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ORIGINAL RESEARCH

Agreement Between Standard Body Composition Methods to Estimate Percentage of Body Fat in Young Male Athletes

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Purpose: To examine the intermethods agreement of dual-energy X-ray absorptiometry (DXA) and foot-to-foot bioelectrical impedance analysis (BIA) to assess the percentage of body fat (%BF) in young male athletes using air-displacement plethysmography (ADP) as the reference method. ***Methods:*** Standard measurement protocols were carried out in 104 athletes (40 swimmers, 37 footballers, and 27 cyclists, aged 12–14 y). ***Results:*** Age-adjusted %BF ADP and %BF BIA were significantly higher in swimmers than footballers. ADP correlates better with DXA than with BIA ($r = .84$ vs $r = .60$, $P < .001$). %BF was lower when measured by DXA and BIA than ADP ($P < .001$), and the bias was higher when comparing ADP versus BIA than ADP versus DXA. The intraclass correlation coefficients between DXA and ADP showed a good to excellent agreement ($r = .67$–$.79$), though it was poor when BIA was compared with ADP ($r = .26$–$.49$). The ranges of agreement were wider when comparing BIA with ADP than DXA with ADP. ***Conclusion:*** DXA and BIA

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seem to underestimate %BF in young male athletes compared with ADP. Furthermore, the bias significantly increases with %BF in the BIA measurements. At the individual level, BIA and DXA do not seem to predict %BF precisely compared with ADP in young athletic populations.

Keywords: validation studies, adolescents, sport, fat mass

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Adolescence is characterized by rapid changes in body composition, which is attributed to the influence of a number of modifiable lifestyle factors including physical activity, diet, and sports participation (30). The assessment of body composition in young athletes, and more specifically the assessment of percentage of body fat (%BF), allows identifying body composition imbalances that can affect athletes' performance and overall health and well-being during growth (1). Adolescents may develop compulsive weight loss behaviors to reach a perceived "ideal" body weight for competition (7). Consequently, %BF is routinely measured among athletes, and therefore, valid and accessible tools are needed for an accurate measure.

To date, there is no universally applicable criterion or "gold standard" methodology for body composition assessment. Multicomponent models (38) or hydrodensitometry (11,13) has been used as potential reference methods to measure body composition in vivo. Hydrodensitometry estimates body volume and density (body mass/body volume) by hydrostatic weighing, but it is a difficult procedure for many youths (11,13). %BF is estimated using standard equations assuming specific density in fat mass (33). Air-displacement plethysmography (ADP) is an alternative method that has been extensively used worldwide to calculate body volume by measuring the volume of air displaced by the participant inside the chamber (22). Nunez et al (27) found a high correlation between body density by ADP and hydrodensitometry in children and adults, but ADP had a better precision than hydrodensitometry in children (11,27). This may be explained by the errors associated when using hydrodensitometry, for example, measuring lung volume at the exact moment of recording body weight at full submersion. By contrast, ADP is perceived as a simple technique with much lower risk for technical error (11). In this regard, the precision for fat mass measures in children was 0.38 kg by ADP and 0.68 kg by hydrodensitometry (11).

In a comprehensive review, ADP was considered a reliable and valid method for measuring body composition (including fat mass) in youth in comparison with the multicomponent models (15). Moreover, this method offers several advantages, including a quick and easy measurement process (15). Fields et al (16) asserted ADP is the only technique that can estimate fat mass accurately and with minimal bias in 9- to 14-year-old children.

Other methods such as bioelectrical impedance analysis (BIA) or dual-energy X-ray absorptiometry (DXA) are commonly used as field and laboratory methods to assess body composition, respectively. The feasibility of the foot-to-foot BIA is greater than that of DXA mainly because of the low cost, absence of radiation, and the ability to obtain data rapidly in the laboratory and field settings (10). BIA estimates properties of fat-free mass (FFM) from the total body water prediction and, by difference with body weight, the body fat (38). DXA has better accuracy for bone outcomes than for soft tissue values, and it also estimates the total body fat indirectly (dividing by body mass); however, its bias varies with age and fatness (38).

Several studies have been conducted to compare different assessment methods of %BF in young athletes involved in different sports (3,4,8,12,18,24,25,35,36). In adolescent cyclists, DXA overestimates %BF compared with ADP (18), whereas in footballers, it is the opposite (8). By contrast, in collegiate female athletes, no differences between methods are found for %BF between DXA and ADP (3). ADP was found to overestimate %BF versus the 5-compartment model in collegiate female athletes (24). Most of these previous studies assess the agreement between ADP and hydrostatic weighing (as the reference method) to estimate %BF from body density (4,8,12,25,35,36), with conflicting results. Some studies reported no significant differences between methods in wrestling athletes (12,35), but other studies showed ADP to underestimate %BF in footballers (8) or overestimate it in a groups of athletes of different sports (25).

The purpose of this study was to examine the intermethods agreement of DXA and BIA with ADP to assess the %BF in young male athletes, such as swimmers, footballers, and cyclists. A number of authors report that hydrodensitometry is poorly tolerated by young people, and ADP, as discussed previously, is an alternative and more accurate method to calculate body density in children (11,27). It does not require water submersion or as in the case of DXA, exposure to ionizing radiation. Therefore, ADP has been selected as "reference method" in the present study. This is a practical approach for research centers where multicomponent models are not available.

Methods

Study Design and Participants

The current report is based on data derived from the ongoing PRO-BONE study (37). A total of 104 young male athletes were recruited from athletic clubs and schools of southwest England, UK. For the purpose to the current study, baseline values (measured between autumn and winter 2014/2015) from 40 swimmers, 37 footballers, and 27 cyclists were analyzed. The inclusion criteria to take part in this study were: 1) males aged 12–14 years old, engaged (≥3 h/wk) in osteogenic (football) and/or

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nonosteogenic (swimming and cycling) sports in the last 3 years or more; 2) participants not taking part in another clinical trial; 3) participants not having any acute infection lasting until <1 week before inclusion; 4) participants had to be free of any medical history of diseases or medications affecting bone metabolism or the presence of an injury; and 5) participants had to be white race.

All participants underwent 3 methods of body composition to measure %BF, and all measurements were performed the same morning. They were asked to attend the tests after a 10- to 12-hour overnight fast but were allowed to consume water. Despite the fact that water intake was not monitored or controlled in this study, participants were instructed to void immediately before the procedures started.

The methods and procedures of the PRO-BONE study have been checked and approved by: 1) the Ethics Review Sector of Directorate-General of Research (European Commission, reference number: 618496), 2) the Sport and Health Sciences Ethics Committee (University of Exeter, reference Number: 2014/766), and 3) the National Research Ethics Service Committee (NRES Committee South West—Cornwall and Plymouth, reference number: 14/SW/0060). Written informed consent and assent forms were obtained from parents and adolescents, respectively.

Anthropometry. Stature (cm) and body mass (kg) were measured by using a stadiometer (Harpenden; Holtain Ltd, Crymych, UK; precision: 0.1 cm) and an electronic scale (Seca 877; Seca Ltd, Birmingham, UK; precision: 100 g), respectively. The mean of 2 measurements of weight and height was used to calculate body mass index as body mass in kilograms divided by the square of the height in meters (kg/m^2). Sexual maturation was self-reported by the participants using adapted drawings of the 5 stages (Tanner stages) of pubertal hair development (34).

Dual-Energy X-Ray Absorptiometry. A DXA scanner (GE Lunar Prodigy Healthcare Corp, Madison, WI) was used to measure %BF. All DXA scans and subsequent in-software analyses were completed by the same researcher, using the same DXA scanner and the GE encore software (2006, version 14.10.022). DXA equipment accuracy was checked daily before each scanning session using the GE Lunar calibration phantom (GE Medical Systems Lunar, Madison, WI) as recommended by the manufacturer. Participants were scanned in the supine position in the middle of the platform with hands facedown near their sides. Subjects were instructed to remain still and breathe normally for the duration of the scan. This technique uses a minimal radiation dose and has been widely used for research purposes with child participants worldwide. The estimated lifetime risks of using GE Lunar Prodigy DXA measurements in the pediatric population were found to be negligible (9).

Bioelectrical Impedance Analysis. The portable foot-to-foot BIA device (BF-350; Tanita, Tokyo, Japan; range: 2–200 kg; precision: 100 g; %BF range: 1%–75%; %BF increments: 0.1%) was used to estimate the %BF, after a single measure, using the values of resistance and reactance. Participants were measured in a fasting state. Any metal objects and socks were removed prior to the measurement. They were positioned on the posterior surface barefoot according to manufacturer's instructions.

Air-Displacement Plethysmography. Body volume was measured by using ADP (BOD POD, Body Composition System; Life Measurement Instruments, Concord, CA) and the device's default software (software version 4.2+, COSMED USA, Inc, Concord, CA). Prior to each daily testing session, the equipment was calibrated following the manufacturer's guidelines using a cylinder of specific volume (49.887 L). Participants were tested wearing swimming suits and swimming caps to rule out air trapped in clothes and hair and with all jewelries removed. Each participant was weighed on the BOD POD calibrated digital scale and then entered into the BOD POD chamber. During the measurements, participants were instructed to sit still with hands on thighs and to breathe normally. Body volume was measured twice by ADP, and if there was a difference of more than 150 mL, a third measurement was taken. Thoracic gas volume was measured at the time of the BOD POD test, and this value was integrated into the calculation of body volume following the manufacturer's recommendations (22). A mean value between the 2 or 3 measurements of body volume was obtained. %BF was calculated from the body density obtained by the BOD POD using the equation reported by Siri (33) as performed in previous studies in children (15,19,23,26). Several formulas other than Siri equation also estimate %BF from body density (6). The basic difference among them generally averages less than 1% in body fat units for body fat levels between 4% and 30% (21).

Statistical Analysis

Both statistical (Kolmogorov–Smirnov test) and graphical methods (normal probability plots) were used to confirm a normal distribution for each variable. Descriptive characteristics of the participants were represented as mean (*SD*) unless otherwise stated.

One-way analysis of variance with Bonferroni correction was used to test mean differences in continuous variables, such as age, stature, body mass, and body mass index by sport groups (Table 1). Chi-square statistics was used to test associations between categorical variables (ie, Tanner stages in sport groups). Analysis of covariance was used to estimate mean-adjusted differences in %BF (dependent variable) by group of athletes (fixed factor) using age as covariate (Table 1). Bonferroni post hoc test was used to calculate pairwise comparisons.

Table 2 shows comparison and agreement between methods. To test for significant differences in %BF between ADP and DXA or between ADP and BIA methods, a paired samples *t* test was used. Spearman's correlation coefficients were calculated to assess the

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Table 1 Descriptive Characteristics of the Participants

	Swimmers (1) (*n* = 40)	Footballers (2) (*n* = 37)	Cyclists (3) (*n* = 27)	*P*	Between-group comparisons[a] 1–2	1–3	2–3	All athletes (*N* = 104) mean (*SD*)
Age, y	13.5 (1.0)	12.9 (0.9)	13.3 (1.0)	.012	<	ns	ns	13.2 (1.0)
Stature, cm	165.7 (9.7)	155.2 (9.3)	160.9 (9.4)	<.001	<	ns	ns	160.7 (10.4)
Body mass, kg	52.5 (9.0)	44.2 (7.5)	48.2 (10.5)	.001	<	ns	ns	48.4 (9.6)
BMI, kg/m^2	19.0 (1.7)	18.3 (1.4)	18.5 (2.7)	.213	–	–	–	18.6 (1.9)
Tanner stages, %				.127[b]	–	–	–	
I	15	24	15					19
II	23	35	26					29
III	13	24	26					21
IV–V	48	16	33					34
Body fat by ADP,[c] %	20.6 (0.9)	17.4 (0.9)	18.3 (1.1)	.045	<	ns	ns	18.9 (6.1)
Body fat by DXA,[c] %	16.8 (0.9)	14.3 (1.0)	15.7 (1.1)	.180	–	–	–	15.6 (6.1)
Body fat by BIA,[c] %	14.8 (0.6)	12.4 (0.6)	13.4 (0.7)	.026	<	ns	ns	13.6 (4.0)

Note. Values presented as mean (*SD*) or (*SE*).
Abbreviations: ADP, air-displacement plethysmography (BOD POD®); BIA, foot-to-foot bioelectrical impedance analysis (Tanita®); BMI, body mass index; DXA, dual-energy X-ray absorptiometry (LUNAR); ns, nonsignificant.
[a]Bonferroni-adjusted pairwise comparisons: The symbol < in the columns indicates a significant difference ($P < .05$). For example, < in the 1–2 column indicates a significant difference in the direction 1 < 2.
[b]Chi-square test.
[c]Analysis of covariance adjusted for age in body fat percentage.

relationships among methods. Intraclass correlation coefficient [$ICC_{3,1}$ (32)] and Bland–Altman plots (5) were also used to assess the agreement between methods. ICCs below .4 represent poor reliability, between .4 and .75 represent fair to good reliability, and above .75 represent excellent reliability (17). Mean bias (1.96 *SD*) [95% limits of agreement (LOA)] was used to define the range of agreement. Heteroscedasticity was examined to verify whether the absolute intermethods difference (bias) was associated with the magnitude of the %BF measured (ie, intermethods mean).

Statistical analyses were conducted using SPSS IBM (software, v.21.0; SPSS Inc, Chicago, IL) and Bland–Altman plots using MedCalc (software, v. 12.3.0; MedCalc, Ostend, Belgium). A *P* value < .05 was considered statistically significant.

Results

Table 1 shows the descriptive characteristics of the study sample by sport and for the entire sample. Most

Table 2 Comparisons and Agreement Between Methods of Measurement of %BF

Difference between methods	Groups	Spearman correlation *R*	Bland–Altman analysis Bias[a] (*SD*), %	95% CI	95% LOA	Trend[b]	ICC *r*	95% CI
DXA − ADP	All (*N* = 104)	.82**	−3.25 (3.48)**	−3.93 to −2.57	−10.07 to 3.57	−.03	.73	.22 to .88
	Swimmers (*n* = 40)	.85**	−3.74 (3.71)**	−4.93 to −2.56	−11.01 to 3.53	.07	.74	.15 to .90
	Footballers (*n* = 37)	.76**	−3.18 (3.31)**	−4.28 to −2.08	−9.66 to 3.30	−.19	.67	.10 to .86
	Cyclists (*n* = 27)	.83*	−2.61 (3.36)**	−3.95 to −1.28	−9.21 to 3.98	−.10	.79	.37 to .92
BIA − ADP	All (*N* = 104)	.55**	−5.29 (4.89)**	−6.24 to −4.34	−14.87 to 4.28	.43**	.36	−.06 to .63
	Swimmers (*n* = 40)	.49**	−5.46 (6.19)**	−7.44 to −3.48	−17.59 to 6.68	.54**	.26	−.06 to .53
	Footballers (*n* = 37)	.70**	−5.45 (3.31)**	−6.55 to −4.35	−11.93 to 1.03	.43*	.37	−.10 to .71
	Cyclists (*n* = 27)	.58***	−4.83 (4.65)***	−6.67 to −2.99	−13.95 to 4.28	.19	.49	−.04 to .77

Abbreviations: ADP, air-displacement plethysmography (BOD POD®); %BF, percentage of body fat; BIA, foot-to-foot bioelectrical impedance analysis (Tanita®); CI, confidence interval; DXA, dual-energy X-ray absorptiometry (LUNAR); ICC, intraclass correlation coefficient; LOA, limits of agreement.
[a]Average difference between methods. The negative sign indicates a lower %BF value for the DXA and the BIA against the ADP.
[b]Pearson's correlation coefficients between the absolute value of the difference versus the average of the 2 variables (DXA vs BOD POD® or BIA vs BOD POD®). If trend >0 and $P < .05$, there is heteroscedasticity between the variables.
*$P < .01$. **$P < .001$.

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traits differed by sport except body mass index and %BF DXA. In addition, between-group comparisons showed raw significant differences between swimmers and footballers in age, stature, and body mass, and also in mean-adjusted %BF ADP and %BF BIA, which were significantly higher in swimmers than footballers.

Table 2 shows comparisons and intermethods agreement in %BF estimates. A higher correlation was found for ADP with DXA than with BIA (Spearman correlation in pooled group: $r = .82$, $P < .001$ and $r = .55$, $P < .001$, respectively). Significant mean bias (t test) was found when comparing %BF DXA and %BF BIA versus %BF ADP in each group of athletes and also in the pooled group. BIA and DXA underestimated %BF compared with ADP ($P < .001$), and the bias was greater when comparing BIA versus ADP than DXA versus ADP. Swimmers showed the highest bias, whereas cyclists showed the lowest in both intermethods comparisons. Swimmers, footballers, and the pooled group of athletes showed heteroscedasticity in BIA versus ADP with positive and significant trends ($r = .54$, .43, and .43, respectively, $P < .01$). In addition, the ICC for %BF showed good to excellent agreement between DXA and ADP ($ICC_{3,1}$, r ranged from .67 to .79), but the agreement was poor between BIA and ADP ($ICC_{3,1}$, r ranged from .26 to .49).

The LOA of the comparison between BIA and ADP were wider than those from DXA and ADP (Figures 1 and 2). Swimmers had the highest range of 95% LOA and footballers the least. In this regard, the range of 95% LOA in swimmers was 24.3% in BIA versus ADP and 14.5% in DXA versus ADP, whereas for footballers, it was 13% in both intermethods comparison. A greater variability between BIA and ADP with increases in %BF is also evident in Figure 2.

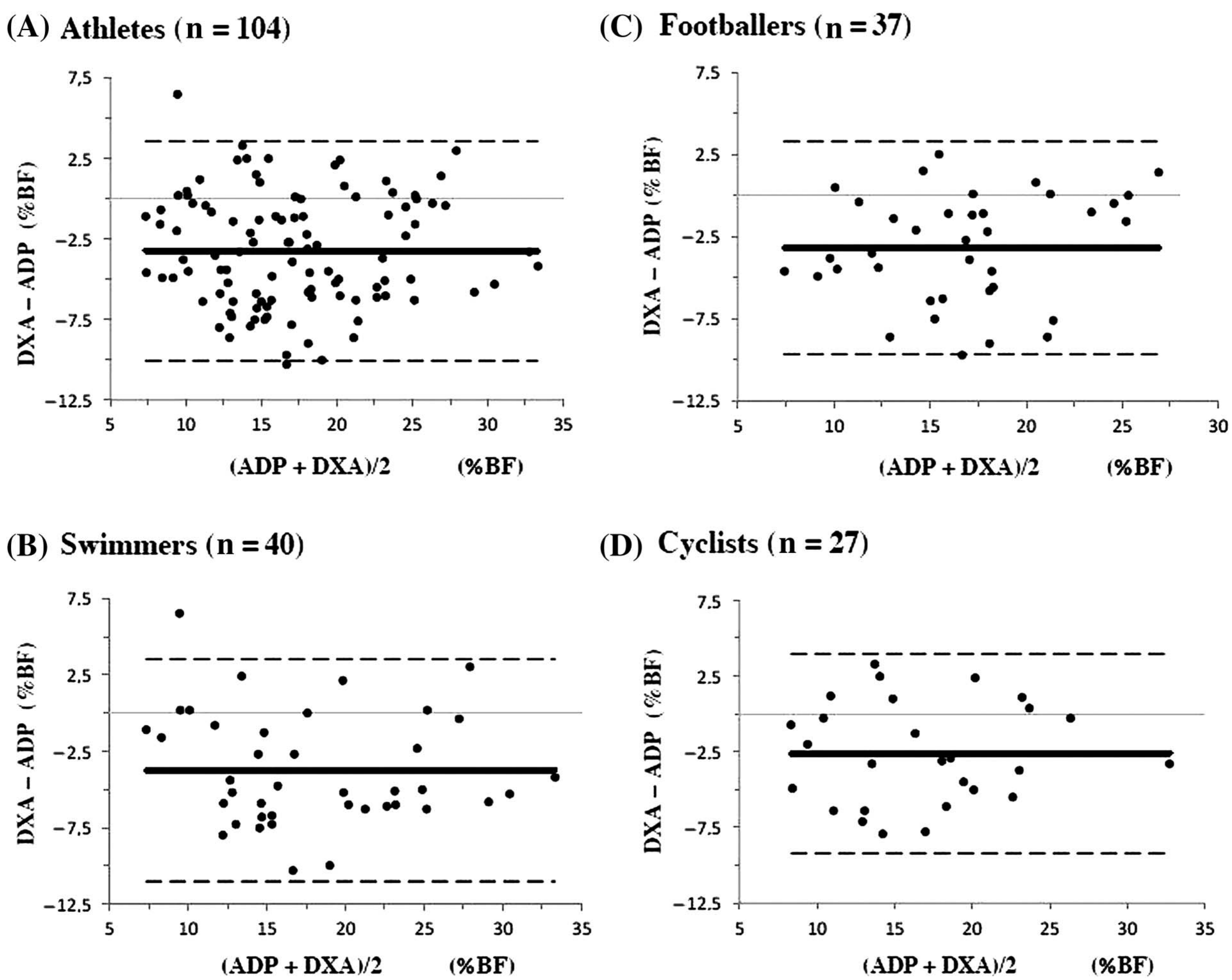

Figure 1 — Bland–Altman plots identifying differences in %BF when comparing DXA versus ADP in (A) pooled athletes ($N = 104$), (B) swimmers ($n = 40$), (C) footballers ($n = 37$), and (D) cyclists ($n = 27$). Central line represents the intermethods difference (bias). Central line below 0 indicates higher estimates of %BF with ADP. Upper and lower broken lines represent the 95% limits of agreement [bias (1.96 SD) of the differences]. %BF indicates percentage of body fat; DXA, dual-energy X-ray absorptiometry; ADP, air-displacement plethysmography.

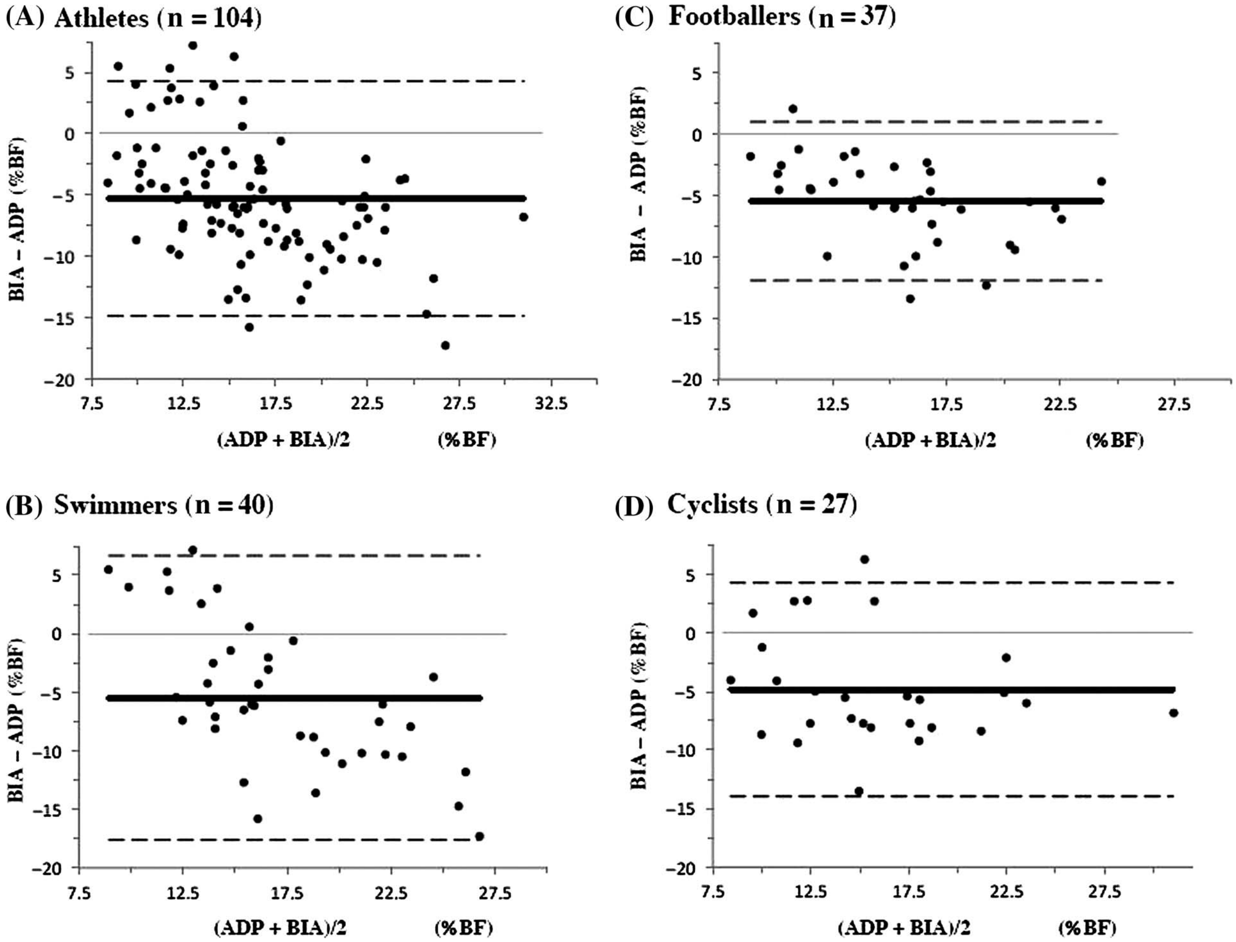

Figure 2 — Bland–Altman plots identifying differences in %BF when comparing BIA versus ADP in (A) pooled athletes ($N = 104$), (B) swimmers ($n = 40$), (C) footballers ($n = 37$), and (D) cyclists ($n = 27$). Central line represents the intermethods difference (bias), and line below 0 indicates higher estimates of %BF with ADP. Upper and lower broken lines represent the 95% limits of agreement [bias (1.96 *SD*) of the differences]. %BF indicates percentage of body fat; BIA, bioelectric impedance analysis; ADP, air-displacement plethysmography.

Discussion

The current study examined the agreement among standard methods commonly used in laboratories to estimate %BF, such as DXA, BIA, and ADP. In the present study, a multicomponent model was not available, and therefore, ADP was chosen as a reference due to its greater precision to estimate %BF than hydrodensitometry in children (11,27).

Agreement Between DXA and ADP

In the present study, the large LOA and a considerable mean bias, even without a significant trend across different levels of %BF, suggest that DXA is not a precise method in this population because it markedly underestimated %BF with high individual measure variability. In spite of this, %BF DXA showed a strong relationship with %BF ADP.

In our study, DXA underestimated %BF by 3.25% compared with ADP, which is in line with previous studies (3,13). In contrast, other studies have observed an overestimation in %BF DXA compared with ADP (2%–3%) in male (8) and female footballers (24) and in young male cyclists (2%–3%) (18). In regard to individual variability, the LOA for DXA and ADP measures were slightly larger in our study than those reported in young cyclists (18). In our study, the large LOA could cause an individual %BF value to be underestimated by −10.07% or overestimated by 3.57%, although no relation between the differences of the methods and adiposity was present. Differences among studies could be partially explained due to the use of different equations to estimate %BF. Siri equation (33) [%fat = (4.95/body density − 4.50) × 100] was developed on the basis that the density of fat mass is 0.9 g/cm^3 and that the density of the FFM is 1.1 g/cm^3 (28). The assumption that the FFM density is constant is based on the premise

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of a constant FFM composition (ie, 73.8% of water, 19.4% of protein, and 6.8% of minerals). Nevertheless, young people have higher hydration and consequently lower density in FFM than adult people (28). In spite of this, the basic difference among different equations (6) generally averages less than 1% in body fat units for body fat levels between 4% and 30% (21), which is where our participants fall.

In the present study, we did not find an increase in the bias of %BF DXA when compared with %BF ADP, as shown in the nonsignificant trend in any of the groups of athletes (Table 2). The literature is conflicting in this regard with previous studies showing presence (13,18) or absence (3,14,24) of increasing bias with increasing %BF. Differences among studies could be explained by different %BF values, with those reporting increasing bias having more %BF (13,14,18).

We found very good and excellent ICCs (ranged from .67 in footballers to .79 in cyclists) between %BF DXA and %BF ADP, which agree with previous literature showing strong correlations between these methods in children ($P < .001$; $R^2 = .88$, SEM = 0.10) (13).

DXA allows monitoring %BF changes at the whole body but also at different regions, which makes it ideal to monitor changes due to sport participation (38). However, DXA uses ionizing radiation, and although the effective dose is below background levels, this is often seen as a limitation. In addition, its economical and practical implications may represent an issue and make measurements more difficult to obtain.

Agreement Between BIA and ADP

Although both methods are correlated, our findings suggest a lack of agreement between methods; therefore, BIA and ADP should not be used interchangeably. We found that %BF estimation using BIA was systematically lower than ADP, with high individual variability and a heteroscedastic behavior. The literature provides little empirical evidence about the agreement between BIA and ADP for assessing body composition in young athletes. In a previous study, %BF BIA showed a positive and strong correlation with %BF ADP ($r > .83$) in elite adolescent volleyball players (29). In obese and nonobese children and adolescents, BIA correlated highly with ADP; however, it underestimated %BF (2). The authors also reported LOA ranging from −13.70% to 6.90% of body fat. Likewise, in our study, we found a mean bias of −5.29% (4.89) (all athletes), with LOA ranging from −14.87% to 4.28% of body fat. In this sense, ADP showed higher variability in individual %BF estimation, in comparison, for example, with our results from DXA.

Recently, a study of female collegiate athletes found moderate correlation ($r = .45$) between BIA and ADP (31), similar to our findings. It is well known that the body composition values obtained by BIA depend on the hydration status of the participants (20), and this might partially explain differences between BIA and ADP estimates of %BF (2). We did not measure the hydration of the participants, but they were asked to come on a fasting status from 9.00 PM (water intake was not restricted) the day before the measurements. In addition, participants were instructed to void immediately before the procedures start.

In our study, the predictive error of %BF was greater in swimmers compared with footballers and cyclists (both in BIA and DXA). This can be explained by the significant trend between the level of adiposity and the error, with an underestimation of %BF with BIA in athletes with higher adiposity.

Strengths and Limitations

Some shortcomings should be taken into account. There are many body composition methods to estimate %BF (29), such as multicomponent models and hydrodensitometry. However, their feasibility and cost can be limiting factors (38). More practical and acceptable methods that are frequently used for the estimation of body composition include DXA and BIA (38).

The accuracy of DXA and BIA has not received sufficient attention in young athletic population (38). DXA may provide useful information on relative fat; however, the accuracy of the method can vary according to age and fatness (38,39). The accuracy of BIA is age and population characteristic dependent, with population-specific BIA equations reporting validity issues in healthy individuals, with errors in individuals of typically ±8% fat (39).

Moreover, ADP can also be used as a potential reference method although it is not a "criterion" method because it is based on a 2-compartment model (2,15). For the purpose of this study, we adopted ADP as the reference method because it is validated against hydrodensitometry, which has been considered a potential reference method studied in vivo for many years (2,16). For example, a review showed a mean difference between ADP and hydrodensitometry ranging from −2.9% to 1.2% inferring that the ADP is a valid technique that can quickly and safely evaluate body composition in a wide range of participants, including those who are often difficult to measure, such as the elderly, children, and obese individuals (15).

Sample size was relatively small in this study, but it was composed by young male athletes with a long-time history in football, swimming, or cycling participation. All measurements (BIA, ADP, and DXA) were taken only once, but the research team was fully trained on this purpose. Despite these shortcomings, the present study compares the agreement between 3 very common methods that have been extensively used worldwide and provides an estimation on their agreement when multicomponent models are not available.

Conclusion

BIA underestimates %BF (and DXA to a lower extent) compared with ADP in young male swimmers,

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footballers, and cyclists. The bias between BIA and ADP increases with %BF. In addition, BIA and DXA are not precise for individual %BF prediction in young athletic populations. Further research using a multicomponent model as reference method in young athletes is needed.

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