RESEARCH ARTICLE

INTERNATIONAL JOURNAL OF KINANTHROPOMETRY

DOI: 10.34256/ijk2519

# Development and Validation of A New Anthropometric Predictive Equation For Estimating Fat Mass In Elite Male Soccer Players

**Francesco Campa [1, *], Alessio Rossi [2], Giulia Martera [3], Athos Trecroci [4], Tindaro Bongiovanni [5, 6]**

[1] Department of Biomedical Sciences, University of Padua, Padua, Italy
[2] Computer Science, University of Pisa, Pisa, Italy and National Research Council (CNR), Institute of Information Science and Technologies (ISTI), Pisa, Italy
[3] Department of Performance Nutrition, Spezia Calcio, La Spezia, Italy
[4] Department of Biomedical Science for Health, University of Milan, Milan, Italy
[5] Department of Biomedical and Neuromotor Sciences, University of Bologna, Bologna, Italy
[6] Department of Performance, Palermo Football Club, Palermo
* Corresponding author email: francesco.campa@unipd.it
DOI: https://doi.org/10.34256/ijk2519
Received: 09-02-2025; Revised: 02-04-2025, Accepted: 09-04-2025; Published: 14-04-2025

## Abstract

**Introduction:** The present study aimed i) to develop and validate an anthropometric soccer-specific equation for predicting fat mass (FM) using dual energy X-ray absorptiometry (DXA) as a reference method; ii) to assess the performance of existing soccer-specific predictive equations. **Methods:** Eighty male soccer players (aged 24.4±5.4 years, BMI 23.7±1.2 kg/m$^2$) participating in the first Italian league underwent anthropometric measurements and DXA scan during the in-season period. The participants were divided into development and validation groups. The validation group returned for a second assessment three months later and was included in an analysis of longitudinal validity. **Results:** The best developed model was: FM (kg)= -9.905 + (sum of triceps, iliac crest, abdominal, and front thigh skinfolds (mm) × 0.175) + (thigh girth (cm) × 0.258) - (ethnicity × 1.577) - (age (years) × 0.068), $R^2$=0.73, standard error of estimation (SEE)=1.01 kg, where ethnicity is 1 for black and 0 for white. Cross-sectional validation showed $r^2$ values ranging from 0.71 to 0.72 with SEE equal to 0.80 kg and 0.86 kg for the baseline and the second assessments, respectively. Concordance correlation coefficients (CCC) were 0.84 at baseline and 0.86 at the second visit. The agreement analysis showed no mean bias at any time (p>0.05) and lower 95% limits of agreement (LoA) ranging from -1.5 kg to 1.8 kg. Longitudinal validation demonstrated a high accuracy at both group ($r^2$= 0.80, SEE= 0.37 kg, CCC= 0.90) and individual (mean bias= 0.04 kg, 95%LoA= -0.7 kg to 0.8 kg, r= 0.117) levels. In contrast, the FM estimated from existing predictive equations differed from DXA for all the cross-sectional and longitudinal assessments, showing less accuracy compared to the new equation. **Conclusions:** This study presents a new soccer-specific predictive equation based on four skinfolds and a girth, allowing for a valid and sport-specific assessment of FM across the competitive season.

**Keywords:** Anthropometry, Body Composition, Body Fat, DXA, Sport, Skinfolds

## Resumen

**Introducción:** El presente estudio tuvo como objetivo i) desarrollar y validar una ecuación antropométrica específica para el fútbol que permita predecir la masa grasa (MG) utilizando la absorciometría dual de rayos X (DXA) como método de referencia; ii) evaluar el rendimiento de las ecuaciones predictivas existentes específicas para el fútbol. **Métodos:** Ochenta futbolistas varones (edad 24,4 ± 5,4 años, IMC 23,7 ± 1,2 kg/m$^2$) que participaban en la primera división italiana se sometieron a mediciones antropométricas y una DXA durante la temporada. Los participantes se dividieron en grupos de desarrollo y validación. El grupo de validación regresó para una segunda evaluación tres meses después y se incluyó en un análisis de validez longitudinal. **Resultados:** El modelo mejor desarrollado fue: FM (kg) = -9,905 + (suma de pliegues cutáneos de tríceps, cresta ilíaca, abdominal y muslo anterior (mm) × 0,175) + (circunferencia del muslo (cm) × 0,258) - (etnia × 1,577) - (edad (años) × 0,068), R2 = 0,73, error estándar de estimación (SEE) = 1,01 kg, donde la etnia es 1 para negro y 0 para blanco.

La validación transversal mostró valores de r2 que van desde 0,71 a 0,72 con SEE igual a 0,80 kg y 0,86 kg para la línea base y la segunda evaluación, respectivamente. Los coeficientes de correlación de concordancia (CCC) fueron 0,84 al inicio y 0,86 en la segunda visita. El análisis de concordancia no mostró sesgo medio en ningún momento ($p > 0,05$) y límites de concordancia (LdA) inferiores al 95 %, que oscilaron entre -1,5 kg y 1,8 kg. La validación longitudinal demostró una alta precisión tanto a nivel grupal ($r^2 = 0,80$, SEE = 0,37 kg, CCC = 0,90) como individual (sesgo medio = 0,04 kg, LdA del 95 % = -0,7 kg a 0,8 kg, $r = 0,117$). Por el contrario, la MG estimada a partir de las ecuaciones predictivas existentes difirió de la DXA en todas las evaluaciones transversales y longitudinales, mostrando una menor precisión en comparación con la nueva ecuación. **Conclusiones:** Este estudio presenta una nueva ecuación predictiva específica para el fútbol basada en cuatro pliegues cutáneos y un perímetro, lo que permite una evaluación válida y específica del deporte de la MG a lo largo de la temporada competitiva.

**Palabras Clave:** Antropometría, Composición corporal, Grasa corporal, DXA, Deporte, Pliegues cutáneos.

## Introduction

Periodic measurement of body composition is a common practice to evaluate nutritional status, as well as for monitoring the effects of training or detraining periods in soccer players (Collins et al., 2021; Paoli, Cenci, et al., 2021). The simplest way to assess body composition is by considering body mass as the sum of fat mass (FM) and fat-free mass, which can be further compartmented into several components (Campa, Toselli, et al., 2021) . The assessment of FM in absolute (kg) or relative (percentage) quantities with respect to the body mass is particularly informative when assessing soccer players. In fact, an excess of FM acts as dead weight in activities where body mass must be repeatedly lifted against gravity, impairing aerobic capacity (Mondal, 2017), power-to-weight ratio (Carling & Orhant, 2010), repeated sprint ability (Campa et al., 2019), and flexibility (Campa et al., 2019). Generally, elite soccer players experience gains in FM during transition periods, whereas decreases in FM occur, as a direct reflection of the increase in training intensity, during the competitive period (Ostojic, 2002).

Dual-energy X-ray absorptiometry (DXA), underwater weighing, and air displacement plethysmography are considered as reference methods (Ackland et al., 2012; Heymsfield et al., 2005) for evaluating FM. Nevertheless, their use implies high costs and requires specialized personnel, resulting unsuitable in the context of resource-limited settings. Alternatives techniques, such as bioelectrical impedance analysis or anthropometry, have been implemented over the years (Campa, Toselli, et al., 2021) and routinely used where there is a need for user-friendly assessment procedures. The surface anthropometry is recognized as a low-cost and time-efficient way to assess body composition (Kasper et al., 2021), and its use is not limited to practitioners but also serves useful to many researchers interested in the assessment of soccer players (Slimani & Nikolaidis, 2019). Particularly, anthropometric measurements such as skinfold thickness and girth are considered as valid predictors of body mass components and are often included into regression models for estimating FM (Ackland et al., 2012; Kasper et al., 2021).

Elite soccer players present a distinct fat pattering (Santos et al., 2014), especially when compared to the general population included in studies aimed at developing predictive equations (Durnin & Womersley, 1974; Jackson & Pollock, 1978). Although optimal values are not well-established, a narrow range of adiposity can be expected due the specific sport requirements (Collins et al., 2021). Such a difference in body composition may be one of the reasons why the use of generalized equations in soccer players can lead to systematic biases with respect to reference methods (Reilly et al., 2009; Suarez-Arrones et al., 2018). In the context of specific sports, a lack of accuracy and precision can also result from the application of predictive equations developed on mixed groups of athletes from different disciplines (Campa et al., 2023; C N Matias et al., 2022). To the best of our knowledge, only two studies have presented anthropometric formulas developed on samples of elite adult soccer players (Reilly et al., 2009; Suarez-Arrones et al., 2018) so far. However, possible methodological limitations can be found in these existing equations and concern the small sample size used for their development (i.e., 45 (Reilly et al., 2009) and 17 (Suarez-Arrones et al., 2018) soccer players), as well as the absence of a validation analysis (Reilly et al., 2009; Suarez-Arrones et al., 2018). With that being said, there is a clear need for further soccer-specific predictive equations to assess FM starting from anthropometric measurements.

Therefore, the present study aimed to develop a new anthropometric equation for predicting FM using DXA as a reference method in a sample of elite male soccer players. Additionally, we aimed to test its validity alongside the already published soccer-specific predictive equations across the competitive season.

## Materials and Methods

### Participants and study design

A total of 80 soccer players (age 24.4 ± 5.4 years, body mass index 23.7 ± 1.2 kg/m$^2$) from the first Italian division (Serie A) were included in this longitudinal study. Fifty-eight participants were included in the analyses for the development of the predictive equation, while twenty-two participants were used as validation group. Data collection was conducted during the first half of their competitive season and a follow-up visit scheduled twelve weeks later for the participant involved in the validation analyses. The participants provided a signed informed consent, and the study procedures were approved by the Ethic Committee of the University of Milan (code: 1052019), attesting the fulfilment of all human research standards set out by the declaration of Helsinki.

## Procedures

Body mass and height were measured using a scale with stadiometer (Seca, Hamburg, Germany) to the nearest 0.1 kg and 0.1 cm, respectively. Body mass index (BMI) was calculated as body mass (kg ) / squared stature (m$^2$). Eight skinfold thicknesses (triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, and medial calf), six girths (relaxed and flexed arm, waist, hip, thigh, and calf), and two bone breadths (femur and humerus) were measured following the procedures established by the International Society for Advancement of Kinanthropometry (ISAK) (International Society for Advancement of Kinanthropometry., 2001). Skinfold thicknesses were measured to the nearest 0.1 mm using a caliper (Holtain, Crosswell, UK), girths were taken to the nearest 0.1 cm using a measuring tape (CESCORF, Porto Alegre, Brazil), and breadths were measured to the nearest 0.1 cm using a sliding caliper (CESCORF, Porto Alegre, Brazil). The technical error of measurement (TEM) scores was within the 5% for skinfolds and within the 1% for girths and breadths (Adão et al., 2005).

DXA was performed on a Lunar Prodigy scan (General Electric, Boston, MA, USA) to derive whole-body measures of FM. The same operator performed the assessments according to procedures recommended by the manufacturer in a ventilated room with controlled temperature and humidity.

### Statistical Analysis

IBM SPSS ì (v. 27.0, IBM, Chicago, Illinois, USA) and MedCalc (v.11, Mariakerke, Belgium) softwares were used to analyze the data. All variables were checked for normality, using Kolmogorov-Smirnov test. A train-test cross-sectional and longitudinal validation approach was used to evaluate the predictive goodness of the models developed in this study. Descriptive characteristics for the development and validation groups are presented as means ± SD. The ability of the following anthropometric measures to predict FM in the development group was assessed using backward stepwise linear regression analysis. In order to assess multicollinearity, the variance inflation factor (VIF) was calculated. To validate the developed and the already existing models, the predictive equations were then applied in the test set. A paired sample t-test was used to compare the mean values obtained from the two methods. Using Lin's approach (Lin, 1989) the concordance correlation coefficient (CCC) was calculated and interpreted as suggested by McBride (McBride, 2007) (almost perfect >0.99; substantial >0.95 to 0.99; moderate =0.90 – 0.95; and poor <0.90). The CCC includes measures of precision and accuracy ($\rho$ and $C_b$, respectively). Agreement between anthropometric models and DXA was determined using the Bland-Altman method (Bland et al., 2012), assessing the correlation between the difference and the mean of the methods. P-value < 0.05 was established as the statistical significance for all tests.

## Results

Table 1 presents the general characteristics for the developmental and validation samples. Of these groups, 12 participants (seven for the development and five for the validation sample) were identified as African /Black, while 68 participants were identified as Caucasian/White.

Table 2 shows the new anthropometric predictive equations. Two different set of models were developed for FM using the sum of four (abdominal, front thigh, iliac crest, and triceps) and eight (abdominal, biceps, front thigh, iliac crest, medial calf, subscapular, supraspinale, and triceps) skinfold thickness as independent variable, separately. Only variables contributing to the estimates using backward stepwise approach were included in the models. The best model for estimating FM was:

FM (kg) = -9.905 + (Σ4SKF × 0.175) + (thigh girth × 0.258) - (ethnicity × 1.577) - (age × 0.068), where Σ4SKF is in mm, thigh girth is in cm, ethnicity is 1 for black and 0 for white, and age in years. Accuracy of the developed model can be observed by the high coefficient of determination ($R^2$ = 0.73) and low standard error of estimation (SEE) = 1.01 kg.

Table 3 presents the results of the cross-sectional and longitudinal validation performed on the new and the former predictive equations. Supplementary Figures (1 and 2) graphically display the results of the validation analyses for the new predictive equations.

**Table 1**. Descriptive characteristics for the development and validation groups

| | Development group | Validation group at baseline | Validation group after three months |
|---|---|---|---|
| Age (years) | 23.8 ± 4.8 | 25.8 ± 6.6 | 26.1 ± 6.6 |
| Body mass (kg) | 81.6 ± 6.1 | 80.2 ± 6.3 | 80.1 ± 6.7 |
| Stature (m) | 1.85 ± 0.5 | 1.84 ± 0.6 | 1.84 ± 0.6 |
| Body mass index (kg/m$^2$) | 23.8 ± 1.2 | 23.5 ± 1.9 | 24. ± 0.9 |
| Fat mass$_{DXA}$ (kg) | 9.7 ± 1.9 | 9.4 ± 1.4 | 9.4 ± 1.4 |
| Fat mass$_{DXA}$ (%) | 12.5 ± 2.2 | 12.4 ± 1.5 | 12.0 ± 1.6 |
| Σ4SKF (mm) | 32.9 ± 6.8 | 32.5 ± 5.8 | 32.5 ± 6.3 |
| Σ8SKF (mm) | 57.3 ± 9.6 | 56.5 ± 8.3 | 56.7 ± 9.2 |
| Relaxed arm girth (cm) | 30.8 ± 1.7 | 30.5 ± 1.7 | 30.9 ± 1.4 |
| Flexed arm girth (cm) | 34.3 ± 1.7 | 34.1 ± 1.7 | 34.4 ± 1.7 |
| Waist girth (cm) | 81.0 ± 2.9 | 81.4 ± 3.1 | 81.8 ± 2.9 |
| Hip girth (cm) | 100.3 ± 3.6 | 100.5 ± 3.8 | 101.1 ± 3.8 |
| Thigh girth (cm) | 60.4 ± 2.5 | 60.1 ± 2.4 | 60.6 ± 2.3 |
| Calf girth(cm) | 38.6 ± 1.6 | 38.5 ± 1.6 | 38.9 ± 1.7 |
| Humerus breadth (cm) | 7.3 ± 0.3 | 7.2 ± 0.4 | 7.2 ± 0.4 |
| Femur breadth (cm) | 10.4 ± 0.4 | 10.4 ± 0.5 | 10.4 ± 0.5 |

Note: Data are reported as mean ± standard deviation. DXA, dual energy X-ray absorptiometry; Σ4SKF, sum of four skinfolds in millimeters (triceps, iliac crest, abdominal, and front thigh); Σ8SKF, sum of eight skinfolds in millimeters (triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, and medial calf).

**Table 2.** Developed anthropometric models for fat mass prediction

| **Four skinfold-based models** | | | | | **Eight skinfolds-based models** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Coefficient** | **$R^2$** | **SEE (kg)** | **VIF** | | **Coefficient** | **$R^2$** | **SEE (kg)** | **VIF** |
| **Model 1** | | 0.61 | 1.17 | | **Model 1** | | 0.55 | 1.26 | |
| Intercept | 2.642 | | | | Intercept | 1.480 | | | |
| Σ4SKF (mm) | 0.215 | | | 1.00 | Σ8SKF (mm) | 0.144 | | | 1.00 |
| **Model 2** | | 0.67 | 1.09 | | **Model 2** | | 0.60 | 1.19 | |
| Intercept | -8283 | | | | Intercept | -9.021 | | | |
| Σ4SKF (mm) | 0.180 | | | 1.29 | Σ8SKF (mm) | 0.117 | | | 3.46 |
| TG (cm) | 0.200 | | | 1.29 | TG (cm) | 0.199 | | | 3.46 |
| **Model 3** | | 0.70 | 1.05 | | **Model 3** | | 0.65 | 1.14 | |
| Intercept | -9.359 | | | | Intercept | -10.116 | | | |
| Σ4SKF (mm) | 0.179 | | | 1.29 | Σ8SKF (mm) | 0.119 | | | 3.46 |
| TG (cm) | 0.220 | | | 1.31 | TG (cm) | 0.217 | | | 3.98 |
| Ethnicity[§] | -1.284 | | | 1.01 | Ethnicity[§] | -1.565 | | | 1.52 |
| **Model 4** | | 0.73 | 1.01 | | **Model 4** | | 0.68 | 1.09 | |
| Intercept | -9.905 | | | | Intercept | -10.650 | | | |
| Σ4SKF (mm) | 0.175 | | | 1.30 | Σ8SKF (mm) | 0.117 | | | 3.42 |
| TG (cm) | 0.258 | | | 1.41 | TG (cm) | 0.257 | | | 3.99 |
| Ethnicity[§] | -1.577 | | | 1.08 | Ethnicity[§] | -1.877 | | | 1.52 |
| Age (years) | -0.068 | | | 1.12 | Age (years) | -0.074 | | | 1.00 |

Abbreviations: Σ4SKF, sum of four skinfolds in millimetres (triceps, iliac crest, abdominal, and front thigh); Σ8SKF, sum of eight skinfolds in millimetres (triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, and medial calf; TG, tightgirth; $R^2$, coefficient of determination; SEE, standard error of the estimate; VIF, variation inflation factor. [§] 1 if black; 0 if white.

DOI: 10.34256/ijk2519

**Table 3.** Validation of the new and former predictive equations at baseline (PRE) and after three months (POST) in the soccer players

| | | Regression analysis | | CCC analysis | | | Agreement analysis | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean ± SD | $r^2$ | SEE (kg) | CCC | ρ | $C_b$ | Bias | 95% LoA | Trend |
| Dual energy X-ray absorptiometry | | | | | | | | | |
| $FM_{PRE}$ (kg) | 9.5 ± 1.4 | - | - | - | - | - | - | - | - |
| $FM_{POST}$ (kg) | 9.4 ± 1.6 | - | - | - | - | - | - | - | - |
| $FM_{POST-PRE}$ (kg) | -0.1 ± 0.8 | - | - | - | - | - | - | - | - |
| Current study (four skinfolds-based equation) | | | | | | | | | |
| $FM_{PRE}$ (kg) | 9.5 ± 1.4 | 0.71 | 0.80 | 0.84 | 0.85 | 0.99 | 0.00 | -1.5; 1.6 | r= -0.250; p=0.191 |
| $FM_{POST}$ (kg) | 9.4 ± 1.6 | 0.72 | 0.86 | 0.84 | 0.85 | 0.99 | 0.05 | -1.7; 1.8 | r= 0.114; p=0.613 |
| $FM_{POST-PRE}$ (kg) | 0.0 ± 0.8 | 0.80 | 0.37 | 0.90 | 0.90 | 0.99 | 0.04 | -0.7; 0.8 | r= 0.117; p=0.603 |
| Current study (eight skinfolds-based equation) | | | | | | | | | |
| $FM_{PRE}$ (kg) | 9.2 ± 1.4 | 0.67 | 0.85 | 0.81 | 0.82 | 0.99 | -0.21 | -1.9; 1.5 | r= 0.102; p=0.650 |
| $FM_{POST}$ (kg) | 9.2 ± 1.5 | 0.70 | 0.87 | 0.83 | 0.84 | 0.99 | -0.16 | -1.9; 1.6 | r= 0.054; p=0.810 |
| $FM_{POST-PRE}$ (kg) | 0.0 ± 0.9 | 0.66 | 0.50 | 0.79 | 0.80 | 0.99 | 0.05 | -1.0; 1.1 | r= -0.261; p=0.241 |
| Reilly et al. (2009) | | | | | | | | | |
| $FM_{PRE}$ (kg) | 7.5 ± 0.9* | 0.47 | 1.07 | 0.26 | 0.69 | 0.38 | -2.00 | -5.0; 0.1 | r= -0.402; p=0.063 |
| $FM_{POST}$ (kg) | 8.1 ± 1.2* | 0.70 | 0.89 | 0.57 | 0.83 | 0.68 | 0.51 | -1.4; 2.5 | r= -0.349; p=0.111 |
| $FM_{POST-PRE}$ (kg) | 0.7 ± 0.6* | 0.68 | 0.45 | 0.50 | 0.83 | 0.60 | 0.74 | -0.1; 1.6 | r= -0.364; p=0.096 |
| Suarez-Arrones et al. (2018) | | | | | | | | | |
| $FM_{PRE}$ (kg) | 12.2 ± 1.7* | 0.38 | 1.16 | 0.23 | 0.62 | 0.38 | 2.70 | -0.1;5.4 | r= 0.325; p=0.309 |
| $FM_{POST}$ (kg) | 12.4 ± 2.1* | 0.68 | 0.66 | 0.33 | 0.82 | 0.40 | 3.0 | 0.7; 5.3 | r= 0.522; p=0.013 |
| $FM_{POST-PRE}$ (kg) | 0.2 ± 0.9* | 0.36 | 0.64 | 0.57 | 0.60 | 0.94 | 0.27 | -1.3; 1.8 | r= 0.361; p=0.099 |

Note: $r^2$, coefficient of correlation; SEE, standard error of estimation; CCC, concordance correlation coefficient; ρ, precision; $C_b$, accuracy; LoA, limits of agreement.
*= Significant differences with the criterion method ($p<0.05$).

Concerning the cross-sectional validation, no differences between methods were observed for the newly developed sport-specific equations, while FM estimated with the routinely used former equations differed from the DXA-derived values at any comparison. Standard error of the estimate ranged from 0.80 kg to 0.87 kg and from 0.66 kg to 1.16 kg for the new and former predictive equations, respectively. Lin's CCC ranged from 0.81 to 0.84 for the new predictive equations and from 0.23 to 0.57 for the existing models. Only the equation of Suarez-Arrones et al. (Suarez-Arrones et al., 2018) exhibited a proportional bias, overestimating FM in the participants with relatively high body fat while underestimating FM in the participants with lower levels of adiposity.

The results of the longitudinal validation showed a mean change in FM as assessed with DXA of -0.1 ± 0.8 kg. The change in FM predicted with new equations did not differ from the reference method, while the former equations overestimated FM ranging from 0.2 kg to 0.7 kg. Poor strength of agreement between methods were measured for all the predictive models (CCC ranging from 0.50 to 0.79), with the exception for the new predictive equations based on four skinfold thickness. There were no significant association between the differences and the means of the predicted and DXA-derived variables.

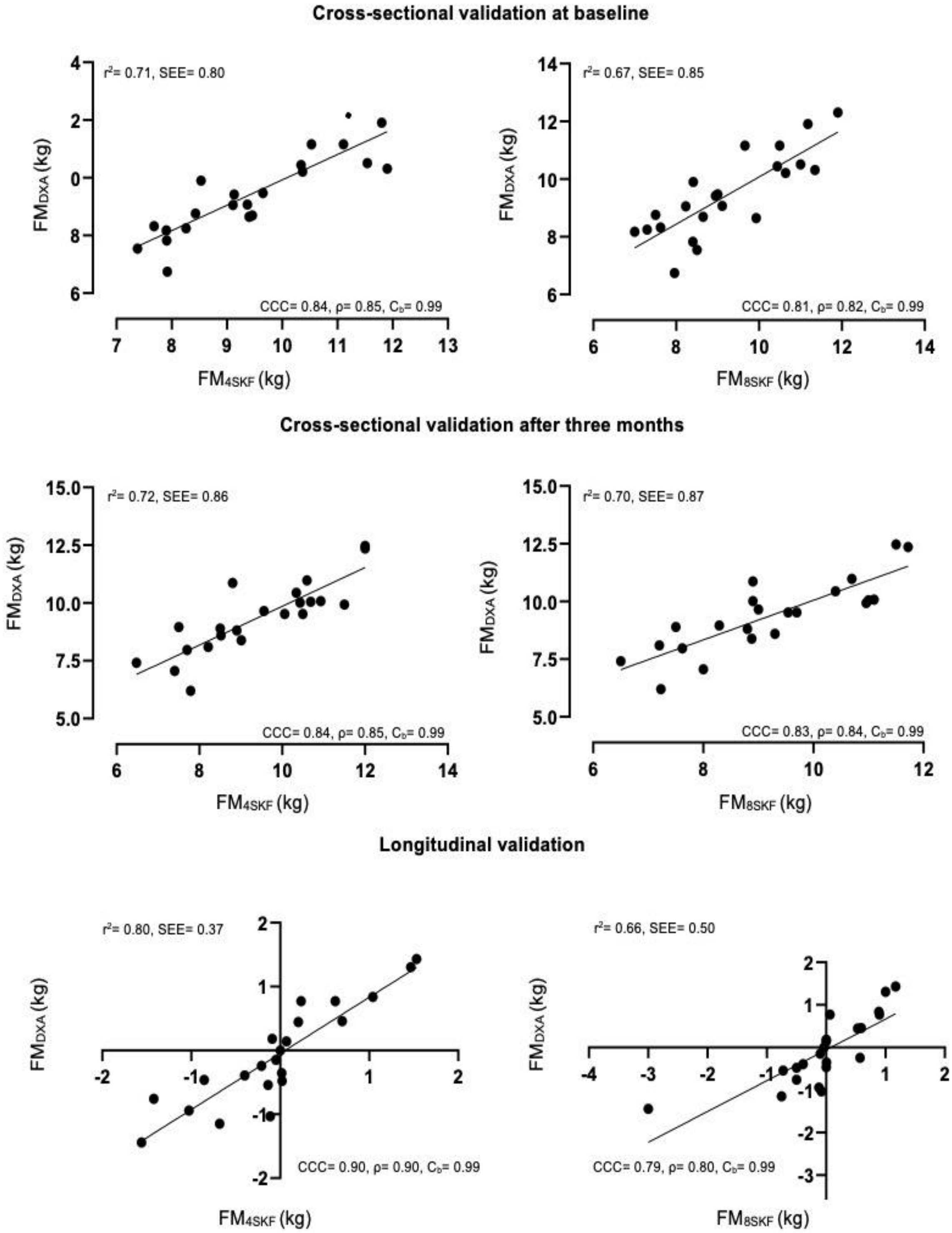


**Figure 1.** Cross-sectional and longitudinal agreement at the group level between the new equations and the reference method.

DOI: 10.34256/ijk2519

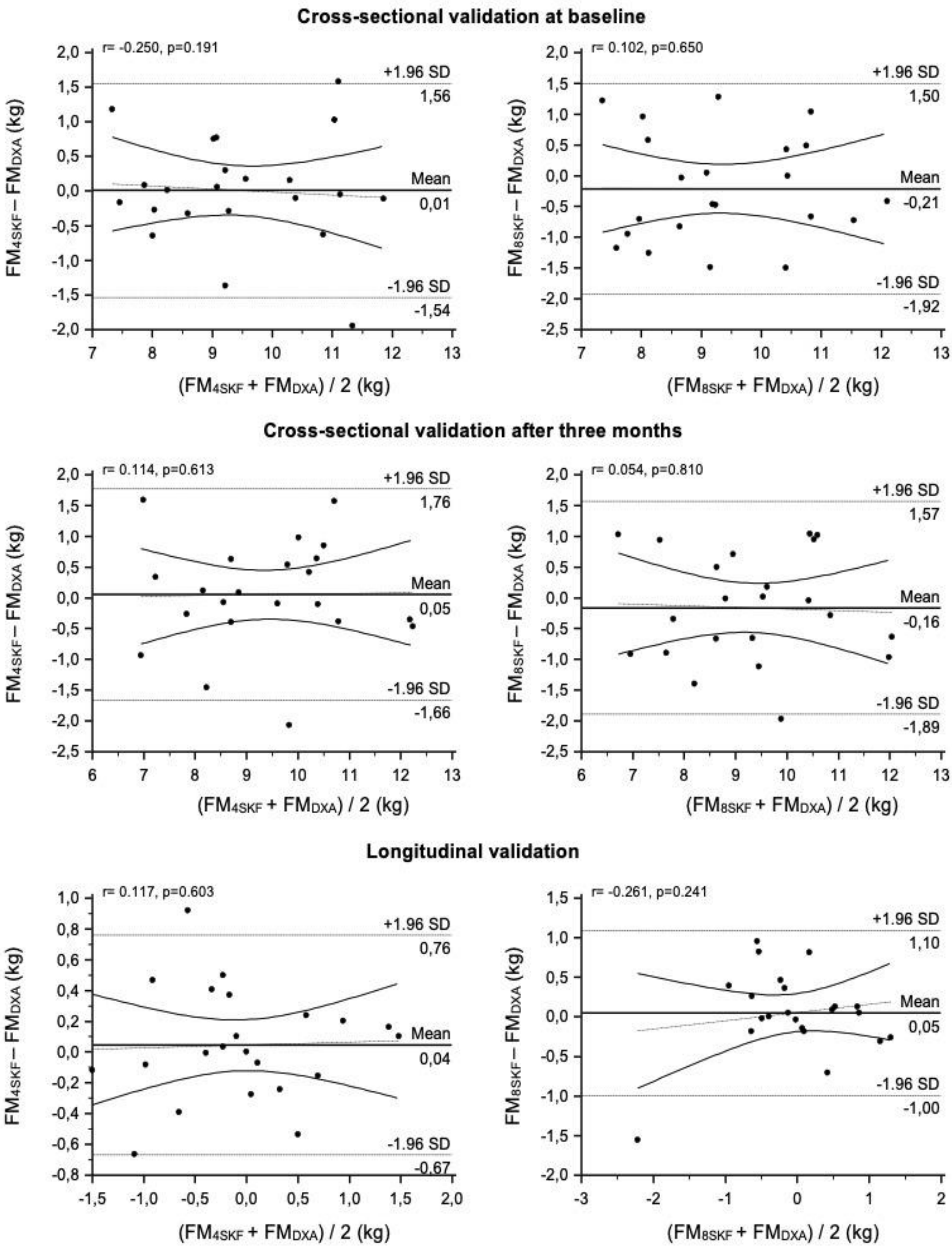


**Figure 2.** Cross-sectional and longitudinal agreement at the individual level between the new equations and the reference method

## Discussion

The present study aimed to develop and validate a new anthropometric predictive equation for assessing FM, while testing the performance of existing formulas for soccer players. The cross-sectional and longitudinal validation analyses presented the new equation based on the sum of triceps, iliac crest, abdominal, and front thigh skinfolds, thigh girth, ethnicity, and age as a valid procedure to estimate FM across the competitive season in elite soccer players. In contrast, the use of existing soccer-specific equations resulted in a lack of accuracy when compared with the DXA-derived values. Our formula adds to two other soccer-specific equations already available in literature (Reilly et al., 2009; Suarez-Arrones et al., 2018), showing the best performances in predicting FM and its variations during the competitive season.

The development analysis provided two set of models based on the sum of different groups of skinfolds. The best model was obtained considering the sum of four skinfolds, which explained the 73% of the DXA-derived variance in FM, with a SEE of 1.0 kg. These values are similar with those reported from previous published soccer-specific anthropometric equations (Reilly et al., 2009; Suarez-Arrones et al., 2018), where coefficient of determination ranged from 0.73 to 0.75. When using the sum of eight skinfolds as an independent variable in the regression analysis, results showed a worse performance (i.e., lower $R^2$ and higher SEE) compared to the four skinfold-based model. This could be due to poor correlations between some of the eight skinfold thickness and whole-body fat. In this regard, previous studies (Giro et al., 2022; Petri et al., 2020) showed a poor correlation between subscapular ($r^2$ ranging from 0.28 to 0.46) and medial calf ($r^2$ ranging from 0.15 to 0.39) with DXA-derived estimations of FM in athletic people. That said, it appears clear that a small part of the variance in FM estimation cannot be explained by using the predictive ability of anthropometric measurements. It could therefore depend on other sports-related factors, such as the compressibility and density of body tissues, or the influence of hydration status on them (Kasper et al., 2021).

Cross-sectional and longitudinal validation analyses were conducted on the new and former soccer-specific equations (Reilly et al., 2009; Suarez-Arrones et al., 2018). Using the new predictive model based on the sum of four skinfolds and a girth, the FM estimations resulted highly correlated ($r^2$ of 0.71 at baseline and 0.72 at the second visit three months later) with the reference values obtained from DXA. Similarly, the predicted change in FM explained the 80% of the variance observed in the reference data. Although the standard error of estimation was lower in all three evaluations, a moderate strength of agreement between the methods was observed only for the longitudinal FM assessment (CCC=0.90). Concerning the Bland-Altman analysis, no trend was verified between the mean and the difference of methods with lower limits of agreement for the cross-sectional and longitudinal validations. The lack of accuracy resulting from the validation of the predictive models provided by Reilly et al. (Reilly et al., 2009) and Suarez-Arrones et al. (Suarez-Arrones et al., 2018) may be due to the small sample size used in their development, especially in the study by Suarez-Arrones et al. (Suarez-Arrones et al., 2018) where only 17 soccer players were recruited. However, it should be recognized that recruiting large numbers of elite athletes to develop sport-specific equations can be a tough task, given the limited number of teams competing in national major leagues as well as the number of players employed on each team. Although smaller than those used in studies with mixed groups of athletes (Evans et al., 2005; Catarina N Matias et al., 2021; Sardinha et al., 2020; Withers et al., 1987), our sample size is to date the largest among those used to develop specific equations for adult soccer players. Therefore, the use of the predictive equation presented in this study should be encouraged and preferred over the previously published soccer-specific equations.

The participants involved in this study were active players of the first Italian league (Serie A). Elite soccer players are characterized by a specific body composition profile which can undergo changes across the competitive season (Mascherini et al., 2015; Silva et al., 2016). When assessing body composition it is crucial to consider that the use of different assessment methods can lead to different estimates, regardless of the considered body mass component (Campa et al., 2023; Kirkendall et al., 1991; Stratton et al., 2021). Our results are in line with other studies on elite soccer players which report DXA-derived FM values around 12% in the main phase of the competitive period (López-Taylor et al., 2018; Reilly et al., 2009; Suarez-Arrones et al., 2018). Such a phase is not usually characterized by a remodeling in body composition which instead can occur during detraining periods, where increases of FM and decreases of skeletal muscle tissue can be expected (Campa, Bongiovanni, et al., 2021; Mascherini et al., 2015; Silva et al., 2016). Considering that high adiposity levels can impair aerobic and anaerobic performance in elite soccer players (Campa et al., 2019; Suarez-Arrones et al., 2019), assessing body composition could be particularly useful during the preparatory or return-to-play phases (Mascherini et al., 2015; Nescolarde et al., 2013; Silva et al., 2016). Indeed, transition periods are considered as a suitable “window” to reach substantial gains in muscle mass and loses of FM, while rehabilitation process involves checks to ensure that body composition features are restored to their pre-injury state (Nescolarde et al., 2013; Silva et al., 2016). Since laboratory techniques such as DXA are not always available, having low-cost and time-efficient tools to assess body composition is essential for practitioners, as well as for researchers interested in field evaluations. The predictive equations presented in this study resulted accurate in tracking FM variation, showing the best performance when compared with other existing soccer-specific equations (Reilly et al., 2009; Suarez-Arrones et al., 2018). Furthermore, the use of generalized predictive equations have been discouraged when sports-specific procedures are available (Campa et al., 2023; C N Matias et al., 2022). For these reasons, the new soccer-specific equation represents a valid solution to predict change in FM across the competitive season, while maintaining the portability of a field-based method.

Some of the strengths of this study include the selection of adult elite male soccer players with international experience. Additionally, anthropometric measurements were collected according to the ISAK protocol by an accredited anthropometrist, resulting in a high level of precision of the collected measurements. If logistical and/or financial resources are limited, the new predictive equation results as a valid alternative to more accurate but less available methods (i.e., DXA) for assessing FM. Indeed, the cost of high-quality materials needed for measuring the considered anthropometric dimensions can range from $500 to $1,000 without additional costs such as for the bioelectrical impedance analysis where it is necessary to use disposable electrodes. As for the time, it typically takes from 5 to 10 minutes for each subject to complete an anthropometric assessment, depending on the complexity and number of measurements.

Some limitations should be acknowledged. First, the present findings cannot be generalized to other sport disciplines, females, youth, or sub-elite players. Second, despite DXA is widely used and accepted as a reference method to assess FM, the state-of-art procedure has been identified in the formula proposed by Wang et al. (Wang et al., 2002), which requires the assessment of bone mineral content by DXA, total body water by deuterium dilution or bioelectrical impedance analysis, and body volume by air displacement plethysmography or underwater weighting.

## Conclusions

This study developed and validated a predictive equation for estimating FM in elite male soccer players using DXA as a reference method. Existing predictive equations for adult soccer players showed a worse performance compared to the "novel" equation, especially in tracking FM changes across the competitive season. The new soccer-specific predictive equation provides researchers and practitioners the possibility to achieve valid estimates of FM using anthropometry in the context of soccer. This allows for the management of training and nutritional strategies aiming to enhance body composition and soccer performance, starting from a low-cost and time-efficient method.

## References


Ackland, T.R., Lohman, T.G., Sundgot-Borgen, J., Maughan, R.J., Meyer, N.L., Stewart, A.D., Müller, W. (2012). Current status of body composition assessment in sport: review and position statement on behalf of the ad hoc research working group on body composition health and performance, under the auspices of the I.O.C. Medical Commission. *Sports Medicine,* 42(3): 227–249. https://doi.org/10.2165/11597140-000000000-00000

Bland, J.M., Altman, D.G., Warner, D.S. (2012). Agreed Statistics: Measurement Method Comparison. *The Journal of the American Society of Anesthesiologists*, 116(1): 182–185. https://doi.org/10.1097/ALN.0b013e31823d7784

Campa, F., Bongiovanni, T., Trecroci, A., Rossi, A., Greco, G., Pasta, G., Coratella, G. (2021). Effects of the COVID-19 Lockdown on Body Composition and Bioelectrical Phase Angle in Serie A Soccer Players: A Comparison of Two Consecutive Seasons. *Biology,* 10(11): 1175. https://doi.org/10.3390/biology10111175

Campa, F., Matias, C.N., Moro, T., Cerullo, G., Casolo, A., Teixeira, F.J., Paoli, A. (2023). Methods over Materials: The Need for Sport-Specific Equations to Accurately Predict Fat Mass Using Bioimpedance Analysis or Anthropometry. *Nutrients,* 15(2): 278. https://doi.org/10.3390/nu15020278

Campa, F., Semprini, G., Judice, P. B., Messina, G., Toselli, S. (2019). Anthropometry, Physical and Movement Features, and Repeated-sprint Ability in Soccer Players. *International Journal of Sports Medicine,* 40(2): 100–109. https://doi.org/10.1055/a-0781-2473

Campa, F., Toselli, S., Mazzilli, M., Gobbo, L. A., & Coratella, G. (2021). Assessment of Body Composition in Athletes: A Narrative Review of Available Methods with Special Reference to Quantitative and Qualitative Bioimpedance Analysis. Nutrients, 13(5): 1620. https://doi.org/10.3390/nu13051620

Carling, C., Orhant, E. (2010). Variation in body composition in professional soccer players: interseasonal and intraseasonal changes and the effects of exposure time and player position. *Journal of Strength and Conditioning Research*, 24(5): 1332–1339. https://doi.org/10.1519/JSC.0b013e3181cc6154

Collins, J., Maughan, R. J., Gleeson, M., Bilsborough, J., Jeukendrup, A., Morton, J. P., Phillips, S. M., Armstrong, L., Burke, L. M., Close, G. L., Duffield, R., Larson-Meyer, E., Louis, J., Medina, D., Meyer, F., Rollo, I., Sundgot-Borgen, J., Wall, B. T., Boullosa, B., Dupont, G., Lizarraga, A., Res, P., Bizzini, M., Castagna, C., Cowie, C.M., Hooghe, M.D., Geye, H., Meyer, T., Papadimitriou, N., Vouillamoz, M., McCall, A. (2021).

UEFA expert group statement on nutrition in elite football. Current evidence to inform practical recommendations and guide future research. *British Journal of Sports Medicine*, 55(8): 416. https://doi.org/10.1136/bjsports-2019-101961

Durnin, J.V., Womersley, J. (1974). Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *The British Journal of Nutrition,* 32(1): 77–97. https://doi.org/10.1079/BJN19740060

Evans, E.M., Rowe, D.A., Misic, M.M., Prior, B.M., Arngrímsson, S.A. (2005). Skinfold prediction equation for athletes developed using a four-component model. *Medicine and Science in Sports and Exercise,* 37(11): 2006–2011. https://doi.org/10.1249/01.mss.0000176682.54071.5c

Giro, R., Matias, C.N., Campa, F., Santos, D.A., Cavaca, M.L., Duque, P., Oliveira, M., Matos, N., Vicente, F., Pereira, P., Santos, H.O., Tinsley, G.M., Teixeira, F.J. (2022). Development and Validation of an Anthropometric Equation to Predict Fat Mass Percentage in Professional and Semi-Professional Male Futsal Players. *Nutrients*, 14(21): 4514. https://doi.org/10.3390/nu14214514

Heymsfield, S., Lohman, T., Wang, Z., Going, S. (2005). Human body composition. *Human Kinetics*. https://doi.org/10.5040/9781492596950

International Society for Advancement of Kinanthropometry. (2001). International standards for anthropometric assessment. *International Society for the Advancement of Kinanthropometry*.

Jackson, A.S., Pollock, M.L. (1978). Generalized equations for predicting body density of men. *The British Journal of Nutrition,* 40(3): 497–504. https://doi.org/10.1079/BJN19780152

Kasper, A.M., Langan-Evans, C., Hudson, J.F., Brownlee, T.E., Harper, L.D., Naughton, R.J., Morton, J.P., Close, G.L. (2021). Come Back Skinfolds, All Is Forgiven: A Narrative Review of the Efficacy of Common Body Composition Methods in Applied Sports Practice. *Nutrients,* 13(4): 1075. https://doi.org/10.3390/nu13041075

Kirkendall, D.T., Grogan, J.W., Bowers, R.G. (1991). Field comparison of body composition techniques: hydrostatic weighing, skinfold thickness, and bioelectric impedance. *The Journal of Orthopaedic and Sports Physical Therapy,* 13(5): 235–239. https://www.jospt.org/doi/10.2519/jospt.1991.13.5.235

Lin, L.I. (1989). A concordance correlation coefficient to evaluate reproducibility. *Biometrics,* 45(1): 255–268. https://doi.org/10.2307/2532051

López-Taylor, J.R., González-Mendoza, R.G., Gaytán-González, A., Jiménez-Alvarado, J.A., Villegas-Balcázar, M., Jáuregui-Ulloa, E.E., Torres-Naranjo, F. (2018). Accuracy of Anthropometric Equations for Estimating Body Fat in Professional Male Soccer Players Compared with DXA. *Journal of Sports Medicine (Hindawi Publishing Corporation),* 2018: 6843792. https://doi.org/10.1155/2018/6843792

Mascherini, G., Gatterer, H., Lukaski, H., Burtscher, M., & Galanti, G. (2015). Changes in hydration, body-cell mass and endurance performance of professional soccer players through a competitive season. *The Journal of Sports Medicine and Physical Fitness,* 55(7–8): 749–755.

Matias, C.N, Campa, F., Cavaca, M., Paoli, A., Teixeira, F. (2022). Fat-free mass estimation in male elite futsal players: development and validation of a new bioelectrical impedance-based predictive equation. *Nutrition,* 107: 111931. https://doi.org/10.1016/j.nut.2022.111931

Matias, Catarina N, Campa, F., Santos, D.A., Lukaski, H., Sardinha, L.B., Silva, A.M. (2021). Fat-free Mass Bioelectrical Impedance Analysis Predictive Equation for Athletes using a 4-Compartment Model. *International Journal of Sports Medicine,* 42(1): 27–32. https://doi.org/10.1055/a-1179-6236

McBride, G.B. (2007). Statistical calculators. *Lin's Concordance*.

Mondal, H., Mishra S.P. (2017). Effect of BMI, Body Fat Percentage and Fat Free Mass on Maximal Oxygen Consumption in Healthy Young Adults. *Journal of Clinical and Diagnostic Research*. 11(6): https://doi.org/10.7860/JCDR/2017/25465.10039

Nescolarde, L., Yanguas, J., Lukaski, H., Alomar, X., Rosell-Ferrer, J., Rodas, G. (2013). Localized bioimpedance to assess muscle injury. *Physiological Measurement,* 34(2): 237–245.

Ostojic, S. M. (2002). Changes in body fat content of top-level soccer players. *Journal of Sports Science & Medicine,* 1(2): 54–55.

Paoli, A., Cenci, L., Pompei, P., Sahin, N., Bianco, A., Neri, M., Caprio, M., Moro, T. (2021). Effects of Two Months of Very Low Carbohydrate Ketogenic Diet on Body Composition, Muscle Strength, Muscle Area, and Blood Parameters in Competitive Natural Body Builders. *Nutrients,* 13(2): 374. https://doi.org/10.3390/nu13020374

Paoli, A., Mancin, L., Caprio, M., Monti, E., Narici, M. V, Cenci, L., Piccini, F., Pincella, M., Grigoletto, D., & Marcolin, G. (2021). Effects of 30 days of ketogenic diet on body composition, muscle strength, muscle area, metabolism, and performance in semi-professional soccer players. *Journal of the International Society of Sports Nutrition,* 18(1): 62. https://doi.org/10.1186/s12970-021-00459-9

Petri, C., Campa, F., Hugo Teixeira, V., Izzicupo, P., Galanti, G., Pizzi, A., Badicu, G., Mascherini, G. (2020). Body Fat Assessment in International Elite Soccer Referees. *Journal of Functional Morphology and Kinesiology*, 5(2): 38. https://doi.org/10.3390/jfmk5020038

Reilly, T., George, K., Marfell-Jones, M., Scott, M., Sutton, L., Wallace, J. A. (2009). How well do skinfold equations predict percent body fat in elite soccer players?. *International Journal of Sports Medicine,* 30(8): 607–613. https://doi.org/10.1055/s-0029-1202353

Santos, D.A., Dawson, J.A., Matias, C.N., Rocha, P.M., Minderico, C.S., Allison, D.B., Sardinha, L.B., Silva, A.M. (2014). Reference values for body composition and anthropometric measurements in athletes. *PLoS ONE*, 9(5): https://doi.org/10.1371/journal.pone.0097846

Sardinha, L.B., Correia, I.R., Magalhães, J.P., Júdice, P.B., Silva, A.M., Hetherington-Rauth, M. (2020). Development and validation of BIA prediction equations of upper and lower limb lean soft tissue in athletes. *European Journal of Clinical Nutrition,* 74(12): 1646–1652. https://doi.org/10.1038/s41430-020-0666-8

Silva, J.R., Brito, J., Akenhead, R., Nassis, G.P. (2016). The Transition Period in Soccer: A Window of Opportunity. *Sports Medicine,* 46(3): 305–313. https://doi.org/10.1007/s40279-015-0419-3

Slimani, M., Nikolaidis, P.T. (2019). Anthropometric and physiological characteristics of male soccer players according to their competitive level, playing position and age group: a systematic review. *The Journal of Sports Medicine and Physical Fitness,* 59(1): 141–163. https://doi.org/10.23736/S0022-4707.17.07950-6

Stratton, M.T., Smith, R.W., Harty, P.S., Rodriguez, C., Johnson, B.A., Dellinger, J.R., Williams, A.D., White, S.J., Benavides, M.L., Tinsley, G.M. (2021). Longitudinal agreement of four bioimpedance analyzers for detecting changes in raw bio impedance during purposeful weight gain with resistance training. *European Journal of Clinical Nutrition*, 75(7): 1060–1068. https://doi.org/10.1038/s41430-020-00811-3

Suarez-Arrones, L., Lara-Lopez, P., Maldonado, R., Torreno, N., De Hoyo, M., Nakamura, F. Y., Di Salvo, V., & Mendez-Villanueva, A. (2019). The effects of detraining and retraining periods on fat-mass and fat-free mass in elite male soccer players. *Peer Journal,* 7: e7466. https://doi.org/10.7717/peerj.7466

Suarez-Arrones, L., Petri, C., Maldonado, R.A., Torreno, N., Munguía-Izquierdo, D., Di Salvo, V., Méndez-Villanueva, A. (2018). Body fat assessment in elite soccer players: cross-validation of different field methods. *Science and Medicine in Football*, 2(3): 203–208. https://doi.org/10.1080/24733938.2018.1445871

Wang, Z., Pi-Sunyer, F.X., Kotler, D. P., Wielopolski, L., Withers, R. T., Pierson, R. N. J., Heymsfield, S. B. (2002). Multicomponent methods: evaluation of new and traditional soft tissue mineral models by in vivo neutron activation analysis. *The American Journal of Clinical Nutrition,* 76(5): 968–974. https://doi.org/10.1093/ajcn/76.5.968

Withers, R.T., Craig, N.P., Bourdon, P.C., Norton, K.I. (1987). Relative body fat and anthropometric prediction of body density of male athletes. *European Journal of Applied Physiology and Occupational Physiology,* 56(2): 191–200. https://doi.org/10.1007/BF00640643

## Funding

There is no external funding to declare

## Conflicts of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

## Informed Consent Statement

All the athletes included in the study provided written informed consent.

## About the License