Accurate Prediction Equation to Assess Body Fat in Male and Female Adolescent Football Players.

Abstract

The aims of this study were (a) to determine which of the most used anthropometric equations was the most accurate to estimate percentage of body fat (%BF), (b) to develop a new specific anthropometric equation, and (c) to validate this football-specific equation. A total of 126 (13.3±0.6 y) football players (86 males) participated in the present study. Participants were divided into two groups: 98 players were included in the assessment of existing equations and in the development of the new prediction equation; and 28 were used to validate it. %BF was measured with dual-energy X-ray absorptiometry (DXA) and also estimated with six different %BF anthropometric equations: Johnston, Slaughter, Carter, Faulkner, Deurenberg and Santi-Maria. Paired *t*-tests were used to analyze differences between methods. The Koenker test was used to examine the heteroscedasticity of the previous equations and the football-specific equation developed by a stepwise linear-regression. The existing anthropometric equations showed significant bias for %BF when compared to DXA ($p<0.001$; %BF differences ranged from -3.43 to 9.24%). On the other hand, the developed football-specific equation was %BF=11.115+0.775(triceps skinfold)+0.193(iliac-crest skinfold)–1.606(sex). The developed equation demonstrated neither %BF differences ($p=0.121$; %BF difference was 0.57%) nor heteroscedasticity ($p=0.159$) when compared to DXA, presenting a high cross-validation prediction power ($R^2=0.85$). Published anthropometric equations were not accurate to estimate %BF in adolescent football players. Due to the fact that the developed football-specific equation showed neither differences nor heteroscedasticity when compared to DXA, this equation is recommended to assess %BF in adolescent football players.

Keywords: Soccer; Body composition; Anthropometry.

Introduction

The assessment of percentage of body fat (%BF) is often performed in sport clubs to monitor body composition changes in the athletes during the season due to its relationship with health and performance (Avlonitou et al., 1997).

Anthropometry, bioelectrical impedance analysis, dual x-ray absorptiometry (DXA), air displacement plethysmography (ADP) and hydrostatic weighing are some of the available methods to assess %BF (Silva et al., 2013). ADP, which uses the two- component model (2C, fat mass (FM) and fat free mass (FFM)) and DXA, which uses the three-component model (3C, fat, mineral and lean soft tissue), have been widely used to calculate %BF (El Hage, 2014; Fields & Allison, 2012). However, these methods are not recommended in pediatric population (A. M. Silva et al., 2013). The four-component model (4C), which divides the body into fat, water, mineral and protein, is considered the most adequate model for assessing body composition in children and adolescents (A. M. Silva et al., 2013). Nevertheless, the use of the 4C model is impractical for most researchers as a consequence of its high costs and time involvement.

DXA (3C model) has been used in several studies to evaluate %BF or as a criterion method to develop anthropometric equations in children and adolescents (A. M. Silva et al., 2013; D. R. Silva et al., 2013). Other studies have used ADP to assess %BF in children, adolescents, and young adults (Gonzalez-Aguero et al., 2011; Moon et al., 2007). Nonetheless, it has been shown that anthropometry presents a better agreement with DXA than ADP (Vicente-Rodriguez et al., 2012). Similarly, previous studies performed in our laboratory also reported higher correlation coefficients between the %BF calculated by DXA and anthropometry than those obtained between the %BF by ADP and anthropometry in adolescent football players (personal observations). However, DXA is not an available method for coaches due to the high economic cost. Thus, the use of a simple, practical and accessible method such as anthropometry to estimate %BF or FFM could be a useful tool for non-professional football teams (Valente-dos-Santos et al., 2012).

Anthropometry has been used to evaluate body composition changes in different athletes from different sports throughout seasons (Falk et al., 2010; Sarria et al., 1998). However, specific anthropometric equations should be used for each population in order to reduce the error of estimation of this method. Many studies have evaluated anthropometric equations for children (Eisenmann et al., 2004) and adolescents (Rodriguez et al., 2005) to find the one that best fits with their morphology. It has been known that only Reilly et al. (2009) and Santi-Maria et al. (2015) created specific equations for adult and adolescent male football players respectively. However, cross-validations using a comparable sample have not been performed yet. In addition, the recent and growing increment on female participation requires especial attention and specific equation. Therefore, due to the importance of monitoring %BF in sports, the aims of this study were (a) to determine the accuracy of the most used anthropometric equation in male and female adolescent football players, (b) to develop a specific equation for male and female football players, and (c) to cross-validate this new equation with another sample of the same population.

Methods

Participants

Ten clubs of Aragon (Spain) participated in the present study. A total of 149 Caucasian football players from these clubs agreed to participate; 23 players were not included because they did not meet the inclusion criteria or could not do the assessment. Finally, 126 adolescent football players participated in this study. They were randomly divided into two groups: 98 (65 males, 13.4 ± 0.6 years old; 33 females, 13.4 ± 0.6 years old, Table 1) participated in the assessment of previous anthropometric equations and the development of a new specific equation, and 28 (21 males, 13.1 ± 0.5 years old; 7 females, 13.3 ± 0.4 years old, Table 1) included in the validation of the new equation.

All participants, their parents and their corresponding clubs were informed about the risk and benefits associated to this study. We obtained written informed consent from parents or legal guardians and written assent from all participants. This study was performed according to the declaration of Helsinki 1961 (revision of Fortaleza 2013) and the protocol was approved by the Ethics Committee of Clinical Research from the Government of Aragon (CEICA, Spain) [C.I. PI13/0091]. The present study is part of the FUTBOMAS project, which is registered in the public database Clinicaltrials.gov [NCT02399553].

Inclusion Criteria

Ages between 11 and 14 years old, at least two football trainings per week during the last year, and free of any medication affecting body composition were the inclusion criteria established for the present study.

Body Fat Measurement with DXA

Whole body %BF was obtained via DXA scan using the QDR-Explorer (pediatric version of the software QDR-Explorer, Hologic Corp. Software version 12.4, Bedford, Massachusetts, USA). Calibration tests with a spine phantom were daily performed before taking any measurements. Participants were measured in supine position and all scans were performed and analyzed by the same technician who had been fully trained in the operation of the scanner, the positioning of participants and the analysis of results according to the manufacturer´s guidelines.

Anthropometric Measurements

Height (stadiometer to the nearest 0.1 cm, SECA 225, SECA, Hamburg, Germany) and weight (scale to the nearest 0.1 kg, SECA, Hamburg, Germany) were measured without shoes and the minimum clothes. Body mass index (BMI) was calculated as weight (in kilograms) divided by squared height (in meters).

Biceps, triceps, subscapular, iliac-crest, supraspinale, abdominal, front thigh and medial calf skinfolds were registered following the recommendations of the International Society of the Advancement of Kinanthropometry (ISAK) (Marfell-Jones et al., 2006) by a level 2 ISAK anthropometrist. Pubertal maturity was self-determined according to the stages proposed by Tanner and Whitehouse (1976).

Total body density was calculated via Johnston et al. (1988). Then, the Siri (1961) equation was used to estimate %BF. In addition, %BF was directly estimated using the equations proposed by Slaughter et al. (1988), Carter (1982), Faulkner (1968), Deurenberg et al. (1991) and Santi-Maria et al. (2015) (Table 2).

Experimental Design

The present study was divided into three experiments in order to achieve the three main aims.

Assessment of previous anthropometric equations (98 football players): %BF calculated by published anthropometric equations were compared to %BF via DXA to determine its accuracy in adolescent football players.

Development of a new anthropometric equation (98 football players): A specific anthropometric equation was created for male and female football players.

Validation study (28 football players): %BF calculated by the new anthropometric equation was compared to DXA %BF in order to determine its accuracy.

Statistical Analysis

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 analysis. Data are presented as means and standard deviation (SD). All variables showed normal distribution by the Kolmogorov-

Smirnov test. Tanner status differences between genders were assessed using the Chi square test.

Paired *t*-tests were performed to analyze differences in %BF between equations and DXA. The potential inflation of multiple comparisons was controlled by Bonferroni correction, and consequently, the *p* value of 0.05 was divided by 6 (number of comparisons that were conducted) when the accuracy of previous anthropometric equations was evaluated. The 95% limits of agreement (inter-methods difference ± 1.96 SD) were also calculated for each equation. In addition, heteroscedasticity was examined by Koenker test (1981) to determine whether the absolute inter-methods difference was associated with the magnitude of the measurement. In heteroscedasticity analyses, inter-method differences were compared with the mean, instead of using a reference method, as proposed by Krouwer (2008).

A new football-specific anthropometric equation was developed using step-wise linear regression models (Lohman et al., 1988). Sex, height, weight and skinfold thickness were the independent variables and %BF from DXA the dependent one. The predictive power of the new equation was calculated with the Stein equation (Field, 2005). Moreover, paired *t*-tests were used to determine the accuracy of the new equation in comparison with DXA.

Effect size statistics using Cohen´s d (G*Power version 3.1.9.2 for Mac OS X) were calculated for paired t-tests. Taking into account the cut-off established by Cohen (1992), 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

Descriptive results are shown in Table 1. Age, height, weight and Tanner stages were not significantly different between genders (all $p>0.05$). BMI was higher in female football players than in males ($p<0.05$). The anthropometric equations used in this study are summarized in Table 2. Anthropometrist's TEM for each skinfold thickness is shown in Table 3.

Accuracy of Previous Anthropometric Equations

Predicted %BF with different anthropometric equations, mean differences between methods, 95% limits of agreement and heteroscedasticity of each equation against DXA are represented in Table 4. All of the equations showed significant differences with DXA (mean differences ranged from -3.43 to 9.24% points; all $p<0.008$, Cohen´s d ranged from 0.71 to 3.15), being the Johnston et al. (1988) equation the one that demonstrated the lowest inter-methods difference (2.31) and 95% limits of agreement (5.25). Moreover, Johnston et al. (1988) and Deurenberg et al. (1991) equations did not show heteroscedasticity ($p>0.05$).

Development of a New Anthropometric Equation

The combination of sex (male = 1; female = 0), triceps and iliac-crest skinfold thickness explained 85.6% of variability in %BF. Moreover, the values of R, adjusted R^2, standard error of the estimation and R^2 calculated by the equation of Stein were 0.925, 0.851, 2.22 and 0.85 respectively (Table 5). The new specific equation was:

$$\%BF = 11.115 + 0.775\ (\text{triceps skinfold}) + 0.193\ (\text{iliac-crest skinfold}) – 1.606\ (\text{sex})$$

Validation of the New Football-specific Equation

The new equation developed in the present study showed neither %BF differences (Table 4; $p>0.05$, Cohen´s d was 0.30) nor heteroscedasticity in comparison to DXA ($p>0.05$).

Discussion

The main findings of the present study were previously published anthropometric equations did not accurately estimate %BF, and a new valid and accurate football-specific equation for assessing %BF presenting no differences and no heteroscedasticity when compared to DXA and being therefore, recommended for assessing %BF in male and female adolescents football players.

According to the review performed by Silva et al. (2013), the Slaughter et al. (1988) equation was the recommended equation to estimate %BF in children and adolescents; however, in this study, the Slaughter et al. (1988) equation presented significant %BF differences when compared to DXA %BF. These differences between %BF obtained by anthropometric equations and the reference method suggest that participants in different sports, even during adolescence, may present different morphologic characteristics, which are probably caused by the practice itself. Therefore, the development and use of a specific equation for each population is recommended.

Only 2 skinfolds are needed for making the calculation in the new developed equation (triceps and iliac crest), compared with 4 in Johnston's (1988) and Santi-Maria's (2015) equations. Furthermore, Reilly et al. (2009) developed and validated an equation for adult football players using also 4 skinfolds. Thus, the specific equation performed herein could be applied spending less time in performing the anthropometric measurements. Moreover, the new equation for male and females football players accounted for 86% variance in DXA %BF, being higher than the amount explained by Johnston et al. (1988), Santi-Maria et al. (2015) and Reilly et al. (2009) equations (49.2, 75.0 and 78.4% of variability compared to DXA, respectively).

One important issue is that Faulkner et al. (Faulkner, 1968), Johnston et al.(Johnston et al., 1988) and Slaughter et al. (Slaughter et al., 1988) equations and the developed equation of this study only included upper-body skinfold sites. The equation designed by Santi-Maria et al. (2015) also included lower-body skinfolds in their equation; even though, it does not improve the explained variability. Other differences between the Santi-Maria et al. (2015) equation and ours could be due to differences in age and ethnicity of the included participants in the studies. On the other hand, Reilly et al. (2009) developed and validated an equation which also employed lower-body sites, but they included adult participants; thus, the differences between both equations might be explained by the age and the type of training of the participants. The type and the amount of hours per week of training are different between amateur and professional football players; therefore, the football-specific adaptations in lower limbs and their influence on fat deposition through the body reported by Reilly et al. (2009) could be more evident in professional football players than in those football players in formation.

This study is not exempt of limitations: the use of DXA (3C model) instead of a 4C one (hydrostatic weighing and air displacement plethysmography are the reference methods for measuring fat) was the main (A. M. Silva et al., 2013). However, several studies have used DXA as a reference method to develop anthropometric equations (A. M. Silva et al., 2013; D. R. Silva et al., 2013).

The main strength of this study was the sample size (n = 126), being much bigger in comparison to that used in published studies (45 adult football players (Reilly et al., 2009) or 26 moderately active adolescents (De Lorenzo et al., 1998)). Moreover, this equation took into account the sex of the participants. Reilly et al. (2009) and Santi-Maria et al. (2015) developed anthropometric equations for male football players; however, the present study is the first one that have created and validated a specific equation for both male and female football players.

In conclusion, the football-specific anthropometric equation for estimating %BF in male and female adolescents (ranged from 12 to 14.5 years old) developed in this study demonstrated to be valid and accurate. Moreover, this equation reported a high average of cross-validation predictive power and a low standard error of estimation. It is therefore recommended to estimate %BF in young football players when no other method than anthropometry is available.

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Practical application statement

The present study has developed an accurate prediction equation to assess %BF in male and female adolescent football players. Although it is true that football coaches could estimate %BF with previous anthropometric equations, the present study can guide coaches towards which anthropometric equation might be used in young male and female football players.

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Table 1 Participants Characteristics.

	Experiment 1			Experiment 2		
	All (n=98)	Males (n=65)	Females (n=33)	All (n=28)	Males (n=21)	Females (n=7)
Age (y)	13.4 ± 0.6	13.4 ± 0.6	13.4 ± 0.6	13.2 ± 0.5	13.1 ± 0.5	13.3 ± 0.4
Weight (kg)	49.4 ± 10.3	48.1 ± 10.8	52.0 ± 8.8	48.6 ± 7.39	47.4 ± 6.0	51.9 ± 10.5
Height (cm)	159.2 ± 8.3	159.4 ± 9.1	158.8 ± 6.3	157.4 ± 6.8	157.2 ± 6.2	158.0 ± 8.8
BMI (kg/m^2)	19.3 ± 2.8	18.7 ± 2.7*	20.6 ± 2.7	19.5 ± 1.8	19.1 ± 1.5	20.6 ± 2.3
Tanner (I/II/III/IV/V)	1/12/37/38/10	0/8/28/23/6	1/4/9/15/4	0/6/13/9/0	0/5/9/7/0	0/1/4/2/0

Note. BMI = body mass index; Experiment 1= Assessment of existing equations and development of a new equation; Experiment 2 = Validation of the new equation.

Values are mean ± standard deviation

*: sex differences; $p<0.05$

Table 2 Anthropometric Equations Used to Estimate Body Density and Percentage of Body Fat.

Authors	R^2	Population	Equations
Johnston et al. (1988)	0.45	8-14	F: D = 1.144 – 0.06 ($\log_{10}$ ($^{A}\Sigma 4_{SKF}$))
	0.49		M: D = 1.166 – 0.07 ($\log_{10}$ ($^{A}\Sigma 4_{SKF}$))
Slaughter et al. (1988)	NA	Pubertal F:	All F: %BF = 1.33 (tric + subsc) – 0.013 (tric + subsc)^2 – 2.5
		11.4 ± 1.9	Pubertal M: %BF = 1.21 (tric + subsc) – 0.008 (tric + subsc)^2 – 3.4
		Pubertal M:	All F when (tric + subsc) > 35mm: %BF = 0.546 (tric + subsc) + 9.7
		12.2 ± 1.4	All M when (tric + susc) > 35mm: %BF = 0.783 (tric + subsc) + 1.6
Carter (1982)	NA	General	F: %BF = 0.1548 ($\Sigma 6_{SKF}$) + 3.58
			M: %BF = 0.1051 ($\Sigma 6_{SKF}$) + 2.58
Faulkner (1968)	NA	8 – 16	F: %BF = 0.213 ($^{B}\Sigma 4_{SKF}$) + 7.9
			M: %BF = 0.153 ($^{B}\Sigma 4_{SKF}$) + 5.783
Deurenberg et al. (1991)	0.38	0 – 15	All (0 – 15): %BF = 1.51 (BMI) – 0.7 (age) – 3.6 (sex) + 1.4
Santi-Maria et al. (2015)	0.94	11 – 18.9	GK: %BF = 20.38 – 0.695 (age) + 0.298 (iliac) + 0.344 (ab) + 0.595 (calf)
	0.75		SCP: %BF = 22.46 – 0.866 (age) + 0.642 (iliac) – 0.055 (ab) + 0.464 (thigh)
Siri (1961)	NA	Adults	All: %BF = 100 (4.95/BD - 4.5)

Note. M = male; F = female; NA = Not available; BD = total body density; %BF = percentage of body fat; $^{A}\Sigma 4_{SKF}$ = sum of biceps, triceps, subscapular and iliac-crest skinfolds); $^{B}\Sigma 4_{SKF}$ = sum of triceps, subscapular, supraspinale and abdominal; $\Sigma 6_{SKF}$ = sum of triceps, subscapular, supraspinale, abdominal, anterior thigh and medial calf; tric = triceps skinfold; subsc = subscapular skinfold; iliac = iliac-crest skinfold; ab = abdominal skinfold; thigh = front thigh skinfold; calf = medial calf skinfold; BMI = body mass index; GK = goalkeeper; SCP = football camp players.

The R^2 reported by each study. Sex: male = 1; female = 0.

Table 3 Technical error of measurement (mm and %) for skinfolds thickness.

	TEM	%
Triceps	0.29	3.32
Subscapular	0.21	3.10
Biceps	0.19	4.61
Iliac-crest	0.41	4.97
Supraspinale	0.27	4.15
Abdominal	0.25	2.71
Front thigh	0.28	2.26
Medial calf	0.28	3.05

TEM = technical error of measurement

Table 4 Body Fat Percentage (%BF) Differences between Methods (DXA and Anthropometry), Limits of Agreement 95% to Estimate %BF from Equations and DXA, Pearson Correlation Coefficient (r) and Heteroscedasticity.

Anthropometric equation	%BF	Mean difference between methods	95% limits of agreement	Confidence interval	p^1	Cohen´s d	r	Heteroscedasticity (p^2)
Johnston et al. (1988)	19.63 ± 6.27	2.31	5.25	[-2.94 7.56]	<0.001	0.86	0.904	0.724
Slaughter et al. (1988)	18.60 ± 7.22	3.33	6.18	[-2.85 9.51]	<0.001	1.06	0.906	<0.001
Carter (1982)	12.69 ± 5.91	9.24	5.75	[3.49 14.99]	<0.001	3.15	0.874	<0.001
Faulkner (1968)	15.13 ± 5.88	6.80	5.96	[0.84 12.76]	<0.001	2.36	0.864	<0.001
Deurenberg et al. (1991)	18.86 ± 4.97	3.07	8.42	[-5.35 11.48]	<0.001	0.71	0.689	0.925
Santi-Maria et al. (2015)[a]	24.25 ± 6.59	-3.43	7.66	[-11.10 4.23]	<0.001	-0.88	0.806	0.023
DXA	21.93 ± 5.77	-	-	-	-	-	-	-
New specific-football equation	22.21 ± 4.50	0.57	3.72	[-3.14 4.29]	0.121	0.30	0.932	0.159
DXA	22.79 ± 5.17	-	-	-	-	-	-	-

Note. %BF = body-fat percentage; DXA = dual energy X-ray Absorptiometry; 95% limits of agreement were calculated using the following equation = (1.96*SD of the inter-methods differences); Confidence interval was calculated as follow = (inter-methods difference ± 95% limits of agreement). [a]Santi-Maria et al. (2015) equation is only performed with males (n = 65). %BF for males (n = 65) was 20.82 ± 5.17. Values are mean ± SD. Pearson correlation coefficient between %BF estimated by each equation and calculated by DXA.

$p^1 = p$ value of the differences between the gold standard and the anthropometric equation. If the *p* value is below *.008*, statistically significant are presented between %BF measured with DXA and estimated with the previous anthropometric equations; and if it is below *.05*, between %BF measured with DXA and estimated with the new specific-football equation. $p^2 = p$ for heteroscedasticity values ($p<0.05$).

Table 5 Lineal regression analyses and the coefficient of determination by Stein of each proposed anthropometric equation in adolescent football players.

Model	R	R square	R square adjusted	Standard error of estimation	R^2 Stein
1	0.907	0.824	0.822	2.44	0.82
2	0.918	0.843	0.839	2.31	0.83
3	0.925	0.856	0.851	2.22	0.85

Dependent variable: whole body percentage of body fat; independent variable: sex, biceps, triceps, subscapular, iliac-crest, supraspinale, front thigh and medial calf skinfolds.

Model 1: (constant), triceps skinfold thickness; model 2: (constant), triceps, iliac-crest skinfold thickness; model 3: (constant), triceps, iliac-crest skinfold thickness, sex.