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?

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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.

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 %CG 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 %CG fue medido mediante cuatro métodos diferentes: DXA, ADP, BIA, y antropometría. ADP %CG 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 %CG al ser comparados (p < 0.05). Los límites de concordancia al 95% oscilaron entre 5.13 y 15.09% puntos. Sólo BIA mostró heterocedasticidad comparada 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 %CG en futbolistas adolescentes, estos resultados demuestran que estos métodos de valoración de la composición corporal no son intercambiables en la población de estudio.
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.

Table I. Subject characteristics (mean ± standard deviation)

| 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*,#| 6.14|
| 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 BIA. 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-method differences, 95% limits of agreement and heteroscedasticity are summarized in table III. ADP, BIA, and Slaughter et al. (17) equation the highest one in female football players. On the other hand, the 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).

DISCUSSION

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

### 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.
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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REFERENCES

1. Wang ZM, Heshka S, Pierson RN Jr, Heymsfield SB. Systematic organization of body-composition methodology: An overview with emphasis on component-based methods. Am J Clin Nutr 1995;61:457-65.
2. Silva AM, Fields DA, Sardinha LB. A PRISMA-driven systematic review of predictive equations for assessing fat and fat-free mass in healthy children and adolescents using multicomponent molecular models as the reference method. J Obes 2013;2013:148696.
3. El Hage R. Fat mass index and hip bone mineral density in a group of Lebanese adolescents and young adults. J Med Liban 2014;62:137-42.
4. Fields DA, Allison DB. Air-displacement plethysmography pediatric option in 2-6-year olds using the four-compartment model as a criterion method. Obesity 2012;20:1732-7.
5. Silva DR, Ribero AS, Paveo FH, Ronque ER, Avetar A, Silva AM, et al. Validity of the methods to assess body fat in children and adolescents using multi-compartment models as the reference method: A systematic review. Rev Assoc Med Bras 2013;59:475-86.
6. Tooms RJ, Ducher G, Shepherd JA, De Souza MJ. The impact of recent technological advances on the trueness and precision of DXA to assess body composition. Obesity 2012;20:30-9.
7. Radley D, Gately PJ, Cooke CB, Carroll S, Oldroyd B, Truscott JG. Estimates of percentage body fat in young adolescents: A comparison of dual-energy X-ray absorptiometry and air displacement plethysmography. Eur J Clin Nutr 2003;57:1402-10.
8. Schoeller DA. Human body composition. In: Heymsfield MD, Lohman TG, Wang Z, Going SB, eds. Human Body Composition. United States: Human Kinetics; 1996.
9. Lohman TG. Applicability of body composition techniques and constants for children and youth. Exerc Sport Sci Rev 1986;14:325-57.
10. Wells JC, Williams JE, Chomtsoo S, Darch T, Grijalva-Eternod C, Kennedy K, et al. Pediatric reference data for lean tissue properties: Density and hydration from age 5 to 20 y. Am J Clin Nutr 2010;91:610-8.
11. Yamada Y, Masuo Y, Nakamura E, Oda S. Inter-sport variability of muscle volume distribution identified by segmented bioelectrical impedance analysis in four ball sports. Open Access J Sports Med 2013;4:97-108.
12. Portal S, Rabinowitz J, Adler-Portal D, Burstein RP, Lahav Y, Meckel Y, et al. Body fat measurements in elite adolescent volleyball players: Correlation between skinfold thickness, bioelectrical impedance analysis, air-displacement plethysmography, and body mass index percentiles. J Pediatr Endocrinol Metab 2010;23:395-400.
13. Artero EG, Espina-Romero V, Ortega FB, Jiménez-Pavón D, Ruiz JR, Vicente-Rodríguez G, et al. Health-related fitness in adolescents: Underweight, and not only overweight, as an influencing factor. The AVENA study. Scand J Med Sci Sports 2010;20:418-27.
14. Nikolaidis PT. Physical fitness is inversely related with body mass index and body fat percentage in soccer players aged 16-18 years. Med Pregl 2012;65:470-5.
15. Vicente-Rodríguez G, Rey-López JP, Mesana MI, Poortvliet E, Ortega FB, Polito A, et al. Reliability and intermethod agreement for body fat assessment among two field and two laboratory methods in adolescents. Obesity 2012;20:221-8.
16. Lasser S, Bedogni G, Agosti F, De Col A, Monati D, Sartorio A. Comparison of dual-energy X-ray absorptiometry, air displacement plethysmography and bioelectrical impedance analysis for the assessment of body composition in severely obese Caucasian children and adolescents. Br J Nutr 2008;100:918-24.
17. Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, Van Loan MD, et al. Skinfold equations for estimation of body fatness in children and youth. Hum Biol 1988;60:709-23.
18. Siri WE. Body composition from fluid spaces and density: Analysis of methods. 1961. Nutrition 1993;9:480-91.
19. Marfell-Jones MJ, Olds T, Stewart AD, Carter L. International Standards for Anthropometric Assessment. Adelaide: International Society for the Advancement of Kinanthropometry; 2006.
20. Krouwer JS. Why bland-altman plots should use X, not (Y+X)/2 when X is a reference method. Stat Med 2008;27:778-80.
21. Lohman TG. Research progress in validation of laboratory methods of assessing body composition. Med Sci Sports Exer 1984;16:596-605.
22. Hewitt MJ, Going SB, Williams DP, Lohman TG. Hydration of the fat-free body mass in children and adults: Implications for body composition assessment. Am J Physiol 1993;265:E88-95.