in adolescents of similar age, but different skeletal maturity

	Male adolescents (≥13.50–14.96 y)			Female adolescents (≥13.10–14.50 y)		
	Skeletally mature (n = 12)	Skeletally immature (n = 48)	*P*-value	Skeletally mature (n = 44)	Skeletally mature (n = 11)	*P*-value
Age, y	14.2 ± 0.5	14 ± 0.6	0.117	13.7 ± 0.4	13.5 ± 0.3	0.117
Weight, kg	66.4 ± 14.5	56.5 ± 13.1	0.023	56.9 ± 10.6	44.4 ± 94	0.001
Height, m	1.7 ± 0.04	1.6 ± 0.08	0.052	1.6 ± 0.06	1.6 ± 0.06	0.106
BMI, kg/m^2	23.1 ± 5.3	20.6 ± 3.9	0.064	22.3 ± 3.9	18.0 ± 2.9	0.001
R, Ω	523.6 ± 46.5	562.8 ± 85.3	0.036	622.3 ± 46.5	724.7 ± 91.2	0.001
R/H	301.3 ± 32.7	373.6 ± 70.5	0.008	388.8 ± 50.5	432.9 ± 73.2	0.543
Xc, Ω	62.4 ± 7.4	63.3 ± 8.8	0.827	69.9 ± 10	74.9 ± 15.3	0.184
Xc/H	36.1 ± 5.3	40.6 ± 7.6	0.001	43.8 ± 6.6	44.5 ± 7.9	0.001
Phase angle, °	6.8 ± 0.9	6.4 ± 0.6	0.199	6.4 ± 0.9	5.9 ± 0.7	0.054
FM_{-DXA}, kg	14.9 ± 6.6	12.8 ± 8.6	0.351	18.4 ± 6.6	12.2 ± 4.9	0.005
FFM_{-DXA}, kg	49.2 ± 7.9	46.6 ± 6.5	0.003	36.2 ± 4.7	30.5 ± 5.4	0.001

BMI, body mass index; FFM, fat free mass; FM, fat mass; H, height; R, resistance; Xc, reactance

Statistical analyses

Statistical analyses were performed using SPSS version 19 software package (IBM, Armonk, NY, USA). Continuous variables were expressed as means ± standard deviation (SD). Independent *t* test was used to determine whether there were statistically significant differences between groups according to skeletal maturity and menarche occurrence. The paired *t* test was used to determine the difference between FFM values obtained using BIA equations and DXA. Lin's concordance correlation coefficient [43], with strength of agreement described by McBridge [44] (almost perfect >0.99; substantial >0.95 to 0.99; moderate 0.90 to 0.95; and poor <0.90) and Bland–Altman test [45] were used to determine the agreement between BIA equations and DXA measurements.

The mean impedance vectors in the different groups of adolescent athletes ("skeletally mature," "skeletally immature," "menarche," and "non-menarche") were compared by mean of confidence ellipses and using Hotelling's T^2 test. The distances between ellipses were calculated using the Mahalanobis test that provides a relative measurement of data point distances (residual) between vectors. Statistical tests were considered significant at the significance level of 5% ($P \leq 0.05$). The analyses were performed using BIVA software.

The DXA-derived FFM was used as the criterion for the development of prediction equations through stepwise multiple regression. Age, sex differences, skeletal maturity (yes = 1, or no = 0), and menarche occurrence (in females only: yes = 1, no = 0) were considered independent variables. To overcome the effect of conductor length and to increase the possibility of comparison among individuals of different heights, the BIA variables have been normalized by height and height squared, as proposed by Segal et al. [46] and Lukaski et al. [47].

Results

The majority of female adolescents (n = 109, 72%) were considered sexually mature. Seventy-four (68%) were considered sexually and skeletally mature, and 35 (32%) only sexually mature. In relation to male adolescents, 22 (13%) were classified as skeletally mature.

Skeletally mature adolescents of both sexes, as well as sexually mature females, showed higher values for age, anthropometric characteristics, FM, and FFM compared with immature adolescents (Tables 2 and 3). The trend of body composition differences brought about by maturity is consistent with the observed variation of bioelectrical values. In fact, phase angle was higher in skeletally or sexually mature adolescents, indicating greater values of FFM, whereas resistance (and R/H) was lower. Reactance (and Xc/H) showed a less consistent pattern of variation. The bioelectrical differences between mature and immature adolescents were clearly shown by the comparisons of confidence ellipses, which were always highly significant (Figs. 1 and 2). A very similar pattern of bioelectrical and body composition differences was observed in adolescents of similar age, but different skeletal maturity (Table 4).

In both sexes, the FFM values determined using regression equations selected from literature showed significant differences when compared with DXA results. With respect to DXA (Table 5), the equation proposed by Deuremberg et al. [24] overestimated FFM, whereas those proposed by Horlick et al. [25] and Pietrobelli [26] underestimated it.

The wide limits of disagreement between DXA output and all BIA equations also were detected in the Bland–Altman analysis (Figs. 3 and 4). Lin's concordance correlation coefficient (ρ_c) showed that Horlick et al. [25] equations (male $\rho_c = 0.91$ and female $\rho_c = 0.87$) performed better than Deuremberg et al. [24] (male $\rho_c = 0.12$ and female $\rho_c = 0.08$) and Pietrobelli et al. [26] equations (male $\rho_c = 0.09$ and female $\rho_c = 0.08$). These latter were classified as poor when compared with DXA results.

The stepwise regression procedure enabled the development of two different models for FFM prediction for each sex. Both models included bioelectrical values, age and skeletal maturity for male and female, and menarche status only for female adolescents. However, for female adolescent equations, menarche status was more important than skeletal maturity. Regarding bioelectrical values, the first model included R/H and Xc/H ($R^2 = 0.857$ and 0.768, males and females, respectively), without referring to reactance for male adolescents, whereas the second one included H^2/R (that

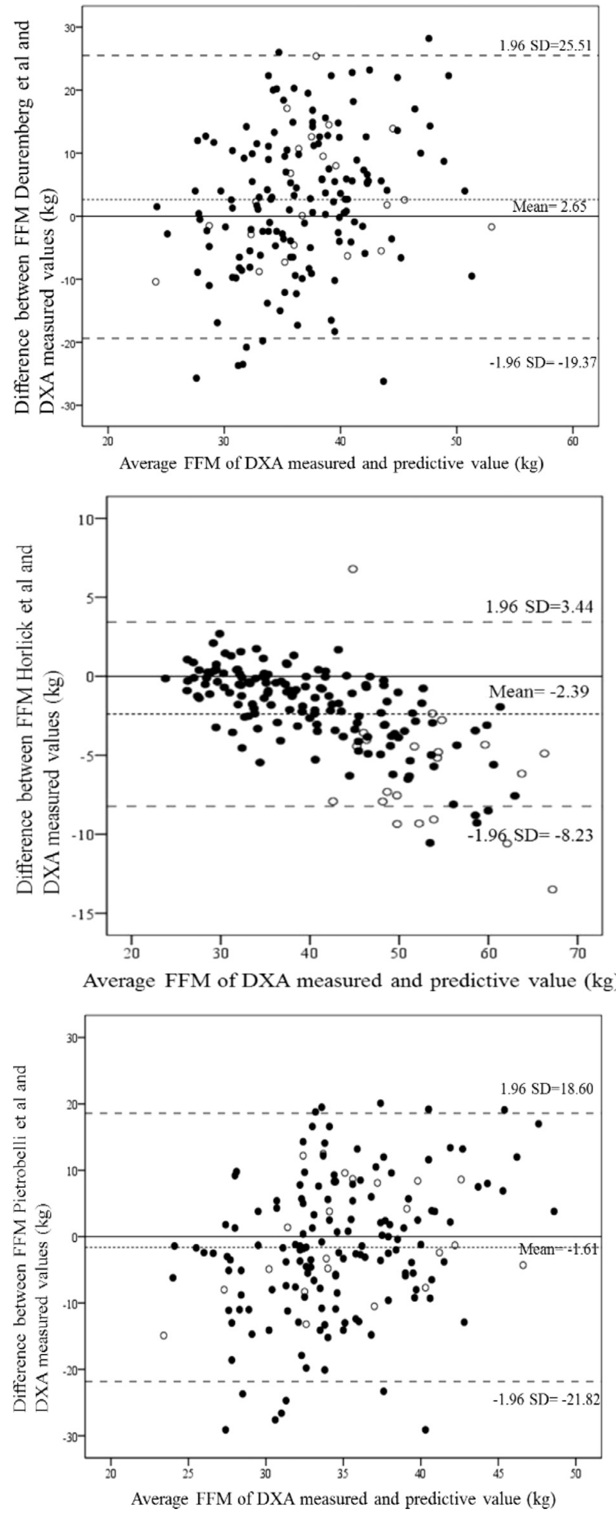


Fig. 3. Bland–Altman analysis between the FFM obtained using BIA equations [24–26] and DXA measured for male adolescent athletes considering skeletal maturation. BIA, bioelectrical impedance analysis; DXA, dual-energy x-ray absorptiometry; FFM, fat-free mass; • skeletally immature; O skeletally mature.

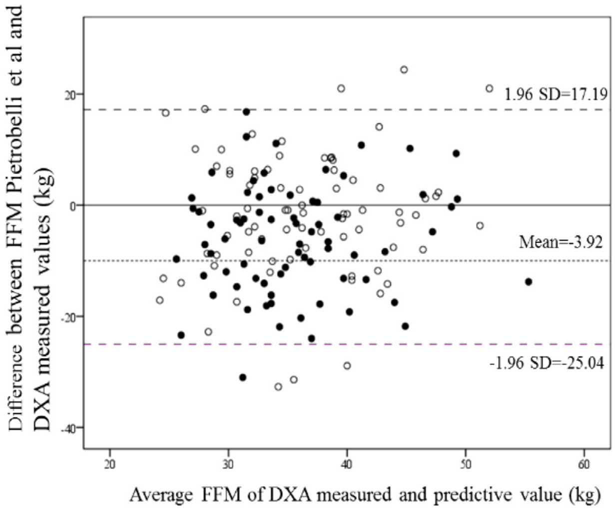


Fig. 4. Bland–Altman analysis between the FFM obtained using BIA equations [24–26] and DXA measured for female adolescent athletes considering skeletal maturation. BIA, bioelectrical impedance analysis; DXA, dual-energy x-ray absorptiometry; FFM, fat-free mass; · skeletally immature; O skeletally mature.

showed higher R^2 values, 0.923 and 0.841, males and females, respectively; Table 6).

Discussion

The effect of age on bioimpedance values is a well-known phenomenon in the general population [34–36] and in male adult and adolescent athletes [17]. This study showed that biological maturity is also important. In fact, skeletal (for adolescents of both sexes) and sexual (observed only in females) maturity were associated with body mass and body composition variations assessed by DXA, such as higher body mass and muscle mass in particular. This pattern was clearly depicted by BIVA, particularly by the higher phase angle of mature adolescents, as shown in adolescent male soccer players [20]. Furthermore, the shortening of the impedance vector with skeletal maturity indicated a trend probably related to higher total body water values. These results were confirmed when, despite the same age, different skeletal and sexual maturity continued to influence body composition.

Indeed, it is well known that adolescents at the same age vary in biological maturity status [7]. Mature male adolescents showed higher functional capacity, more strength, power, and speed than immature male adolescents of similar age [7]. Conversely, mature female adolescents presented more FM than immature ones [37].

Similar results on the major effect of puberty on bioelectrical values have been detected in previous studies on Brazilian young people [19], Brazilian adolescent soccer players [20], and non-athlete Italian females [18].

However, despite the recognized importance of skeletal or sexual maturity, regression equations existing in the literature for the assessment of body composition in adolescents never include these variables. In general, BIA equations adjust bioelectrical values for height (H^2/R) to predict FFM [32,33]. Some equations also incorporate variables such as age [25,38], weight [24–26,39–47], and sex [24–26,39,45,47,48]. In particular, Deuremberg et al. [24] and Mathias-Genovez et al. [19] observed that the relationship between FFM and body impedance is affected by sex differences after 13 y of age. Otherwise, Montagnese et al. [49] suggested that the main factor preventing deviation in results using a single BIA for the youth population (4–24 y of age) is age or maturation, whereas the effects of sex and nutritional status are relatively modest.

As demonstrated in the present study, equations selected from literature [24–26] showed poor efficacy in assessing body composition in adolescent Brazilian athletes. In fact, in all cases, a large bias with DXA output was detected by the Bland–Altman method. Furthermore, two of the three equations [24,26] had low efficacy, as stated by Lin's concordance correlation coefficient [29], possibly owing to the large age range considered, including children and adults. Probably, Horlick's equation [25] presented a better performance/precision than the others [24,26] owing to the inclusion of age as a predictor variable.

The newly proposed equations (including age and skeletal maturity in males and menarche status in females, besides bioelectrical values) demonstrated good performance and are promising for Brazilian adolescent athletes. The one proposed for females is particularly interesting because it simply requires adding the information on menarche. In males, there is the need to determine bone maturation, which may make it more difficult to use the equation. However, currently, the use of bone age for proper training prescription is frequent and necessary [7].

This study had some strong points. In fact, to our knowledge, this is the first study to identify BIA equations for adolescents considering skeletal and sexual maturity. Furthermore, the present study included DXA analysis, which is considered an accurate method for these measurements, to determine body composition and skeletal maturity, and BIVA, which allows detecting differences in hydration or body cell mass. However, a limitation was the lack of experimentation of equations in different populations of adolescents, athletes or not, and in groups from other geographic regions, to verify their wider applicability.

Table 6
Predictive equations of FFM suggested for adolescent athletes, according to sex and bioelectrical values*

	Male adolescents Equations	R^2 adjusted	SEE
R/H and Xc/H	$\hat{y} = 54.092 + 1.643 \times (\text{age}) + 3.347 \times (\text{skeletal maturity})\ 0.103 \times (R/H)$	0.857	3.726
CV,%	9		
H^2(m)/R	$\hat{y} = -6.340 + 0.795 \times (\text{age}) + 2.071 \times (\text{skeletal maturity}) + 0.744 \times (H^2/R)$	0.923	2.744
CV,%	6		
	Female adolescents† Equations	R^2 adjusted	SEE
R/H and Xc/H	$\hat{y} = 50.805 + 0.910 \times (\text{age}) + 1.783 \times (\text{menarche occurrence}) - 0.06 \times (R/H) - 0.121\ (Xc/H)$	0.768	2.724
CV,%	8		
H^2(m)/R	$\hat{y} = -2.615 + 0.603 \times (\text{age}) + 0.954 \times (\text{menarche occurrence}) + 0.713\ (H^2/R)$	0.841	2.256
CV, %	7		

BIA, bioelectrical impedance analysis; CV, coefficient of variation; SEE/mean; H, height; R, resistance; Xc, reactance; SEE= standard error of estimate.
*In addition to the BIA vectors, all models considered skeletal maturity (0, immature, 1, mature) and age (y) for both sexes.
†For female adolescents the menarche occurrence (0, no occurrence, 1, occurrence) was added.

Conclusions

The present study highlighted the effect of biological maturity on bioelectrical values. It also showed that equations selected from the literature are not adequate for analyzing body composition in Brazilian adolescent athletes. The newly proposed equations, considering age and skeletal maturity for boys and girls and menarche status for girls, besides bioelectrical values, demonstrated promising results in young Brazilians. A test in different populations is necessary to evaluate the general suitability of the new equations in adolescent athletes.

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