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Body fat percentage comparisons between four methods in young football players: are they comparable?

Comparación del porcentaje de grasa corporal medido con cuatro métodos diferentes en jóvenes futbolistas: ¿son comparables?

Gabriel Lozano Berges[1,2,3,4], Ángel Matute Llorente[1,2,3,4], Alejandro Gómez Bruton[1,2,3,4], Alejandro González Agüero[1,2,3,4], German Vicente Rodríguez[1,2,3,4] and José Antonio Casajús[1,2,3,4]

[1]Growth, Exercise, Nutrition and Development (GENUD) Research Group. Universidad de Zaragoza. Zaragoza, Spain. [2]Faculty of Health and Sport Science (FCSD). Department of Physiatry and Nursing. Universidad de Zaragoza. Zaragoza, Spain. [3]Instituto Agroalimentario de Aragón-IA2. Universidad de Zaragoza-CITA. Zaragoza, Spain. [4]Centro de Investigación Biomédica en Red de Fisiopatología de la Obesidad y Nutrición (CIBERObn)

Abstract

Introduction: Dual X-ray absorptiometry (DXA), air displacement plethysmography (ADP), bioelectrical impedance analysis (BIA) and anthropometry are four body composition methods that have been frequently used for the assessment of body fat percentage (%BF) in athletes. However, the agreement between these methods has not been studied yet in adolescent football players.

Objectives: The aim of this study was to compare %BF calculated by DXA, ADP, BIA and anthropometry in 92 participants.

Methods: Sixty-four males (13.4 ± 0.6 years of age) and 28 females (13.4 ± 0.6 years) participated in this study. %BF was measured with four methods: DXA, ADP, BIA, and anthropometry. ADP %BF was calculated by using Siri's equation. The equation proposed by Slaughter et al. was used to calculate %BF by anthropometry. Paired t-test was used to compare %BF means. The heteroscedasticity was calculated by Bland-Altman analyses.

Results and conclusions: Both in males and females, DXA, ADP, BIA and Slaughter et al. equation demonstrated significant %BF differences when compared to each other ($p < 0.05$); 95% limits of agreements ranged from 5.13 to 15.09% points. Only BIA showed heteroscedasticity compared to the other methods in both genders ($p < 0.05$). Although DXA, ADP, BIA, and anthropometry have been used in the scientific literature in order to assess %BF in adolescent football players, these results demonstrate that these body composition methods are not interchangeable in this population.

Key words:

Soccer. Body composition. Absorptiometry. Photon. Skinfold thickness.

Resumen

Introducción: los métodos absorciometría fotónica dual de rayos X (DXA), pletismografía por desplazamiento de aire (ADP), análisis de la impedancia bioeléctrica (BIA) y antropometría han sido utilizados para el cálculo del porcentaje de grasa corporal (%CG) en atletas. Sin embargo, la concordancia entre estos métodos no ha sido estudiada en futbolistas adolescentes.

Objetivos: el objetivo de este estudio fue comparar el %GC calculado mediante DXA, ADP, BIA y antropometría en 92 participantes.

Métodos: sesenta y cuatro chicos (13,4 ± 0,6 años) y 28 chicas (13,4 ± 0,6 años) participaron en este estudio. El %GC fue medido mediante cuatro métodos diferentes: DXA, ADP, BIA, y antropometría. ADP %GC fue calculado a partir de la ecuación de Siri. La ecuación propuesta por Slaughter y cols. fue utilizada para calcular el %CG mediante antropometría y se emplearon las pruebas t de Student para muestras relacionadas para comparar las medias de %CG. La heterocedasticidad fue calculada por análisis de Bland-Altman.

Resultados y conclusiones: tanto en chicos como en chicas, DXA, ADP, BIA y la ecuación de Slaughter y cols. demostraron diferencias significativas en el %GC al ser comparados ($p < 0,05$). Los límites de concordancia al 95% oscilaron entre 5,13 y 15,09%. El BIA fue el único método que mostró heterocedasticidad con los otros métodos ($p < 0.05$). Aunque los métodos DXA, ADP, BIA y la antropometría han sido usados en la literatura científica para calcular el %GC en futbolistas adolescentes, estos resultados demuestran que estos métodos de valoración de la composición corporal no son intercambiables en la población de estudio.

Palabras clave:

Fútbol. Composición corporal. Absorciometría fotónica dual de rayos X. Pliegues cutáneos.

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Correspondence:

José Antonio Casajús. Growth, Exercise, Nutrition and Development (GENUD) Research Group. Faculty of Health and Sport Science. University of Zaragoza. C/ Pedro Cerbuna, 12. 50009 Zaragoza, Spain
e-mail: joseant@unizar.es

INTRODUCTION

The components of human body can be quantified at five-levels of body composition according to their complexity from atomic to anatomic levels (1). Methods for analysis of body composition can divide body mass into components on the basis of differing physical properties. At a molecular level, a four-component model (4C) of body composition divides body mass into fat, water, mineral and protein; a three-component model (3C), into fat, mineral and lean soft tissue; and a two-component model (2C), into fat and fat-free mass (1). The 4C model is considered as the gold standard to assess body composition in pediatric populations (2). Nevertheless, the use of a 4C model is not available for most researches due to its high economic cost and time involvement (2). For example, dual energy X-ray absorptiometry (DXA), as a body composition analysis device, derives a 3C model, or air displacement plethysmography (ADP) uses a 2C model, therefore these two are not the most recommended methods to be used in children and adolescents (2). Nevertheless, several studies have monitored the percentage of body fat (%BF) with DXA as well as ADP in these populations (3,4).

In fact, despite DXA is the criterion method for measuring bone mass, it also calculates fat and lean masses, and several studies have used DXA as a reference method for measuring body composition, concretely %BF (5,2). Toombs et al. (6) pointed out that DXA may be a convenient method to be used in the assessment of body composition because of its high precision, safety and time efficiency. ADP is considered as the reference method for evaluating %BF in adults (7), but it can over- or underestimate it in children and adolescents assuming the adult constant values for lean tissue hydration (8). Lohman (9) and Wells et al. (10) adapted Siri's equation and developed age- and gender-specific equations for pediatric populations.

At a whole-body level, bioelectrical impedance analysis (BIA) and anthropometry are simple and low cost techniques that have also been used for the estimation of %BF in young athletes (11,12).

Body composition has been related to physical performance through childhood and adolescence (13). An elevated %BF has a negative effect on the performance of athletes such as football players (14). Thus, assessments of %BF during the season might be a useful variable for coaches in order to plan specific training.

Some studies have demonstrated that DXA, ADP and BIA are not interchangeable for the evaluation of %BF in different populations such as moderately active adolescents (15), overweight children (7) and obese adolescents (16). However, to our knowledge, no studies have determined the agreement between body composition methods such as DXA, ADP, BIA, and anthropometry in young football players. Therefore, the aim of the present study was to compare %BF calculated by DXA, ADP, BIA and anthropometry (Slaughter et al. [17]) in adolescent football players.

MATERIAL AND METHODS

PARTICIPANTS

Eight clubs of Aragón (Spain) participated in this cross-sectional study. A total of 121 football players (81 males and 40 females) signed the written consent. Twenty-nine football players were not included because they did not meet the inclusion criteria or could not do the assessment. Finally, 92 adolescent football players (64 males, 13.4 ± 0.6 years; 28 females, 13.4 ± 0.6 years) participated in this study.

Participants, their parents and their corresponding clubs were informed about the protocol of this study. Their parents or guardians completed and signed each written informed consent to participate in the study prior to taking any measurement. This study was performed in accordance with the Declaration of Helsinki of 1964 (revised in Fortaleza, 2013) and was reviewed and approved by the Research Ethics Committee of the Government of Aragon (CEICA, Spain) (C.I. PI13/0091).

INCLUSION CRITERIA

Age between eleven and 14 years and at least one year of football practice were the inclusion criteria of the present study.

DUAL ENERGY X-RAY ABSORPTIOMETRY MEASUREMENTS

Whole body %BF was calculated by DXA QDR-Explorer (pediatric version of the software QDR-Explorer, Hologic Corp., software version 12.4, Bedford, Massachusetts, USA). DXA equipment was calibrated daily with a spine phantom following the manufacturer guidelines. Football players were measured in supine position and all DXA scans were performed and analyzed by the same technician who was fully trained to perform them.

AIR DISPLACEMENT PLETHYSMOGRAPHY MEASUREMENTS

Total body density was calculated via ADP (BODPOD®, Body Composition System, Life Measurement Instruments, Concord, CA). The same technician performed all exams and ADP was calibrated following the guidelines established by the manufacturer. The software of the BODPOD® estimated pulmonary capacity. Total body density was inserted in Siri equation (18) to calculate %BF.

BIOELECTRICAL IMPEDANCE ANALYSES MEASUREMENTS

Each participant was also measured using BIA (TANITA BC-418, Tanita, Tokyo, Japan) to obtain %BF. Sex, age, and height were inserted into BIA prior to the impedance measure. The same trained technician following the device guidelines also performed these measurements.

ANTHROPOMETRIC MEASUREMENTS

Height with a stadiometer (SECA 225, SECA, Hamburg, Germany) to the nearest 0.1 cm and weight with a scale (SECA, Hamburg, Germany) to the nearest 0.1 kg were measured with participants in underwear and barefoot. Body mass index (BMI) was calculated as weight (in kilograms) divided by squared height (in meters).

Triceps and subscapular skinfolds were measured following the recommendations of the International Society for the Advancement of Kinanthropometry (ISAK), with a skinfold calliper (Holtain Ltd. Crymmych, UK) to the nearest 0.2 mm, by the same trained technician (level 2 ISAK anthropometrist) (19). BF% was directly estimated via the Slaughter et al. (17) equation.

STATISTICAL ANALYSES

Statistical Package for the Social Sciences (SPSS) version 22.0 for Mac OS X (SPSS Inc., Chicago, IL, USA) was used to perform all statistical analyses. The studied variables showed a normal distribution according to the Kolmogorov-Smirnov test. Data were presented as mean and standard deviation (SD).

Differences between %BF obtained via DXA, ADP, BIA and anthropometry were analyzed by two-paired samples t-test. The 95% limits of agreement (inter-methods difference ± 1.96 SD) of each equation were also calculated. The agreement between DXA, ADP, BIA and Slaughter et al. (17) equation was evaluated according to Bland-Altman plots (20), in both genders separately. Inter-method differences were plotted against the mean of both methods. In addition, heteroscedasticity was examined by linear regression to determine whether the absolute inter-methods difference was associated with the magnitude of the measurement. Effect size statistics using Cohen's d were calculated. The effect size for Cohen's d can be small (0.2-0.5), medium (0.5-0.8) or large (> 0.8). Statistical significance was set at $p < 0.05$.

RESULTS

Table I shows the characteristics of the participants. No differences were found in age, height and Tanner between males and females (all $p > 0.05$). Male football players were heavier and showed higher BMI than their female counterparts ($p < 0.05$; Cohen's d were 0.5 and 0.7).

Comparisons of %BF for DXA, ADP, BIA and the Slaughter et al. (17) equation are shown in table II. In both genders, these methods demonstrated %BF differences when compared to each other ($p < 0.05$; Cohen's d ranged from 0.4 to 1.6).

Inter-methods differences, 95% limits of agreement and heteroscedasticity are summarized in table III. ADP, BIA, and Slaughter et al. (17) equation underestimated %BF between -1.24 and -10.52% points compared to DXA ($p < 0.05$; Cohen's d ranged from 0.5 to 1.6). Moreover, all methods showed a random error between 5.13 and 12.99, being the Slaughter et al. (17) equation the highest one in females. As compared with ADP, significant %BF differences were found with BIA and the Slaughter et al. (17) equation in both genders ($p < 0.05$; Cohen's d ranged from 0.4 to 0.9). BIA and the Slaughter et al. (17) equation showed a random error between 7.13 and 15.09, being also the Slaughter et al. (17) equation the highest one in female football players. On the other hand, the Slaughter et al. (17) equation underestimated %BF by 0.96 and 9.47% points in males and females, respectively.

Bland-Altman plots for the differences between DXA, ADP, BIA and anthropometry are shown in figure 1. In males, ADP, BIA and Slaughter et al. (17) equation showed heteroscedasticity when compared to DXA ($p < 0.05$). Moreover, BIA showed heteroscedasticity when compared with ADP and Slaughter et al. (17) equation both in males and females ($p < 0.05$).

Table I. Subject characteristics (mean ± standard deviation)

	All (n = 92)	Males (n = 64)	Females (n = 28)
Age (years)	13.4 ± 0.6	13.4 ± 0.6	13.4 ± 0.6
Weight (kg)	49.8 ± 10.7	48.3 ± 10.9*	53.1 ± 9.6
Height (cm)	159.8 ± 8.5	159.8 ± 9.1	159.8 ± 7.1
BMI (kg/m^2)	19.3 ± 2.9	18.7 ± 2.7*	20.7 ± 2.9
Tanner (I/II/III/IV/V)	1/11/34/36/10	0/7/28/22/7	1/4/6/14/3

*BMI: Body mass index. *$p < 0.05$ between genders.*

Table II. Percentage of body fat calculated by DXA, ADP, BIA and the Slaughter et al. equation in young football players

Model	Males (n = 64)		Females (n = 28)	
	%BF	SD	%BF	SD
DXA	19.93	4.75	26.38	4.72
ADP	18.48*	5.65	22.38*	5.69
BIA	16.92*,#	3.92	25.14*,#	4.01
Slaughter et al. (17)	15.95*,#,$	6.29	15.47*,#,$	6.14

*DXA: Dual energy X-ray absorptiometry; ADP: Air displacement plethysmography; BIA: Bioelectrical impedance analysis; %BF: Percentage of body fat; SD: Standard deviation. *%BF differences with DXA; #%BF differences with ADP; $%BF differences with BIA. Statistical significance was set at $p < 0.05$.*

DISCUSSION

The main finding of the present study is that significant differences in determining %BF exist between different body compo-

Table III. Percentage of body fat differences between methods (DXA, ADP, BIA and Slaughter et al. equation), limits of agreement 95%, confidence interval, correlation coefficient (R) and heteroscedasticity

Model	Differences between methods	95% limits of agreement	Confidence interval	R	Heteroscedasticity (p)
Compared to DXA					
Males (n = 64)					
DXA	-	-	-	-	-
ADP	1.45	5.13	(-3.69-6.58)	0.355	0.004*
BIA	3.02	5.17	(-2.15-8.18)	0.330	0.008*
Slaughter et al. (17)	3.98	6.41	(-2.43-10.39)	0.490	< 0.001*
Females (n = 28)					
DXA	-	-	-		
ADP	4.00	7.60	(-3.61-11.60)	0.269	0.166
BIA	1.24	5.21	(-3.97-6.45)	0.281	0.148
Slaughter et al. (17)	10.52	12.99	(-2.47-23.51)	0.346	0.078
Compared to ADP					
Males (n = 64)					
ADP	-	-	-	-	-
BIA	1.57	7.13	(-5.56-8.70)	0.506	< 0.001*
Slaughter et al. (17)	2.53	6.09	(-3.56-8.62)	0.214	0.089
Females (n = 28)					
ADP	-	-	-		
BIA	-2.76	8.57	(-11.33-5.82)	0.424	0.025*
Slaughter et al. (17)	6.94	15.09	(-8.16-22.03)	0.057	0.778
Compared to BIA					
Males (n = 64)					
BIA	-	-	-	-	-
Slaughter et al. (17)	0.96	7.20	(-6.23-8.16)	0.674	< 0.001*
Females (n = 28)					
BIA	-	-	-	-	-
Slaughter et al. (17)	9.47	12.95	(-3.48-22.43)	0.423	0.028*

*DXA: Dual energy X-ray absorptiometry; ADP: Air displacement plethysmography; BIA: Bioelectrical impedance analysis. *p < 0.05.*

sition analysis methods in young football players, and they are therefore non comparable. In addition, these methods demonstrated high random errors when compared to each other.

The different model that the ADP and DXA use (2C *vs* 3C) could explain the differences in %BF between these two methods. Fat-free mass assumptions of the 2C model is its major disadvantage (21). The 2C model used by ADP was developed from adult body dissection and its application in children might be inadequate (9). Even when age- and sex-specific equations for children and adolescents (Lohman [9] and Wells et al. [10] equations) were used, significant differences for %BF were found between methods (personal observations). In addition, these differences between DXA and ADP, using the Lohman (9) and Wells et al. (10) equations, were even higher in comparison with the differences found between DXA and ADP, and using the Siri equation (personal observations).

In the present study, BIA also underestimated %BF compared with DXA. BIA was created to calculate total body water by the resistance offered to an alternate current. Fat mass has lower hydration than fat-free mass (22) and BIA assumes that total body water is the 73.2% of fat-free mass; however, Wells et al. (10) demonstrated that the hydration of fat-free mass was higher than 75% during growth. These assumptions and hydration differences between participants could explain the differences between DXA and BIA in the present study. Moreover, the amount of water could be modified during the day depending on physical activity performed or water

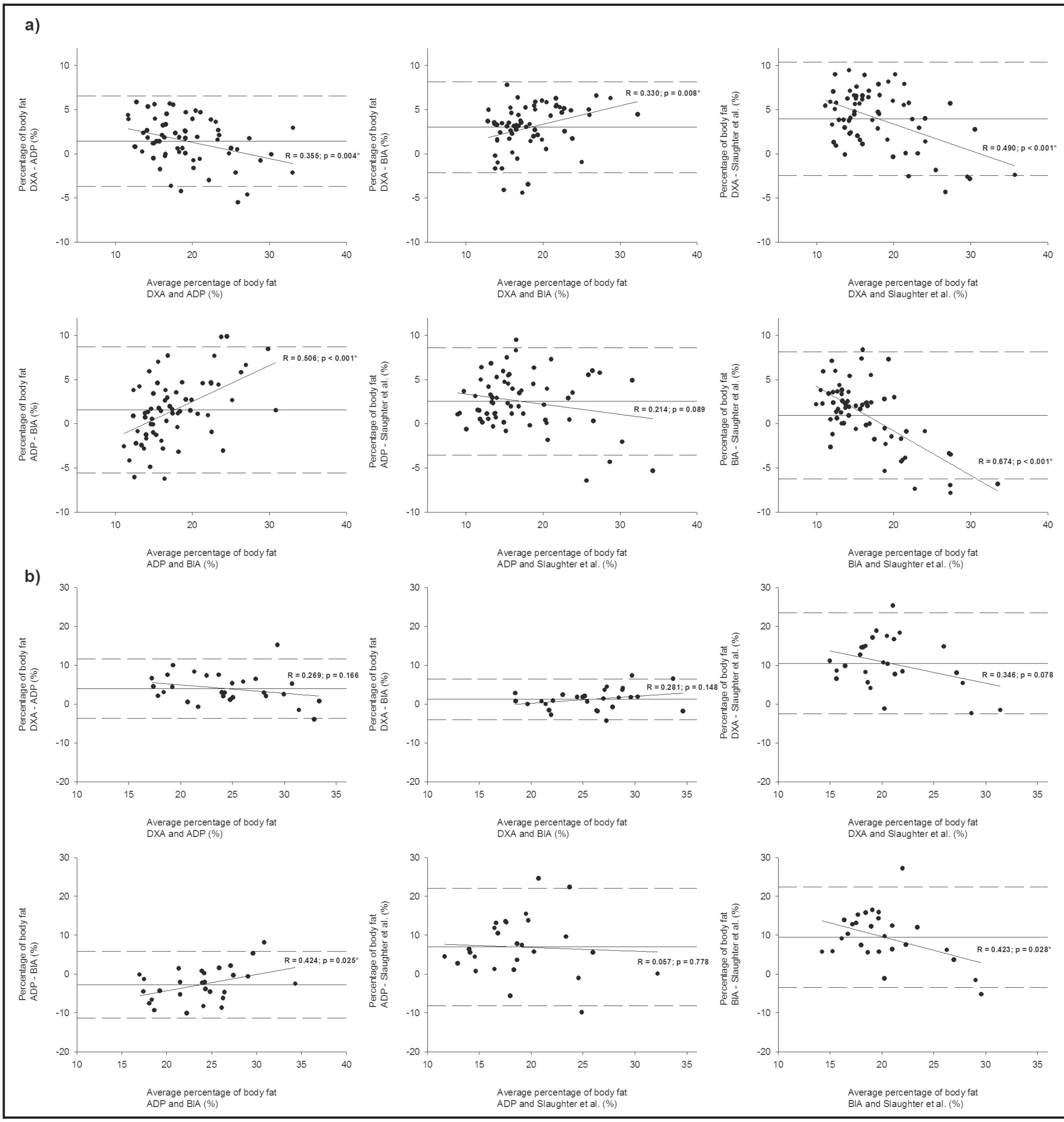

Figure 1.

Comparison of percentage of body fat between DXA, ADP, BIA and Slaughter et al. equation by Bland-Altman plots. Caption: comparison of predicted percentage of body fat between DXA, ADP, BIA and Slaughter et al. (17) equation a) in males; b) in females. Each point describes individual differences values between methods. Central line represents standard error and dash lines represent the 95% limits of agreement (standard error ± 1.96 x SD). The solid line in each plot represents the linear regression between the average of both field methods and differences between these methods (%BF: percentage of body fat; DXA: dual X-ray absorptiometry; ADP: air displacement plethysmography; BIA: bioelectrical impedance analysis. *$p < 0.05$).

drunk before the measurement; nevertheless, DXA and other measurement methods are not affected by these external variables.

The use of the Slaughter's (17) equation has been recommended for estimating %BF in adolescents because it has been developed with a 4C model (2). A study comparing different methods for measuring %BF in adolescents reported that DXA showed better agreement with the Slaughter et al. (17) equation than with ADP or BIA (15). In contrast, our results showed that %BF by the

Slaughter et al. (17) equation was not interchangeable with DXA and ADP neither in male nor female football players. The highest %BF difference was found between DXA and the Slaughter et al. (17) equation, and heteroscedasticity was found. This equation was created with a 4C model that uses underwater weighing to measure volume and estimate fat mass. Underwater weighing and DXA use different techniques and processes to measure fat mass and this could explain the differences found.

The main limitation of the present study is the use of DXA, ADP, BIA and anthropometry, instead of a 4C model as recommended in pediatric populations. However, the main objective of the present study was not to evaluate %BF in these athletes, but to compare the different methods to ascertain whether or not those are comparable. On the other hand, the main strengths of this study are sample size, which is bigger than any previous comparable study (84 moderately active adolescents [15] or 69 overweight and obese children [7]). Also, all measurements were made in the same session by the same technician, which means that intra-variability changes in the participants were avoided.

Overall, this study demonstrates that %BFs assessed by DXA, ADP, BIA and anthropometry in adolescents football players are not comparable. Compared with DXA, all methods underestimated %BF in a higher or smaller way. Future studies should evaluate agreement between these methods in comparison to %BF estimated by using a 4C model (it combines different methods such as DXA, ADP and deuterium dilution).

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