Nutrition 31 (2015) 948–954

Contents lists available at ScienceDirect

Nutrition

journal homepage: www.nutritionjrnl.com

Applied nutritional investigation

Utility of novel body indices in predicting fat mass in elite athletes

Diana A. Santos Ph.D. [a], Analiza M. Silva Ph.D. [a,*], Catarina N. Matias Ph.D. [a], João P. Magalhães M.Sc. [a], Cláudia S. Minderico Ph.D. [b], Diana M. Thomas Ph.D. [c], Luís B. Sardinha Ph.D. [a]

[a] Exercise and Health Laboratory, CIPER, Faculdade de Motricidade Humana, Universidade de Lisboa, Lisbon, Portugal
[b] Faculty of Physical Education and Sport, Lusófona University, Lisbon, Portugal
[c] Center for Quantitative Obesity Research, Montclair State University, Montclair, New Jersey, USA

ARTICLE INFO

Article history:
Received 30 May 2014
Accepted 8 February 2015

Keywords:
Athletes
Multicomponent models
Adiposity
Body adiposity index
Body roundness index
Body mass index

ABSTRACT

Objective: Recently, new body indices, including body adiposity (BAI), a body shape (ABSI), and body roundness (BRI) indices have been developed to estimate adiposity. The aim of this study was to compare percent fat mass (%FM) with novel indices in an elite athlete population.
Methods: Using a cross-sectional design, %FM in 159 male and 50 female athletes using a four-component model was assessed. The %FM was compared with body mass index (BMI), BAI, ABSI, BRI, and with other %FM field methods (bioimpedance spectroscopy and skinfold prediction equation). These associations were determined using multilinear regression analysis, which resulted in predictive models of %FM in athletes. Cross-validation was performed using the prediction residual error sum of squares (PRESS) statistics method.
Results: Although higher associations than other indices were observed, BRI still presented low coefficients of determination (men: $R^2 = 0.36$; women: $R^2 = 0.25$) when comparing with other field methods (R^2 range, 0.33–0.75). Using BAI as the independent variable, the R^2 was 0.07 for men and 0.14 for women. ABSI did not result in a significant association with %FM in women ($R^2 = 0.05$) while in men a significant association was found ($R^2 = 0.22$). The BMI model resulted in a $R^2 = 0.20$ for men and $R^2 = 0.22$ for women. Waist circumference and the sum of skinfolds were the anthropometric variables with the highest association with adiposity. New alternatives were presented with higher coefficients of determination (PRESS R^2 ranged from 0.47 to 0.71).
Conclusions: The newly developed body indices are limited in predicting %FM in elite athletes, particularly when compared with other commonly and readily available field methods like bioimpedance analysis or skinfold prediction models.

Introduction

For individuals who regularly expend high amounts of energy on a daily basis, adequate nutrition is a primary concern. It is recognized that an accurate body composition assessment is relevant for prescribing an adequate nutritional regimen in highly trained athletes [1]. Specifically, athlete adiposity is regularly monitored to ensure mandatory levels of body adiposity are maintained [1,2]. Higher adiposity can have a negative effect on physical performance. Conversely, a deliberately induced underweight condition that leads to severe health problems is of equal concern [1,3]. To meet these growing concerns, the International Olympic Committee Medical Commission recently advised regular monitoring of body composition in athletes and emphasized the need for standardizing assessment procedures [1,2].

A multicomponent model [4] is the state-of-art method for assessing fat mass (FM) as it accounts for the known variability of fat-free mass (FFM) variability by including measures of body

This work was supported by the Portuguese Foundation for Science and Technology (Grant: PTDC/DES/098963/2008). All authors were responsible for the conception and design of the study. DAS was responsible for the analysis and interpretation of data and drafting the manuscript. AMS and CSM were responsible for interpretation of data and revision of the manuscript. CNM and JPM were involved in the collection of data and drafting the manuscript. DMT and LBS were responsible for analysis and interpretation of data and revision of the manuscript.

* Corresponding author. Tel.: +35 121 414 9160; fax: +35 121 414 9193.
E-mail address: Lsardinha@fmh.ulisboa.pt (A. M. Silva).

http://dx.doi.org/10.1016/j.nut.2015.02.003
0899-9007/

water, mineral, and protein. Omission of these components of FFM contributes to the major error source in the assessment of the athlete's body composition. Unfortunately, multicomponent models are time consuming and require access to expensive and sophisticated technology, making them unfeasible for widespread individual application [1]. There is a gap in valid alternate proxies to estimate adiposity in athletes [5]. Recently, there has been an effort to develop new approaches [6,7] but these approaches are still time consuming. Thus, alternate less-expensive, simple, scalable alternatives need to be validated for adiposity estimates in athletes.

Bioelectrical impedance spectroscopy (BIS) [8] or skinfold prediction models [9] may be useful to routinely assess adiposity in athletes. Quantifying adiposity via an index derived from anthropometric measures offers widespread utility for body composition assessment [1]. The most popular index is the body mass index (BMI) [10,11], however, BMI has limited utility in athletes often misclassifying individuals with high FFM relative to stature as having higher adiposity [12]. More recently, novel indices to predict adiposity have been derived, including a body adiposity index (BAI) [13]; a body shape index (ABSI) [14]; and a recently derived geometric-based index, the body roundness index (BRI) [15]. The BAI has already been established as inferior to BMI in predicting %FM [16–21], however, the body indices have not been compared in elite athletes.

The aim of this study was to analyze the accuracy of BMI and novel indices such as BAI, ABSI, and BRI in predicting %FM assessed by a four-component (4-C) model in elite male and female athletes.

Material and methods

Participants

Using a cross-sectional design, 209 athletes (159 men, 50 women) were evaluated during the in-season. The sample included national elite-level athletes involved in 15 sports recruited at the National Sports Center. Athletes participating in this study were subject to the following inclusion criteria: 1) training >10 h/wk; 2) testing negative for performance-enhancing drugs; and 3) taking no additional medications. Medical screening indicated that all individuals were in good health. All participants provided informed consent before participating. All procedures were approved by the Ethics Committee (Faculty of Human Kinetics, Technical University of Lisbon), and were conducted in accordance with the declaration of Helsinki for human studies of the World Medical Association [22].

Procedures

Athletes came to the laboratory in a fasted state, and had refrained from exercise and alcohol or stimulant beverages for at least 10 h.

Anthropometry

Body mass (BM) to the nearest 0.01 kg and stature to the nearest 0.1 cm were measured as described in the Anthropometric Standardization Reference Manual [23] on an electronic scale connected to the plethysmograph computer (BOD-POD© COSMED, Rome, Italy) and a stadiometer (Seca, model 222 [6–230 cm], Hamburg, Germany), respectively.

Waist and hip circumference (WC and HC) were measured with a tape (Lufkin W606 PM, Apex Tool Group, Sparks, MD, USA) and reported to the nearest 0.1 cm. WC was measured at minimal respiration by positioning a flexible anthropometric tape parallel to the floor and immediately above the iliac crest [10]. HC was measured over nonrestrictive underwear or lightweight shorts, at the level of the maximum extension of the buttocks posteriorly in a horizontal plane [23].

Body indices calculations

The formulas for BMI, BAI [13], ABSI [14], and BRI [15] are described in equations 1 to 4.

$$BMI = body\ mass/stature^2 \quad (1)$$

$$BAI = \left(hip\ circumference/stature^{1.5}\right) - 18 \quad (2)$$

$$ABSI = waist\ circumference/\left(BMI^{2/3} \times stature^{1/2}\right) \quad (3)$$

$$BRI = 364.2 - 365.5 \times eccentricity \quad (4)$$

$$eccentricity = \left(\frac{\sqrt{a^2 - waist\ circumference^2}}{a}\right)$$

where stature, hip, and waist circumference are in m and BM in kg; a = stature/2.

In equation 4, eccentricity quantifies the degree of circularity of an ellipse, and its values range between 0 and 1, with 0 characterizing a perfect circle, and 1, a vertical line.

Skinfold measurement including abdominal, thigh, and triceps were performed as described by previously [23] using a Slim Guide caliper (Creative Health Products, Ann Arbor, MI, USA). Three measurements of each skinfold were performed to the nearest 0.5 mm and the average was used. The Evans-3 skinfold [9] equation for athletes was used to estimate %FM using the sum of the three skinfolds (3SKF) as described in equation 5:

$$\%FM = 8.997 + 0.24658 \times (3SKF) + 6.343 \times (sex) + 1.998 \times (race) \quad (5)$$

where sex: 0 = women and 1 = men; race: 0 = white and 1 = black.

Somatotype equations were applied to calculate endomorphy, mesomorphy, and ectomorphy, and athletes were categorized according to the following classifications: central, endomorph, endomorph-mesomorph, mesomorph, mesomorph-ectomorph, ectomorph, ectomorph-endomorph [24].

Body composition

A 4-C model was used to estimate FM [4]. The 4-C model is formulated as,

$$FM(kg) = 2.748 \times BV - 0.699 \times TBW + 1.129 \times Mo - 2.051 \times BW \quad (6)$$

where BV is body volume (L), TBW is total body water (kg), Mo is bone mineral (kg), and BW is body mass (kg).

TBW was assessed by deuterium dilution using a stable Hydra gas isotope ratio mass spectrometer (PDZ, Europa Scientific, UK), according to procedures formerly described [25]. A whole-body dual-energy X-ray absorptiometry scan (Hologic Explorer-W, fan-beam densitometer, software QDR for Windows v12.4, Hologic, Waltham, MA, USA) was performed to estimate Mo, total lean soft tissue (LST), and appendicular lean soft tissue (ALST) according to procedures described previously [26]. Body volume was assessed by air displacement plethysmograph (BOD POD©COSMED, Rome, Italy), as previously described [27].

FFM was calculated as BM minus FM and calculation of FFM density (FFM_D) was estimated [28].

Bioelectrical impedance spectroscopy

Whole-body resistance and reactance were assessed with a bioelectrical impedance spectroscopy (BIS) model 4200 (Xitron Technologies, San Diego, CA, USA) according to procedures described elsewhere [29]. The FFM was computed using the equipment's prediction equations and %FM calculated assuming a two-component model (BM = FM + FFM).

Statistical analysis

Data analysis was performed using IBM-SPSS Statistics version 21.0, 2012 (IBM, Chicago, IL, USA). Descriptive statistics including means ± SD were calculated for all outcome measurements. One-sample t tests were used to compare group means with the established values for FFM_D and composition values based on cadaver analysis [30]. Simple and age-adjusted linear regression analyses were used to verify the association between body indices and other anthropometric and body composition variables with %FM and to test for interactions. Body indices association with %FM from the 4-C model was compared with the association with other field methods (BIS and skinfold model) to establish criteria on whether body indices are useful to predict adiposity in athletes. Correlation coefficients were compared using the Fisher's Z-transformation test using the MedCalc Statistical Software v.11.1.1.0 (Mariakerke, Belgium).

Models for predicting %FM were developed using multiple regression analysis. Significance of the covariates, sex, age, BM, stature, waist eccentricity, hip eccentricity, WC, and HC were explored using a backward stepwise procedure. During model development, normality and homoscedasticity of residuals were tested. The criterion for inclusion of a predictor was significant at $P = 0.05$ and removal at $P = 0.10$. If more than one variable remained in the model, a variance inflation factor for each independent variable was calculated to evaluate multicollinearity [31]. Internal cross-validation of the new models was performed