TITLE: Agreement between standard body composition methods to estimate percentage of body fat in young male athletes.

Running title: Agreement between three methods to estimate percentage of body fat.

ABSTRACT

Purpose: to examine the inter-methods 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. **Method:** Standard measurement protocols were carried out in 104 athletes (40 swimmers, 37 footballers and 27 cyclists, aged 12–14y). **Results:** Age-adjusted %BF-ADP and %BF-BIA were significantly higher in swimmers than footballers. ADP correlates better with DXA than with BIA (r=0.84 vs r=0.60, p<0.001). %BF was lower when measured by DXA and BIA than ADP (p < 0.001) and the bias was higher when comparing ADP vs BIA than ADP vs DXA. The intraclass-correlation coefficients ($ICC_{3,1}$) between DXA and ADP showed a good to excellent agreement (r=0.67 to r=0.79), though it was poor when BIA was compared to ADP ($ICC_{3,1}$, r=0.26 to r=0.49). The ranges of agreement were wider when comparing BIA to ADP than DXA to ADP. **Conclusion**: DXA and BIA seem to underestimate %BF in young male athletes compared to 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 to ADP in young athletic populations.

Keywords: validation studies, body composition, adolescents, sport.

Introduction

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 wellbeing 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 (39) or hydrodensitometry (11,13) have 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 (HW) 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 (16). Moreover, this method offers several advantages, including a quick and easy measurement process (16). Fields et al. (15) 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, like 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 from the total body water prediction and, by difference with body weight, the body fat (39). DXA has better accuracy for bone outcomes than for soft tissue values, it also estimates the total body fat indirectly (dividing by body mass), however, its bias varies with age and fatness (39).

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 to ADP (18), whereas in footballers 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 (25). Most of these previous studies assess the agreement between ADP and HW (as the reference method) to estimate %BF from body density (4, 8, 12, 24, 35, 36), with conflicting results. Some studies reported no significant differences between methods in wrestling athletes (12, 35), but others showed ADP to underestimate %BF in footballers (8) or overestimate it in a groups of athletes of different sports (24).

The purpose of this study was to examine the inter-methods agreement of DXA and BIA with ADP to assess the %BF in young male athletes, swimmers, footballers and cyclists. A number of authors report that hydrodensitometry is poorly tolerated by young people and ADP, as discussed above, is an alternative and more accurate method to calculate body density in children (11, 27). It does not require of 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 on-going PRO-BONE study (37). One hundred and four male young athletes were recruited from athletic clubs and schools of the South West of the England, United Kingdom. For the purpose to the current study, baseline values (measured between autumn and winter 2014/15) 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/week) in osteogenic (football) and/or non-osteogenic (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; 5) participants had to be white Caucasian race.

All participants underwent three methods of body composition to measure %BF and all measurements were performed the same morning. They were asked to attend the tests after a 10-12 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, ref. number 618496); 2) the Sport and Health Sciences Ethics Committee (University of Exeter, ref. number 2014/766) and 3) the National Research Ethics Service Committee (NRES Committee South West – Cornwall & Plymouth, ref. 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 two measurements of weight and height was used to calculate body mass index (BMI) 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 five stages (Tanner) of pubertal hair development (34).

Dual energy x-ray absorptiometry

A DXA scanner (GE Lunar Prodigy Healthcare Corp., Madison, WI, USA) was used to measure %BF. All DXA scans and sub-sequent 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) 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 was found to be negligible (9).

Bioelectrical impedance analysis

The portable foot-to-foot BIA device (Tanita BF-350, 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, by 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, USA) and the device's default software (Software version 4.2+, COSMED USA, Inc.). 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 jewelry 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 two or three 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 (16, 19, 23, 26). Several formulas other than Siri's 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 ± standard deviation (SD) unless otherwise stated.

One-way ANOVA with Bonferroni correction was used to test mean differences in continuous variables, such as age, stature, body mass, and BMI by sport groups (Table 1). Chi square statistics was used to test associations between categorical variables (i.e. Tanner stages in sport groups). Analysis of covariance (ANCOVA) 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 relationships among methods. Intraclass correlation coefficient – (ICC3,1 (32)) and Bland-Altman plots (5) were also used to assess the agreement between methods. ICCs below 0.4 represent poor reliability, between 0.4 and 0.75 represent fair to good reliability and above 0.75 represent excellent reliability (17). Mean bias ± 1.96 SD (95% limits of agreement (LOA) was used to defined the range of agreement. Heteroscedasticity was examined to verify whether the absolute inter-methods difference (bias) was associated with the magnitude of the %BF measured (i.e. inter-methods mean).

Statistical analyses were conducted using SPSS IBM (software, v.21.0 SPSS Inc., Chicago, IL, USA) and Bland-Altman plots using MedCalc (Software, v. 12.3.0, Ostend, Belgium). A *p*-value <0.05 was considered statistically significant.

Results

Table 1 shows the descriptive characteristics of the study sample by sport and for the entire sample. Most traits differed by sport except BMI and %BF DXA. In addition, between-group comparisons showed raw significant differences between swimmers and footballers in age, stature, 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 inter-methods agreement in %BF estimates. A higher correlation was found for ADP with DXA than with BIA (Spearman correlation in pooled group, $r=0.82$, $p<0.001$; and $r=0.55$, $p<0.001$, respectively). Significant mean bias (t-test) was found when comparing %BF DXA and %BF BIA vs %BF ADP in each group of athletes and also in the pooled group. BIA and DXA underestimated %BF compared to ADP ($p<0.001$), and the bias was greater when comparing BIA vs ADP than DXA vs ADP. Swimmers showed the highest bias while cyclists showed the lowest in both inter-methods comparisons. Swimmers, footballers and the pooled group of athletes showed heteroscedasticity in BIA vs ADP with positive and significant trends ($r=0.54$, $r=0.43$ and $r=0.43$, respectively, $p<0.01$). In addition, the ICC for %BF showed good to excellent agreement between DXA and ADP ($ICC_{3,1}$ ranged from $r=0.67$ to $r=0.79$) but the agreement was poor between BIA and ADP ($ICC_{3,1}$ ranged from $r=0.26$ to $r=0.49$).

The limits of agreement (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 vs ADP and 14.5% in DXA vs ADP, while for footballers, it was 13% in both inter-methods comparison. A greater variability between BIA and ADP with increases in %BF is also evident in Figure

2.

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 limits of agreement and a considerable mean bias, even without a significant trend across different levels of %BF, suggest 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 to ADP which is in line with previous studies (3, 13). In contrast, other studies have observed an overestimation in %BF DXA compared to ADP (2-3%) in male (8) and female footballers (25) and young male cyclists (2-3%) (18). In regards 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 limits of agreement 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/DB - 4.50)*100) was developed on the basis that the density of fat mas is 0.9 g/cm^3 and that the density of the fat free mass (FFM) is 1.1 g/cm^3 (28). The assumption that the FFM density is constant is based on the premise of a constant FFM composition (i.e. 73.8% water, 19.4% protein, and 6.8% 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 non-significant 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, 25) 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 between 0.67 in footballers to 0.79 in cyclists) between %BF DXA and %BF ADP which agree with previous literature showing strong correlations between these methods in children ($p<0.001$; $R^2 = 0.88$, 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 (39). 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>0.83) in elite adolescent volleyball players (29). In obese and non-obese 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 %BF. 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 %BF. 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=0.45) 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 to 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 (39). More practical and acceptable methods that are frequently used for the estimation of body composition include DXA and BIA (39).

The accuracy of DXA and BIA has not received sufficient attention in young athletic population (39). 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 (38).

Moreover, ADP can also be used as a potential reference method although it is not a 'criterion' method because it is based on a two-compartment model (2, 16). 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, 15). 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 (16).

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 three very common methods that have been extensively used worldwide and provides with an estimation on their agreement when multicomponent models are not available.

Conclusion

BIA underestimates %BF (and DXA to a lower extent) compared to ADP in young male swimmers, 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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Table 1. Physical characteristics of the participants.

Values presented as mean ± SD or standard error (in brackets).

† Analysis of covariance adjusted for age in body fat percentage.

‡ chi-square.

*Bonferroni-adjusted pairwise comparisons: The symbol < in the columns indicates a significant difference ($P < 0.05$). For example, < in the 1–2 column indicates a significant difference in the direction 1 < 2. ns, non-significant.

BMI: Body mass index; ADP: Air displacement plethysmography, BOD POD; BIA: foot-to-foot bioelectrical impedance analysis, TANITA; DXA: Dual energy X-ray absorptiometry, LUNAR.

Table 2. Comparisons and agreement between methods of measurement of body fat (%BF).

[a] Bias: average difference between methods; The negative sign indicates a lower %BF value for the DXA and the BIA against the ADP.

[b] LOA: Limits of agreement.

[c] Trend, Pearson's correlation coefficients between the absolute value of the difference versus the average of the two variables (DXA vs BOD POD or BIA vs BOD POD): If trend > 0 and $p < 0.05$, there is heteroscedasticity between the variables.

[d] ICC, Intraclass correlation coefficient. *** $p < 0.001$; ** $p < 0.01$.

DXA: Dual energy X-ray absorptiometry (LUNAR), ADP: Air displacement plethysmography (BOD POD); BIA: foot-to-foot bioelectrical impedance analysis (Tanita).

Figure 1. Bland-Altman plots identifying differences in percentage of body fat (%BF) when comparing dual energy x-ray absorptiometry (DXA) vs air displacement plethysmography (ADP) in (A) pooled athletes (N=104), (B) swimmers (N=40), (C) footballers (N=37), and (D) Cyclists (N= 27). Central line represents the inter-methods difference (bias). Central line below zero 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).

Figure 2. Bland-Altman plots identifying differences in percentage of body fat (%BF) when comparing bioelectric impedance analysis (BIA) vs air displacement plethysmography (ADP) in (A) pooled athletes (N=104), (B) swimmers (N=40), (C) footballers (N=37), and (D) Cyclists (N= 27). Central line represents the inter-methods difference (bias), line below zero 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).

Table 1. Physical characteristics of the participants

	Swimmers (1) (n=40)	Footballers (2) (n=37)	Cyclists (3) (n=27)	P	Between-group comparisons* 1-2	1-3	2-3	All athletes (n=104) mean ± SD
Age (yr)	13.5 ± 1.0	12.9 ± 0.9	13.3 ± 1.0	**0.012**	<	ns	ns	13.2 ± 1.0
Stature (cm)	165.7 ± 9.7	155.2 ± 9.3	160.9 ± 9.4	**<0.001**	<	ns	ns	160.7 ± 10.4
Body mass (kg)	52.5 ± 9.0	44.2 ± 7.5	48.2 ± 10.5	**0.001**	<	ns	ns	48.4 ± 9.6
BMI (kg/m^2)	19.0 ± 1.7	18.3 ± 1.4	18.5 ± 2.7	0.213	-	-	-	18.6 ± 1.9
Tanner stages (I, II, III, IV-V) (%)	(15/23/13/48)	(24/35/24/16)	(15/26/26/33)	0.127‡	-	-	-	(19/29/21/34)
Body Fat by ADP (%)†	20.6 (0.9)	17.4 (0.9)	18.3 (1.1)	**0.045**	<	ns	ns	18.9 ± 6.1
Body Fat by DXA (%)†	16.8 (0.9)	14.3 (1.0)	15.7 (1.1)	0.180	-	-	-	15.6 ± 6.1
Body Fat by BIA (%)†	14.8 (0.6)	12.4 (0.6)	13.4 (0.7)	**0.026**	<	ns	ns	13.6 ± 4.0

Values presented as mean ± SD or standard error (in brackets).

† Analysis of covariance adjusted for age in body fat percentage.

‡ chi-square.

*Bonferroni-adjusted pairwise comparisons: The symbol < in the columns indicates a significant difference (P < 0.05). For example, < in the 1–2 column indicates a significant difference in the direction 1 < 2. ns, non-significant.

BMI: Body mass index; ADP: Air displacement plethysmography, BOD POD; BIA: foot-to-foot bioelectrical impedance analysis, TANITA; DXA: Dual energy X-ray absorptiometry, LUNAR.

Table 2: Comparisons and agreement between methods of measurement of body fat (%BF)

Difference between Methods	Groups	Spearman correlation	Bland-Altman Analysis				ICC[d]	
		r	bias[a] ± sd (%)	95% CI	95%LOA[b]	Trend[c]	r	95% CI
DXA – ADP	All (n= 104)	0.82 ***	-3.25 ± 3.48***	-3.93 to -2.57	-10.07 to 3.57	-0.03	0.73	0.22 to 0.88
	SWIMMERS (n=40)	0.85***	-3.74 ± 3.71***	-4.93 to -2.56	-11.01 to 3.53	0.07	0.74	0.15 to 0.90
	FOOTBALLERS (n=37)	0.76***	-3.18 ± 3.31***	-4.28 to -2.08	-9.66 to 3.30	-0.19	0.67	0.10 to 0.86
	CYCLISTS (n= 27)	0.83**	-2.61 ± 3.36***	-3.95 to -1.28	-9.21 to 3.98	-0.10	0.79	0.37 to 0.92
BIA – ADP	All (n= 104)	0.55***	-5.29 ± 4.89***	-6.24 to -4.34	-14.87 to 4.28	0.43***	0.36	-0.06 to 0.63
	SWIMMERS (n=40)	0.49***	-5.46 ± 6.19***	-7.44 to -3.48	-17.59 to 6.68	0.54***	0.26	-0.06 to 0.53
	FOOTBALLERS (n=37)	0.70***	-5.45 ± 3.31***	-6.55 to -4.35	-11.93 to 1.03	0.43**	0.37	-0.10 to 0.71
	CYCLISTS (n= 27)	0.58***	-4.83 ± 4.65***	-6.67 to -2.99	-13.95 to 4.28	0.19	0.49	-0.04 to 0.77

[a] Bias: average difference between methods; The negative sign indicates a lower %BF value for the DXA and the BIA against the ADP.

[b] LOA: Limits of agreement.

[c] Trend, Pearson's correlation coefficients between the absolute value of the difference versus the average of the two variables (DXA vs BOD POD® or BIA vs BOD POD®): If trend > 0 and p< 0.05, there is heteroscedasticity between the variables.

[d] ICC, Intraclass correlation coefficient. *** p< 0.001; ** p<0.01.

DXA: Dual energy X-ray absorptiometry (LUNAR), ADP: Air displacement plethysmography (BOD POD); BIA: foot-to-foot bioelectrical impedance analysis (Tanita®).

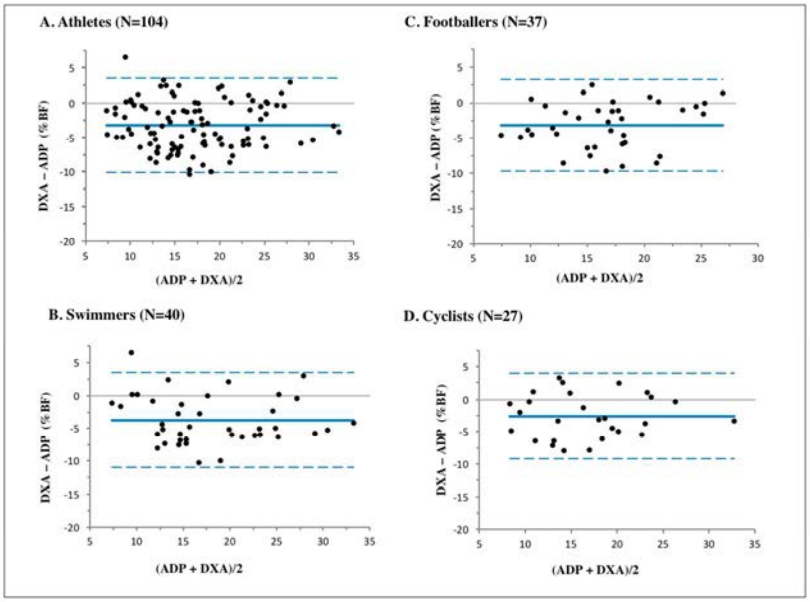

Figure 1. Bland-Altman plots identifying differences in percentage of body fat (%BF) when comparing dual energy x-ray absorptiometry (DXA) vs air displacement plethysmography (ADP) in (A) pooled athletes (N=104), (B) swimmers (N=40), (C) footballers (N=37), and (D) Cyclists (N= 27). Central line represents the inter-methods difference (bias). Central line below zero indicates higher estimates of %BF with ADP. Upper and lower broken lines represent the 95% Limits of agreement (bias ± 1.96xSD of the differences).

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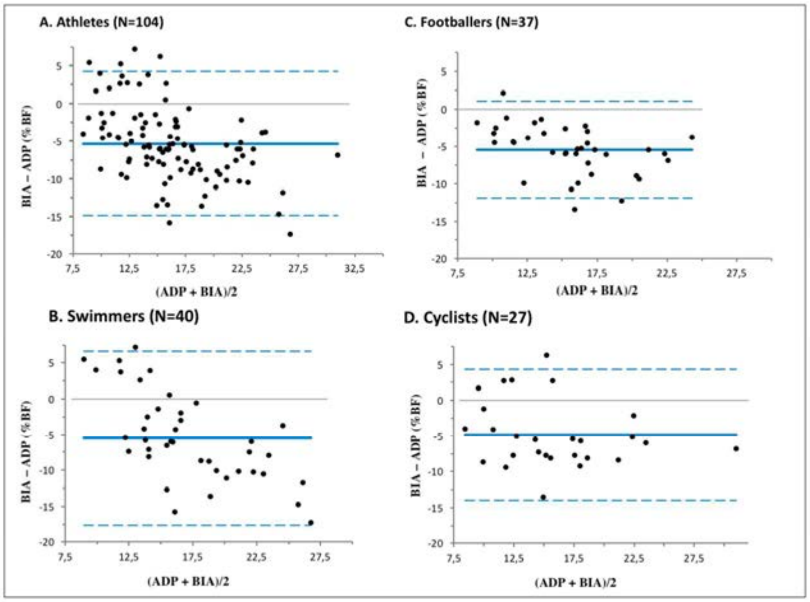

Figure 2. Bland-Altman plots identifying differences in percentage of body fat (%BF) when comparing bioelectric impedance analysis (BIA) vs air displacement plethysmography (ADP) in (A) pooled athletes (N=104), (B) swimmers (N=40), (C) footballers (N=37), and (D) Cyclists (N= 27). Central line represents the inter-methods difference (bias), line below zero indicates higher estimates of %BF with ADP. Upper and lower broken lines represent the 95% Limits of agreement (bias ± 1.96xSD of the differences).

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