Evaluation of the accuracy of different body composition prediction formulas compared to DXA in Colombian Women's Professional Soccer

Evaluación de la exactitud de distintas fórmulas de predicción de la composición corporal en comparación con DEXA en el Fútbol Profesional Femenino Colombiano

***Santiago Gómez Velásquez*[1]**
***Bryan Fidel Sarmiento Sánchez*[1]**
***Vanesa Castañeda Ramírez*[1]**
***Carol Susana Zapata Arango*[1]**
***Maximiliano Kammerer López*[1]**

[1] Grupo de Investigación NUTRAL, Universidad CES, Colombia

Correspondence:
Bryan Fidel Sarmiento Sánchez
bryanfsarmientos@gmail.com

Short title:
Accuracy of Body Composition Formulas vs. DEXA in Women's Soccer

How to cite this article:
Gómez Velázquez, S., Sarmiento Sánchez, B., Castañeda Ramírez, V., Zapata Arango, S. y Kammerer López, M. (2024). Evaluation of the accuracy of different body composition prediction formulas compared to DXA in Colombian Women's Professional Soccer. *Cultura, Ciencia y Deporte, 19*(59), 103-121. https://doi.org/10.12800/ccd.v19i59.2007

Received: 12 December 2022 / **Accepted**: 16 January 2024

Abstract

The aim of the present study was to compare different body composition prediction formulas with the reference method, DEXA, in the context of Colombian professional women's soccer during a competitive season. The purpose of this was to determine which of these formulas most closely replicates the gold standard and could offer an alternative for evaluating body fat percentage (%) and lean mass in the absence of more precise methods. Formulas were used to calculate body fat percentage using two components, specifically, those conceived by Yuhasz (15.17 [13.98 – 16.72]%), Durnin and Rahaman (25.57 [24.5.-.28.07]%), Jackson and Pollock (16.71 [14.33 – 19.33]%), and Durnin and Womersley (24.90 [24.02 – 27.01]%). For five components, lipid mass was calculated from body weight (19.80 [17.80 – 22.30]%), whilst DEXA provided body fat percentage data (23.94 ± 3.51%). A cross-sectional analytical study with non-probabilistic convenience sampling was conducted of 24 female soccer players from two first-division teams. A total of 26 anthropometric variables were measured. Descriptive analysis was performed using *SPSS v.21*, in addition to correlation (*SP*), Lin's concordance, and Bland and Altman analyses. The lowest inter-method difference relative to DEXA was obtained via the Durnin and Womersley formula, with a value of – 0.70, indicating that fat % estimates would, on average, overestimate DEXA by a value of 0.7. Durnin and Womersley formula produced the closest body fat % values to those produced by the reference method, DEXA.

Keywords: Anthropometry, performance, sport, women, muscle.

Resumen

El objetivo fue comparar diferentes fórmulas de predicción de composición corporal con el método de referencia DEXA en el contexto del Fútbol Profesional Femenino Colombiano durante la temporada competitiva. Esto se hizo para determinar cuáles de estas fórmulas se acercan más al estándar de referencia y pueden ser utilizadas para evaluar el porcentaje (%) de grasa y la masa magra en ausencia de métodos más precisos. Para hallar % de grasa en dos componentes se usaron Yuhasz (15.17 (13.98 - 16.72)%), Durnin y Rahaman (25.57 (24.95 – 28.07)%), Jackson y Pollock (16.71 (14.33 – 19.33)%) y Durnin y Womersley (24.90 (24.02 – 27.01)%), para cinco componentes se calculó masa lipídica del peso (19.80 (17.80 – 22.30)%) y en DEXA los datos del % de grasa (23.94 ± 3.51%). Se llevó a cabo un estudio analítico transversal con muestreo no probabilístico por conveniencia en 24 futbolistas de dos equipos de primera división usando 26 variables antropométricas, se realizó un análisis descriptivo en el *SPSS v.21*; y un análisis de correlaciones (*SP*), índices de concordancia de Lin y método de Bland y Altman. La menor diferencia intermétodo con DEXA la obtuvo Durnin y Womersley con valor de – 0.70, así que % de grasa hallados sobreestimarían DEXA en promedio 0.7 puntos. Los % de grasa calculados mediante la fórmula de Durnin y Womersley, fueron los más parecidos a los valores de % de grasa arrojados por el método de referencia DEXA.

Palabras clave: Antropometría, rendimiento, deporte, mujer, músculo.

Introduction

Body composition refers to the quantification of body components. It provides evidence of the relationship between respective components and the changes they are subjected to by external factors (González, 2013). In the 20th century, body composition assessment began through the dissection of corpses. This became known as the direct method. Over time, other methods evolved such as hydrostatic weighing, and the two and five component methods, amongst others (Costa et al., 2015). This means that values vary widely depending on the assessment method used (Merrigan et al., 2018). Nevertheless, dual-energy X-ray absorptiometry (DEXA) has been described as the criterion method (Zulet et al., 2019), given that other methods, such as bioelectrical impedance and anthropometry, exhibit large error terms. This has led to substantial variations in outcomes even within the same subjects (Cumberledge et al., 2018).

It has been discussed that muscle mass can vary among athletes and is one of the most strongly related components with sports performance. For this reason, it has become of great importance in professional football, which is one of the most popular sports in the world according to the International Federation of Association Football (FIFA, 2018). In addition, body composition varies according to playing position (Holway, 2008; López et al., 2021; Rodríguez et al., 2019). In order to address this, different methods have been used to assess body composition in a number of sports such as football (Pons et al., 2015). A better understanding of these variables provides useful information for the specification of training loads (Almăjan et al., 2015), diet and nutritional planning, and injury prevention, amongst other important aspects (García et al., 2014; Ceballos et al., 2021).

Research in professional football has been mainly inclined towards the male sex; hence, knowledge and information about the female population is limited. Thus, the main aim was to evaluate different methods used for the estimation of body composition, in comparison with DEXA, in Colombian women's professional football during a competitive period of the season. The reason for this was to assess the accuracy of alternative field methods for instances when the criterion method may not be available.

Methodology

Study Design and Sample

A cross-sectional analytical study was carried out using prospectively gathered data. Non-probabilistic convenience sampling was used to select the study sample. The final study sample comprised 24 Colombian professional female soccer players signed to one of two Colombian women's professional soccer teams competing in the first division. Data was collected between September 2021 and March 2022, which corresponded to a competitive period of the season. During the study period, participating footballers presented optimal levels of hydration, given that during training and competition they consumed isotonic sports drinks alongside water. It is important to mention that the level of hydration of each study participant was based on personal needs.

All soccer players participating in the study were over 18 years old and, prior to the beginning of the study, signed an informed consent form which included details about the assessments to be carried out. The study did not include players with injuries or pacemakers, or those who were pregnant or breastfeeding. Additionally, the authors had no financial or personal relationships with participants that could lead to any conflict of interest.

The present research adhered to international ethical principles laid out by the Declaration of Helsinki made by the World Medical Association (1975), and national guidelines and Resolution 8430 of October 1993 established by the Ministry of Health and Social Protection of Colombia (1993), which establishes the scientific, technical and administrative standards for health research. The study was classified as minimal risk and approved by the Ethics Committee of CES University, under minutes No. 0031, dated February 9th, 2021, with the code Act0031Proy117TG.

Data Collection: Techniques Used and Instruments

All data were collected during a single session with a time requirement of one hour per player. Demographic and anthropometric information were gathered and evaluated via the two- and five-component methods, as well as via DEXA.

The Lunar Prodigy from General Electric Healthcare (United States) was used for dual-energy X-ray absorptiometry (DEXA) assessment. For two and five-component measurements, a SECA brand scale and stadiometer were used (Hamburg, Germany/Cali, Colombia). Skinfold thickness was measured using a Harpenden Skinfold caliper (Holtain Ltd., Wales, United Kingdom). Diometers, segmometers and anthropometers were sourced from CESCORF (Porto Alegre, Brazil), and a Lufkin measuring tape (LUFKIN INDUSTRIES, Texas, United States) was used for circumferences. All equipment was calibrated and accompanied by their respective certificates.

Anthropometric measurements were taken in accordance with the Protocol of the International Society for the Advancement of Kinanthropometry (ISAK), and all anthropometrists responsible for taking measurements were ISAK I and II certified (Marfell & Steward, 2006).

All data were collected at the Center for Advanced Studies, CESNUTRAL, within CES University between September 2021 and March 2022.

Data Analysis

A database was elaborated to house data collected from which body mass index (BMI), percentages (%), and adiposity, muscle mass, bone mass, skin mass, and residual tissue (all in kilograms [kg]) were calculated via the five-component anthropometric model proposed by Kerr (1988). Fat mass and fat-free mass were also analyzed, according to the two-compartment model, using formula conceived by Yuhasz and modified by Carter (1982), and formula conceived by Durnin and Womersley (1974), Jackson and Pollock (1978), Faulkner (1968), Reilly et al. (2009), and Parizkova and Buskova (1971).

In addition, results obtained by DEXA for fat mass, lean mass and bone mineral content were analyzed. In order to compare adipose mass estimated made via the five-component method and fat mass obtained via DEXA, the lipid fraction of the adiposity % was calculated using the equation proposed by Martin et al. (1994): Lipid fraction (%) = 0.327 + (0.0124 x % adiposity). Subsequently, this value was multiplied by overall adipose mass in kilograms.

Data analysis was conducted using statistical software including *SPSS version 21.0, Excel* and *R*. For qualitative variables, univariate analysis was performed of absolute and relative frequencies pertaining to the variables of gender, playing position, body mass index and Cormic index. Quantitative variables, such as age, height weight and body composition variables calculated according to the two- and five-component methods and DEXA, were analyzed using measures of central tendency and dispersion (mean, median, standard deviation, interquartile range) in order to describe the general and anthropometric characteristics of participating athletes.

Subsequently, bivariate analysis was conducted to examine the relationship of variables such as playing position with anthropometric characteristics of participating athletes. The aim of this was to compare the outcomes produced by the different body composition estimation methods under analysis. With regards to DEXA, correlational analysis was performed using the Pearson or Spearman test, according to data distribution of the variables. Concordance analysis was also performed to calculate intraclass correlation coefficients and the Bland & Altman graphical method was employed.

Results

A total of 24 Colombian professional female football players were evaluated, of which two were goalkeepers, three were defenders, three were forwards, four were wingers and twelve were midfielders. Average age was 24 ± 3.7 years, with a weight of 57 ± 5.2 kg, height of 161 ± 5.2 cm and BMI of 22 ± 1.8 kg/m².

Outcomes produced using the five-component model are presented in Table 1. Based on this methd, it was observed that goalkeepers exhibited the highest measurements pertaining to adiposity (18.73 ± 2.04 kg), followed by forwards (17.95 ± 2.52 kg) and defenders (16.44 ± 2.96 kg). In contrast, adiposity was lowest in midfielders and wingers (15.85 ± 2.49 kg and 14.92 ± 2.58 kg, respectively). With regards to muscle mass, highest values emerged in forwards, followed by goalkeepers (28.94 ± 1.82 kg and 26.14 ± 1.03 kg, respectively). Lowest muscle mass values were recorded in defenders and wingers (25.38 ± 1.83 kg and 22.48 ± 1.68 kg, respectively). Bone mass was highly similar in all athletes, regardless of playing position. This being said, highest values pertained to forwards (6.23 ± 0.55 kg), whilst lowest values were found in wingers (5.26 ± 0.53 kg).

Table 1. Body composition data calculated using the five-component method according to playing position

Variable		Goalkeeper	Centerback	Forward	Fullback	Midfielder
Kg Mass	Adipose Mass (*Kg*)	18.73 ± 2.04	16.44 ± 2.96	17.95 ± 2.52	14.92 ± 2.58	15.85 ± 2.49
	Muscle Mass (*Kg*)	26.14 ± 1.03	25.38 ± 1.83	28.94 ± 1.82	22.48 ± 1.68	25.60 ± 2.86
	Bone Mass (*Kg*)	6.02 ± 0.82	5.94 ± 1.286	6.23 ± 0.55	5.26 ± 0.53	6.17 ± 0.61
	Skin Mass (*Kg*)	3.40 ± 0.17	3.22 ± 0.25	3.55 ± 0.24	3.17 ± 0.12	3.28 ± 0.20
	Residual Mass (*Kg*)	5.54 ± 0.36	5.73 ± 0.51	6.28 ± 0.53	4.60 ± 0.50	5.42 ± 0.77
% Mass	Adipose Mass (%)	31.26 ± 1.29	28.85 ± 2.60	28.48 ± 3.65	29.49 ± 3.94	28.15 ± 3.80
	Muscle Mass (%)	43.73 ± 1.26	44.94 ± 2.95	45.99 ± 3.02	44.62 ± 2.83	45.40 ± 2.97
	Bone Mass (%)	10.04 ± 0.68	10.39 ± 1.12	9.89 ± 0.69	10.44 ± 0.98	10.99 ± 1.12
	Skin Mass (%)	5.71 ± 0.68	5.70 ± 0.43	5.64 ± 0.38	6.29 ± 0.39	5.83 ± 0.34
	Residual Mass (%)	9.26 ± 0.03	10.13 ± 0.73	9.99 ± 1.06	9.16 ± 1.18	9.63 ± 1.24

Note: Reported statistics correspond to the Mean ± *DS*.

DEXA measurements revealed average body fat % to be 23.90 ± 3.51. In the same way, data on lean mass, bone mineral content and fat mass, expressed as kg or %, where appropriate, were also obtained. These outcomes can be observed in detail in Table 2.

Table 2. Average and standard deviation (±) of body composition via DEXA

	Variable	$\dot{X}$	*SD*	*ME*	*IR*
Kg Mass	Fat Mass (*Kg*)	13.60	2.65	13.40	(12.00 - 15.50)
	Lean Mass* (*Kg*)	40.70	3.88	39.90	(38.40 - 44.10)
	BMC** (*Kg*)	2.46	0.21	2.41	(2.29 - 2.61)
% Mass	Fat Mass (%)	23.90	3.51	24.10	(22.10 - 26.00)
	Lean Mass* (%)	71.70	3.39	71.90	(69.70 - 73.60)
	BMC** (%)	4.34	0.32	4.29	(4.14 - 4.47)

Note: *Muscle + residual; ***BMC*: Bone Mineral Content; $\dot{X}$: Mean; *SD*: Standard deviation; *ME*: Median; *IR*: Interquartile range

Next, outcomes produced following the calculation of fat % through application of formulas proposed by Yuhasz, Durnin and Rahaman, Jackson and Pollock, and Durnin and Womersley for two components are compared with lipid mass outcomes produced through five-component calculations. Following this analysis it was evident that fat mass outcomes produced using the Yuhasz formula, with a median of 15.17% and an interquartile range (*IQR*) of 13.98% - 16.72%, are always indicative of a lower mass than that suggested by the other formulas. The highest fat mass % calculation was produced using the Durnin and Rahaman formula, with a median of 25.57% and an IQR of 24.95% - 28.07% (Table 3).

Table 3. Fat percentage data measured with various body composition prediction formulas for the two-component method according to playing position

Position	Yuhasz (%)	Durnin & Rahaman (%)	Jackson & Pollock (%)	Durnin & Womersley (%)	Lipid Mass of Weight (%) five-component
Goalkeeper (n=2)	17.37 ± 4.05 17.37 (15.94 - 18.80)	27.51 ± 4.58 27.51 (25.89 - 29.12)	19.24 ± 2.74 19.24 (18.27 - 20.21)	26.92 ± 2.58 26.92 (26.01 - 27.83)	22.35 ± 1.42 22.35 (21.85 - 22.85)
Centerback (n= 3)	16.30 ± 2.88 16.12 (14.82 - 17.70)	28.27 ± 3.14 27.90 (26.62 - 29.74)	17.74 ± 3.48 17.82 (16.02 - 19.50)	27.21 ± 3.11 26.84 (25.57 - 28.66)	19.81 ± 2.67 20.78 (18.79 - 21.32)
Forward (n= 3)	16.19 ± 3.88 15.81 (14.16 - 18.02)	27.06 ± 3.19 25.30 (25.21 - 28.02)	17.14 ± 4.84 17.52 (14.82 - 19.65)	26.00 ± 3.17 24.26 (24.17 - 26.96)	19.48 ± 3.78 19.35 (17.56 - 21.34)
Fullback (n= 4)	13.67 ± 2.32 14.69 (13.48 - 14.88)*	23.89 ± 2.76 25.02 (23.58 - 25.33)*	14.95 ± 3.13 15.68 (13.47 - 17.16)	22.86 ± 2.74 23.98 (22.55 - 24.29)*	20.57 ± 4.13 20.90 (18.17 - 23.30)
Midfielder (n= 12)	14.80 ± 2.63 15.30 (13.67 - 16.72)	25.02 ± 4.46 26.45 (23.61 - 27.99)	16.38 ± 3.39 15.45 (14.68 - 19.33)	23.86 ± 4.33 25.40 (22.15 - 26.92)	19.19 ± 3.73 19.44 (17.83 - 21.66)
Total	15.19 ± 2.82 15.17 (13.98 - 16.72)	25.70 ± 3.92 25.57 (24.95 - 28.07)	16.64 ± 3.39 16.71 (14.33 - 19.33)	24.63 ± 3.79 24.90 (24.02 - 27.01)	19.80 ± 3.42 19.80 (17.80 - 22.30)

Note: The reported statistics correspond to Mean ± *SD* and Median (*Q*1 – *Q*3); * Values that did not present a normal distribution.

In order to ensure appropriate comparisons of body fat % calculations and compare outcomes produced by formulas applying two- and five-component methods, the lipid fraction of mass calculated by the five-component method was first determined. This indicated more similar outcomes between methods with body fat values no longer being overestimated by the five-component method. In fact, estimates were approximately 14 points higher than body fat % estimates produced using the Yuhasz formula and 3 points higher than those produced using the Durnin and Rahaman formula.

With respect to correlational analysis using Pearson or Spearman coefficients, in accordance with variable data distribution (Table 4), all fat % values produced using the two- and five-component methods correlated data provided by DEXA, which, for the purpose of the present study, provided the criterion method (García et al., 2014). Outcomes pertaining to the formulas proposed by Yuhasz and Durnin, and Rahaman stand out due to their high correlations with DEXA, specifically, 0.825 and 0.809, respectively ($p < .001$). Other outcomes also correlated well with DEXA (> 0.6-0.8), with lipid fraction of adipose tissue outcomes calculated using the five-component method producing the lowest correlation ($r < .616$; $p < .001$).

Table 4. Correlation coefficients between fat percentages calculations made with various body composition prediction formulas in relation to DXA

Test	Parameter 1	Parameter 2	*r*	*CI*	*p*
Pearson	DXA	% Lipid mass of weight	.616	.282 - .826	.345
	DXA	% Fat Jackson & Pollock	.757	.509 - .889	.237
	DXA	% Fat Yuhasz	.825	.632 - .922	.653
	DXA	% Fat Durnin & Rahaman	.809	.601 - .914	.055
Spearman	DXA	% Fat Durnin & Womersley*	.749	.559 - .903	.042
	DXA	% Fat Slaughter*	.679	.542 - .898	.035

Note: * Spearman's coefficient was used according to the distribution of the variable, other coefficients are Pearson's; **$p < .05$.

With regards to Lin concordance coefficients (Table 5), the highest intraclass correlation coefficient was produced for fat % calculations made using the Durnin and Womersley formula (ccc = 0.768), followed by those made using formula proposed by Durnin and Rahaman (ccc = 0.719). The method producing the lowest concordance correlation coefficient was Yuhasz with 0.163.

Table 5. Lin's Concordance Correlation Coefficients Between Fat Percentages Measured with Various Body Composition Prediction Formulas in Relation to DXA

Parameter 1	Parameter 2	*rho*	*CI*
DXA	% Lipid mass of weight	.352	.119 - .548
	% Fat Jackson & Pollock	.227	.093 - .352
	% Fat Yuhasz	.163	.069 - .254
	% Fat Durnin & Rahaman	.719	.491 - .855
	% Fat Durnin & Womersley*	.768	.543 - .891
	% Fat Slaughter*	.633	.385 - .796

Table 6. Inter-method difference (IMD) and agreement limits between fat percentages measured with various body composition prediction formulas in relation to DXA

Body Composition Method	% Fat (Ẋ- SD)	*IMD with respect to DXA (Ẋ- SD)**	Agreement Limits	
			Lower	Upper
DXA	23.94 ± 3.507	-	-	-
% Lipid mass of weight	19.80 ± 3.417	4.14	2.86	5.43
% Fat Jackson & Pollock	16.64 ± 3.389	7.30	6.28	8.31
% Fat Yuhasz	15.19 ± 2.816	8.75	7.91	9.59
% Fat Durnin & Rahaman	25.70 ± 3.921	- 1.76	- 2.75	- 0.78
% Fat Durnin & Womersley*	24.63 ± 3.793	- 0.70	- 1.71	0.32
% Fat Slaughter*	26.27 ± 3.580	- 2.33	- 3.33	- 1.3

Note: *Difference obtained by the Bland-Altman method

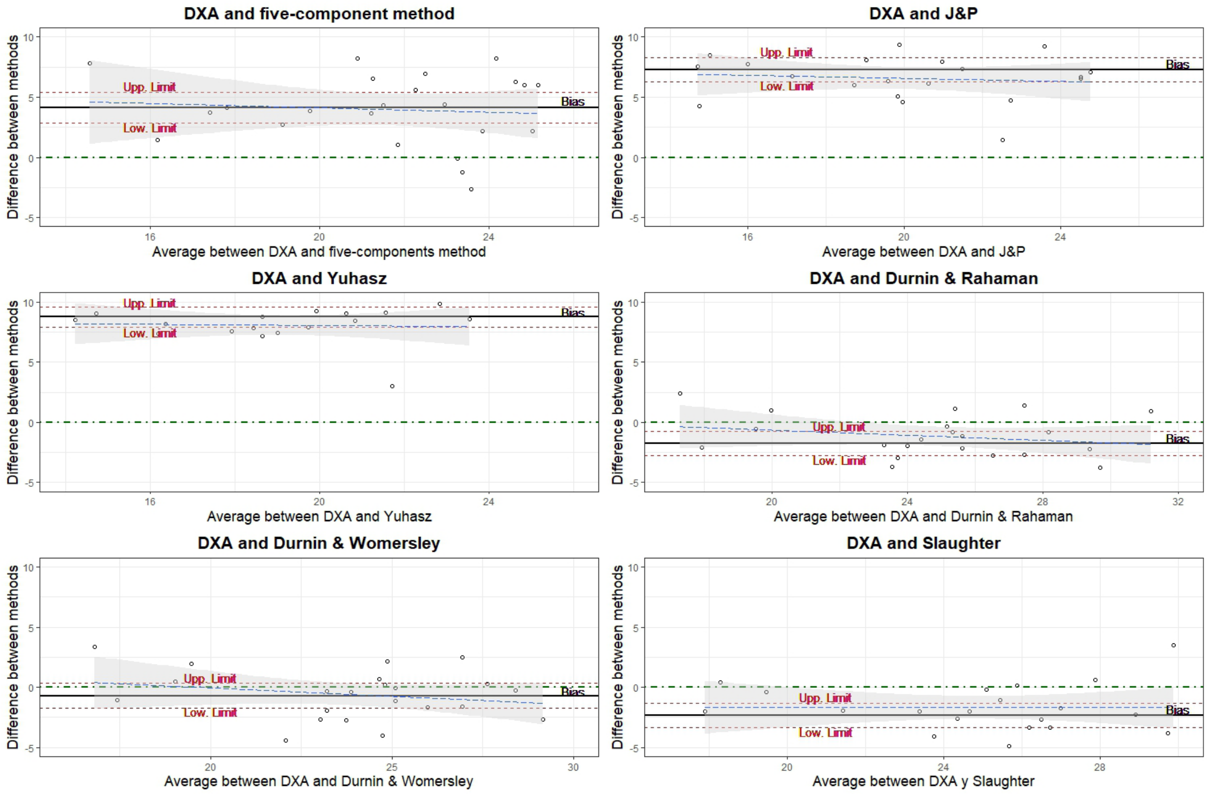

Figure 1. Comparison of fat mass percentage measured with body composition prediction formulas and DXA in Bland-Altman Plots

Discussion

The importance of properly determining body composition lies in its correlation with various aspects such as agility, lower limb power, flexibility and overall athlete performance (Zanini et al., 2020). However, body composition values vary widely depending on the method or formula used, with greater differences observed in variables such as body fat, fat mass and fat-free mass (Merrigan et al., 2018; Vaquero 2023). Additionally, body fat % is an indicator that varies significantly based on subject gender and age (López et al., 2018; Reilly et al., 2009; Santos & Tavares, 2007).

Present findings coincide with those reported in a study conducted with Chilean professional footballers, in which it was evidenced that the adipose mass of goalkeepers (18 ± 2.1 kg) was greater than that of defenders (16.2 ± 2.8 kg), forwards (15.5 ± 2.4 kg) and playmakers (15.0 ± 2.0 kg) (López, 2018; Rodríguez et al., 2019). In the same way, other studies describe that playmakers have lower body weight, adipose mass and muscle mass. This is explained by the fact that they provide support and act as a link between defenders and forwards, normally exhibiting physical characteristics such as endurance, speed and power, and high levels of maximum oxygen consumption (Ochoa, 2008).

Previous studies using the DEXA technique to analyze body composition, such as that conducted with a sample of 175 university women's soccer players, have reported average body fat to be 25.7% during preseason (Roelofs, 2020). This is similar to outcomes produced in the present research, in which the average was 23.9%; however, the peculiarity of these studies is that fat mass estimates vary depending on the formula used (Randell, 2021) and the population studied. On the other hand, it is also worth highlighting that the two-component method only considers chemically defined lipid mass, whilst the five-component method considers anatomically defined adipose mass, i.e., adipocytes with lipids, water, electrolytes and proteins. As the five-component method produces higher values (Holway, 2008), it was necessary to adjust fat mass values produced by the five-component model using the formula proposed by Alan Martin (Lipid Fraction (%) = 0.327 + (0.0124 x % adiposity) so that these values could be compared with fat mass values yielded using the two-component formulas.

In the present study, fat % values calculated according to the two-component method using the Durnin and Womersley formula were found to be the most similar to those calculated using the DEXA reference method. Similar findings were reported in another study conducted with male footballers. In this previous case, *DIM* outcomes pertaining to fat mass when using the Durnin and Womersley formula were rho= 0.66 (Kammerer et al., 2021), whilst, in the present study, a rho of 0.77 was produced when using this formula. Moreover, previous studies have also concluded that fat % estimates in young footballers and other elite athletes using the Durnin and Womersley equation are highly similar to those produced with the reference method, arguing that this method could be used to assess body fat when more precise methods are not available (Blue et al., 2018; España et al., 2015). This being said, fat mass estimates will continue to demonstrate high variability as a function of the exact method employed. Similar findings were reported in a study conducted on obese or overweight individuals. In this aforementioned study, high correlations were found between values produced using DEXA and the four-component model (4C), however, fat % values were significantly higher using DEXA compared to the 4C model (García et al., 2015).

It is also important to note that, despite the fact that anthropometry has been used over the years as a double indirect method of evaluating body composition in athletes, when comparing Yuhasz's equation with the criterion method (Hind et al., 2018), it presented the lowest correlation-concordance and the highest *DIM*, with values of 0.163 and 8.75, respectively. This means that Yuhasz formula fat mass estimates would be underestimated by almost nine percent, preventing the realization of effective nutritional interventions.

In a study conducted on sub-elite rugby players, both the Yuhasz and Faulkner equations tended to underestimate fat % compared to the Reilly equation, with the Yuhasz equation showing higher systematic error (Escrivá et al., 2021). This is consistent with the findings of the present research, in which the Yuhasz formula underestimated body fat mass in comparison with the reference method.

Alongside the findings discussed above, a number of studies have demonstrated the importance of the availability of information on the body composition of professional soccer players, with such information being highly useful to coaches and managers when it comes to directing training processes (Randell et al., 2021). In light of this, it is important to highlight that the anthropometric method that most closely mirrors the criterion method (DEXA) is the Durnin and Womersley formula. Further present findings suggest that the Yuhasz formula is obsolete when it comes to the calculation of body fat % in athletes, since it produces fairly distinct outcomes to those of the criterion method. Based on that discussed here, the need to determine parameters and shape anthropometric and body composition objectives for professional female soccer players that vary as a function of playing position is highlighted. This is of great importance given that the consideration of such parameters is currently absent from existing research evaluating the influence of body composition on performance achievement (Sedano et al., 2009) in women's soccer.

Limitations

One of the main limitations of the present study was its use of a relatively small sample that was recruited according to convenience. However, it is important to keep in mind that women's soccer in Colombia continues to experience significant growth and, despite this limitation, it was possible to analyze all playing positions based on the sample used. Another limitation is that not all soccer players were measured by the same evaluator, introducing potential measurement bias. However, all evaluators were ISAK certified and all measurements were performed in accordance with a standardized protocol and using the same equipment for all measurements.

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