Are Skinfold-Based Models Accurate and Suitable for Assessing Changes in Body Composition in Highly Trained Athletes?

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Abstract

Silva, AM, Fields, DA, Quitério, AL, and Sardinha, LB. Are skinfold-based models accurate and suitable for assessing changes in body composition in highly trained athletes? *J Strength Cond Res* 23(6): 1688–1696, 2009—This study was designed to assess the usefulness of skinfold (SKF) equations developed by Jackson and Pollock (JP) and by Evans (Ev) in tracking body composition changes (relative fat mass [%FM], absolute fat mass [FM], and fat-free mass [FFM]) of elite male judo athletes before a competition using a 4-compartment (4C) model as the reference method. A total of 18 male, top-level (age: 22.6 ± 2.9 yr) athletes were evaluated at baseline (weight: 73.4 ± 7.9 kg; %FM4C: 7.0 ± 3.3%; FM4C: 5.1 ± 2.6 kg; and FFM4C: 68.3 ± 7.3 kg) and before a competition (weight: 72.7 ± 7.5 kg; %FM4C: 6.5 ± 3.4%; FM4C: 4.8 ± 2.6 kg; and FFM4C: 67.9 ± 7.1 kg). Measures of body density assessed by air displacement plethysmography, bone mineral content by dual energy X-ray absorptiometry, and total-body water by bioelectrical impedance spectroscopy were used to estimate 4C model %FM, FM, and FFM. Seven SKF site models using both JP and Ev were used to estimate %FM, FM, and FFM along with the simplified Ev3SKF site. Changes in %FM, FM, and FFM were not significantly different from the 4C model. The regression model for the SKF in question and the reference method did not differ from the line of identity in estimating changes in %FM, FM, and FFM. The limits of agreement were similar, ranging from −3.4 to 3.6 for %FM, −2.7 to 2.5 kg for FM, and −2.5 to 2.7 kg for FFM. Considering the similar performance of both 7SKF- and 3SKF-based equations compared with the criterion method, these data indicate that either the 7- or 3-site SFK models are not valid to detect %FM, FM, and FFM changes of highly trained athletes. These results highlighted the inaccuracy of anthropometric models in tracking desired changes in body composition of elite male judo athletes before a competition.

Key Words weight change, anthropometry, judo, multicomponent models

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Introduction

The lack of quick and valid body composition methods to assess fat mass (FM) and fat-free mass (FFM) do not allow the estimation of a correct minimal weight of athletes in specific sports such as wrestling and the martial arts (e.g., judo and karate), although a few studies reported accurate estimations when using the National Collegiate Athletic Association methods (6,9,39). A correct evaluation of weight reduction or gain in terms of body components at the molecular level is important to understand the implication for the composition of FFM changes, particularly in athletes. At the simplest level, techniques for measuring body composition can assume that the body is divided into two compartments, FM and FFM. The fat component is relatively homogeneous, but FFM consists of a heterogeneous mix of water, mineral, protein, and additional minor constituents (4). To quantify the amount of FM and FFM using a 2-compartment model, one must assume that these components exist in a known relationship to each other. For example, hydrodensitometry (i.e., underwater weighing), assumes known densities of FM and FFM. By measuring the mass and volume of a subject, one could estimate the amount of FM and FFM on the basis of the assumed densities of these compartments. In clinical practice, however, there is considerable interindividual variability in the density of FFM (DFFM) that can affect the accuracy of this measure (2,18). These within-subject differences, particularly in the proportion of water and mineral in FFM, is particularly determinant in an athletic population, contributing to increase the absolute error of a method that may not account for this variability. Molecular models that assess more than one FFM component have become widely used as the reference for FM estimation (35).

Because of the changes in FFM and total body composition that can occur to reach a target body weight (BW) before a competition, the use of multicompartment models is crucial as various components of the FFM are independently measured, thus reducing the error involved with body composition measurement (15). The 4-compartment (4C) model, which divides BW into FM, total-body water (TBW), mineral, and protein, is an example of a reference molecular model that permits the evaluation of these 3 most important FFM components. One of the primary advantages of the 4C model is that it provides a more accurate measure of body composition than do other methods, particularly because it requires fewer assumptions than 3- and 2-compartment models (20). Despite their apparent advantages, few studies have used 4C models to evaluate changes in body composition (14). The elevated cost and lack of accessibility in using a 4C model may explain the shortage of body composition research developed on athletes, particularly in follow-up studies, highlighting a need to identify alternative methods that are convenient, reliable, and accurate for measuring changes in body composition that occur in this population. Anthropometric methods are, therefore, a widely used technique to assess and track body composition in athletes in the clinical practice (29). However, few studies have validated skinfold (SKF)-based models against a 4C model to detect body composition changes in male athletes (40). Therefore, the aim of the present study was to assess the usefulness of 3 anthropometric-based models in tracking body composition changes of elite Portuguese men judo athletes before a competition.

Methods

Experimental Approach to the Problem

Elite male judo athletes were studied at baseline and before a competition. The absolute (FM) and relative fat mass (%FM) and FFM changes were assessed by a reference method (dependent variables) used to validate %FM, FM, and FFM obtained from SKF -based equations (independent variables); that is, the predictability of bedside techniques in assessing body composition changes estimated by the 4C model was tested. This information will be useful for determining the ability of bedside techniques in accurately tracking body composition changes before a competition.

Subjects

Eighteen male judo athletes were eligible to participate in the study. Subject demographic data are presented in Table 1.

The inclusion criteria were (a) greater than 18 years of age, (b) practiced rapid weight reduction on their own volition greater than 3 times in the past year, (c) minimal sport practice period of approximately 5 years, (d) participated in at least 15 hours of training per week; (e) minimum technical level of first degree black belt, (f) negative antidoping controls, (g) not taking any drugs or medication or any supplements. Medical screening indicated that none of the subjects had any endocrine or other medical problems that would confound their participation in the study. All subjects were informed about the possible risks of the investigation before giving their written informed consent to participate, and all procedures were approved by the Institutional Review Board of the Faculty of Human Movement, Technical University of Lisbon.

Table 1. Subject characteristics at baseline, before competition, and respective differences in fat mass, percent fat mass, and fat-free mass.

	Baseline	Before competition	Changes
N = 18	Mean ± *SD*	Mean ± *SD*	Mean ± *SD*
Age (yr)	22.6 ± 2.9		
Stature (m)	1.74 ± 0.05		
Weight (kg)	73.4 ± 7.9	72.7 ± 7.5	−0.78 ± 2.15
BMI (kg/m^2)	24.1 ± 2.1	23.8 ± 1.9	−0.26 ± 0.71

*BMI = body mass index.

Experimental Design

A convenient sample of national top-level judo athletes engaged in this sport for more than 7 years was used. Data collection was performed between September (1 month after beginning the season) to December.

Body composition assessment was made during a period of weight maintenance (T1) and again before competition (T2). A period of approximately 1 month was used between T1 and T2. The period of weight maintenance (T1) is considered the baseline phase, with judo athletes performing their regular regimens of judo training, which typically last approximately 2 hours in the morning and approximately 2 hours in the evening. Two of the morning sessions are used for improving cardiorespiratory fitness and strength, whereas the other sessions consist of judo-specific skills and drills and randori (fighting practice) with varying intensity above and up to 90–95% of $\dot{V}O_{2max}$. Before the competition, some of these athletes lost weight through self-determined means, whereas others remained or increased their BW.

Body Composition Measurements

Subjects came to the laboratory at T1 and T2, after a 12-hour fast, and after approximately 15 hours without exercise, alcohol, or stimulant beverages. All measurements were carried out on the same morning. The procedures are described as follows.

Anthropometry. Subjects were weighed to the nearest 0.01 kg while they wore a bathing suit and without shoes on an electronic scale connected to the plethysmograph computer (BOD POD, Life Measurement, Inc., Concord, CA, USA). Height was measured to the nearest 0.1 cm with a stadiometer (Seca, Hamburg, Germany). Three anthropometric SKF models were used: (a) Jackson and Pollock (JP), (b) Evans-7 skinfold (Ev7SKF), and (c) Evans-3 skinfold (Ev3SKF), as described below.

a. Jackson and Pollock: 7 - site SKF method (22)

$$\text{Body density (BD)(g/mL)} = 1.112 - 0.00043499 \times (\Sigma\,7\text{SKF}) + 0.00000055 \times (\Sigma\,7\text{SKF})^2 - 0.00028826 \times (\text{age})$$

BD is then converted to %FM using the Siri equation (37):

$$\%\text{FM} = [(4.95/\text{BD}) - 4.50] \times 100$$

b. Evans: 7 - site SKF Method (12)

$$\%\text{FM} = 0.566 + 0.12077 \times (7\text{SKF}) - 8.057 \times (\text{sex}) - 2.545 \times (\text{ethnicity})$$

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

c. Evans: 3 - site SKF Method (12)

$$\%\text{FM} = 8.997 + 0.24658 \times (3\text{SKF}) - 6.343 \times (\text{sex}) - 1.998 \times (\text{ethnicity})$$

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

A trained researcher performed the SKF measurements according to the standardized procedures described elsewhere (28) using a Lange caliper (Cambridge Scientific, Cambridge, MD, USA). On the basis of test-retest using 10 subjects, the technical error of measurement (TEM) and intraclass coefficient of correlation (ICC) ranged from 0.3 to 1 mm for TEM and from 0.97 to 1.00 for ICC.

Four-Compartment Model. A 4C model was used as the reference method, calculated after using the total-body soft tissue mineral (Ms) component obtained as Ms = 0.0129 × TBW (41). The model is as follows:

$$\text{FM} = 2.748 \times \text{BV} - 0.715 \times \text{TBW} + 1.129 \times \text{Mo} + 1.222 \times \text{Ms} - 2.051 \times \text{BW} \quad (1),$$

where BV is body volume (L), TBW is total-body water (kg), Mo is bone mineral (kg), Ms is total-body soft tissue mineral, and BW is body weight (kg).

Accordingly, equation 1 was then recalculated as

$$\text{FM(kg)} = 2.748 \times \text{BV} - 0.699 \times \text{TBW} + 1.129 \times \text{Mo} - 2.051 \times \text{BW} \quad (2),$$

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

Calculation of Fat-Free Mass Density

The DFFM was estimated from TBW, Mo, Ms, and protein (protein is equal to BW minus FM from the 4C model, TBW, Mo, and Ms) contents of FFM (estimated as BW minus FM from the 4C model) and their densities (0.9937, 2.982, 3.317, and 1.34 g/mL) for TBW, Mo, Ms, and protein, respectively,

$$\text{DFFM} = 1/[(\text{TBW}/\text{DTBW}) + (\text{Mo}/\text{DMo}) + (\text{Ms}/\text{DMs}) + (\text{protein}/\text{Dprotein})]$$

Bone Mineral. Dual energy x-ray absorptiometry (DXA), a Hologic model QDR 4500A fan-beam densitometer (QDR-4500, Hologic, Waltham, USA), was used to measure bone mineral content (BMC) by using a software version 8.21. Scan positioning, acquisition, and analysis were standardized. All subjects had fan-beam scans. Considering that BMC represents ashed bone, BMC was converted to total-body Mo by multiplying it by 1.0436 (19). On the basis of test-retest using 10 subjects, the TEM, the coefficient of variation (CV), and ICC for BMC in our laboratory were 0.02 kg, 1.6%, and 1.00, respectively.

Body Volume. Body volume was assessed by air displacement plethysmograpy (ADP) (Life Measurement, Inc., Concord, CA, USA). The use of this method is described in detail elsewhere (8,31). After voiding the bladder, each subject was weighed to the nearest gram while he wore a swimsuit. The ADP device was calibrated according to the manufacturer's instructions, and raw BV was determined. The effects of clothing and hair are accounted for by using minimal clothing, such as a bathing suit, and by compressing hair with a swim cap. Finally, thoracic gas volume was measured in the BOD POD by using a technique common to standard pulmonary plethysmography called the "panting maneuver." While wearing a nose clip, the subjects breathed through a tube; after 2 to 3 normal breaths, the airway occluded for 3 seconds at midexhalation. During this time, the subject was instructed to gently puff against the occlusion by alternately contracting and relaxing the diaphragm. At baseline, thoracic gas volume was measured in all subjects and was entered during their 1-month follow-up precompetition assessment.

All measurements were conducted with software version 1.68. The TEM, CV, and ICC for BV, on the basis of test-retest using 10 subjects, were 0.2 L, 0.5%, and 1.00, respectively.

Total-Body Water. An accurate method to estimate TBW is bioelectrical impedance spectroscopy (BIS) analysis (model 4000B, Xitron Technologies, San Diego, CA, USA). Before the test, subjects were instructed to lie in a supine position with their arms and legs abducted at a 45° angle for 10 minutes. This impedance spectra was modelled with the Cole-Cole cell suspension model (7) to derive a theoretical impedance at zero and infinity frequency based on a nonlinear curve fitting from the measured resistance and reactance. Intracellular water (ICW) and extracellular water (ECW) were predicted from the Hanai mixture theory (17), and TBW was estimated by the sum of ICW and ECW. A correlation coefficient of 0.96 between BIS and a dilution method has been reported (30). Unpublished results from our

laboratory indicate that estimations of TBW using isotopic mass spectrometry and deuterium are highly correlated ($r = 0.93$). On the basis of test-retest using 10 subjects, the TEM, CV, and ICC for TBW were 0.47 L, 1.1%, and 1.00, respectively.

Propagation Measurement Error. In the present study, we selected ADP to assess BV, DXA to estimate Mo, and BIS to estimate TBW. The propagation of measurement errors associated with the determination of BV, TBW, and Mo can be calculated by assuming that the squared technical errors of measurement (TEM²) are independent and additive (42). Accordingly,

$$\text{TEM} = [\text{TEM}^2 \text{ for effect of ADP on \%FM} + \text{TEM}^2 \text{ for TBW on \%FM} + \text{TEM}^2 \text{ for Mo on \%FM}]^{0.5}$$

Using the above equation,

$$\text{TEM} = [0.81^2 + 0.34^2 + 0.04^2]^{0.5} = 0.77$$

% FM from TEM values.

From these calculations, the test-retest reliability in the present study was seen to be approximately 0.8% FM units.

Statistical Analysis

Data were analysed with SPSS for Windows version 14.0 (SPSS, Inc., Chicago, IL, USA). Descriptive statistics including means ± *SD* were calculated for all outcome measurements.

Using 18 subjects, this study is 80% powered to detect a correlation coefficient higher than 0.60 or lower than −0.60. Also, with 18 subjects, using a paired *t*-test for dependent data, this study is 80% powered to detect an effect size of 0.7 or larger.

Simple linear regressions were performed to calculate the relationship between FM, %FM, and FFM estimated by the reference 4C model and 3 SKF-based methods. Comparison of group means was performed using one-sample *t*-test. Agreement between methods was assessed (3), including the 95% limits of agreement. The correlation between the mean of the reference method and the assessed method with difference between both was used as an indication of trend (i.e., the difference between the methods varied across fatness levels). Also, the correlation between BW, FFM hydration, and density changes were performed, with the differences between FM, %FM, and FFM changes estimated by the reference 4C model and the 3 SKF-based methods. Also, the correlation between the sum of trunk SKF and trunk FM changes assessed by DXA were performed. For all tests, statistical significance was set at $p < 0.05$.

Results

The mean and *SDs* at baseline, before competition, and respective differences in %FM, FM, and FFM by the indicated methods are summarized in Table 2.

When compared with the reference 4C model, %FM, FM, and FFM assessed by JP, Ev7SKF, and Ev3SKF did not differ at baseline and after weight loss ($p < 0.05$), whereas the equations developed by Ev significantly overestimated %FM and FM and underestimated FFM in relation to the 4C model cross-sectionally ($p < 0.05$). At baseline (DFFM = 1.099 ± 0.006 g/mL) and before the competition

Table 2. Body composition variables at baseline, before competition, and respective differences in fat mass, percent fat mass, and fat-free mass.

	Baseline	Before competition	Changes
N = 18	Mean ± *SD*	Mean ± *SD*	Mean ± *SD*
$\%FM_{4C}$	7.0 ± 3.3	6.5 ± 3.4	−0.44 ± 2.17
FM_{4C} (kg)	5.1 ± 2.6	4.8 ± 2.6	−0.37 ± 1.64
FFM_{4C} (kg)	68.3 ± 7.3	67.9 ± 7.1	−0.41 ± 1.79
$\%FM_{JP}$	6.5 ± 2.4	6.0 ± 2.0	−0.53 ± 1.08
FM_{JP} (kg)	4.9 ± 2.1	4.4 ± 1.7	−0.47 ± 0.92
FFM_{JP} (kg)	68.6 ± 6.7	68.3 ± 6.7	−0.31 ± 1.73
$\%FM_{Ev7SKF}$	9.0 ± 1.9‡	8.6 ± 1.5‡	−0.42 ± 0.85
FM_{Ev7SKF} (kg)	6.7 ± 1.9‡	6.3 ± 1.5‡	−0.40 ± 0.78
FM_{Ev7SKF} (kg)	66.8 ± 6.6‡	66.4 ± 6.6‡	−0.38 ± 1.72
$\%FM_{Ev3SKF}$	8.7 ± 1.8‡	8.4 ± 1.5‡	−0.36 ± 0.90
FM_{Ev3SKF} (kg)	6.5 ± 1.8‡	6.1 ± 1.4‡	−0.36 ± 0.79
FM_{Ev3SKF} (kg)	67.0 ± 6.7‡	66.5 ± 6.7‡	−0.43 ± 1.66

*%FM = percent fat mass; FM = fat mass; FFM = fat-free mass; JP= Jackson and Pollock; Ev = Evans; 4C = 4-compartment; SKF = skinfold.

†Changes are calculated as Before Competition minus Baseline.

‡Significant difference from reference method, $p < 0.05$.

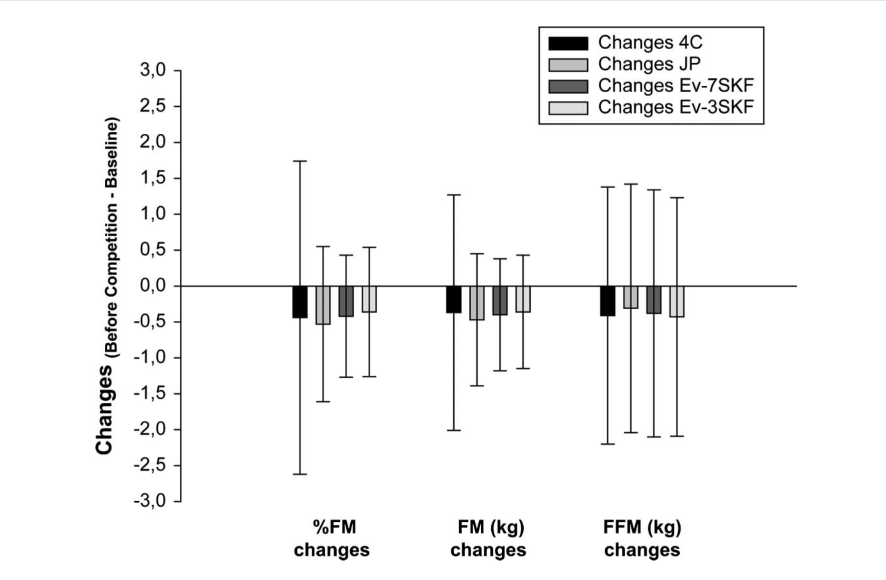

Figure 1. Mean percent fat mass (%FM), absolute FM, and fat-free mass (FFM) changes (calculated as baseline minus before competition) observed using each method against 4-compartment (4C) model. No mean differences were found between the skinfold-based equations and the 4C model ($p > 0.05$).

(DFFM = 1.102 ± 0.001 g/mL), DFFM was not different from the value obtained based on chemical cadaver analysis (1.1g/mL) (4), whereas all the FFM compartments deviated from the established values. At baseline, FFM hydration (TBW/FFM) was approximately 0.72 ± 0.02 and before the competition changed to approximately 0.71 ± 0.02; baseline mineral fraction (Mo/FFM) was approximately 0.057 ± 0.003 and before the competition approximately 0.058 ± 0.003; baseline protein fraction (Protein/FFM) was 0.22 ± 0.02 changing to 0.23 ± 0.02. Only DFFM significantly increased (ΔDFFM = 0.003 ± 0.005 g/mL, $p < 0.05$), whereas the changes observed on the FFM components were not significantly different from 0 (ΔTBW/FFM = 0.008 ± 0.017 g/mL; ΔMo/FFM = 0.0004 ± 0.0139; ΔProtein/FFM = 0.008 ± 0.017, $p > 0.05$).

A trend for a %FM, absolute FM, and FFM reduction assessed by the reference method was observed (not significantly different from 0, $p > 0.05$), ranging from −3.22 to

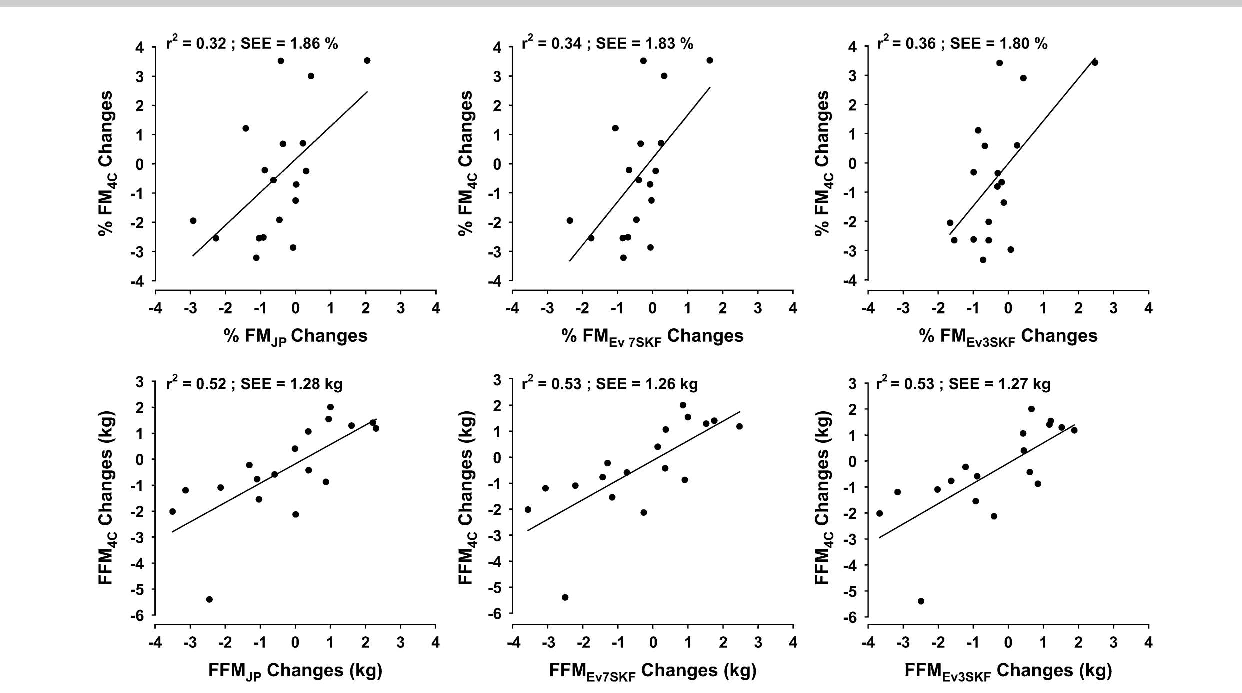

Figure 2. Regression of percent fat mass (%FM) changes (calculated as baseline minus before competition) obtained by each anthropometric model with reference method in upper panels and fat-free mass (FFM) changes by each method with reference method in lower panels. All regression lines did not differ from line of identity because slope and intercept were not different from 1 and 0, respectively ($p > 0.05$).

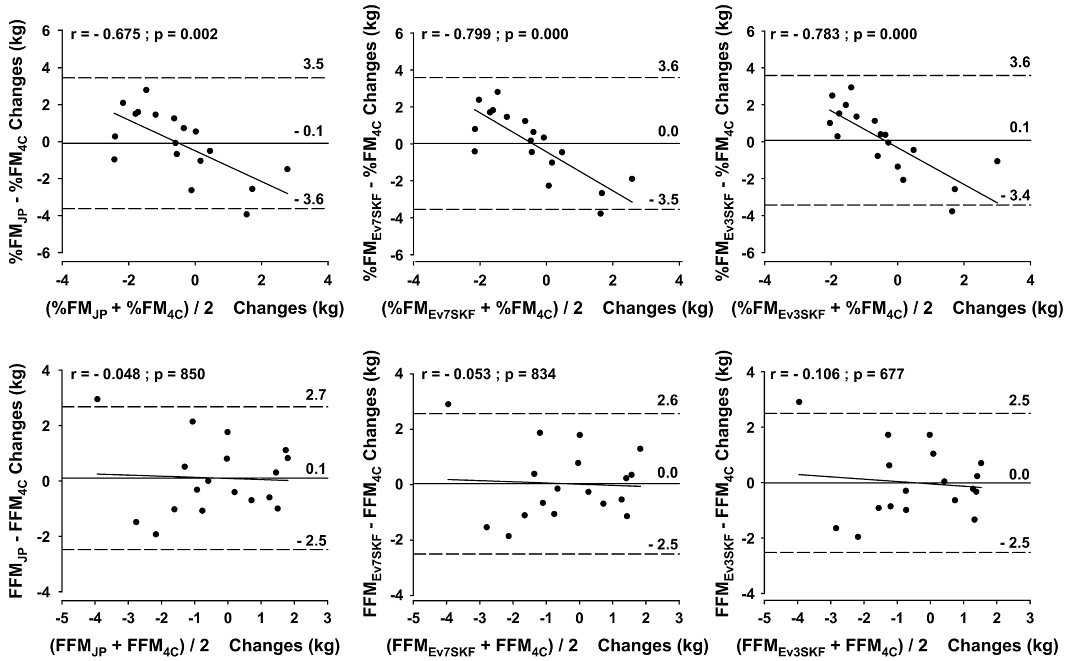

Figure 3. Bland-Altman analysis of agreement between methods in tracking body composition changes (calculated as baseline minus before competition). Middle solid line represents mean difference between percent fat mass (%FM) from each method minus %FM from 4C model (upper) and fat-free mass (FFM) from each method minus FFM from 4C model (lower). Upper and lower dashed line represents ± 2 *SD* from mean (i.e., 95% limits of agreement)(±1.96 *SD*). Trend line represents association between differences of methods (each technique minus 4C model) and mean of both methods in assessing %FM and FFM. Significant correlation was observed for %FM differences and mean %FM estimation of methods ($p < 0.05$) but not for FFM changes, as indicated by nonsignificant p value ($p > 0.05$).

3.53 %FM, −2.46 to 2.76 kg of FM, and from −5.4 to 2.0 kg of FFM. No mean differences were found between the 3 anthropometric models and the reference method in tracking mean %FM, FM, and FFM changes (Figure 1).

The body composition changes obtained using the selected SKF equations were highly related with those obtained from the 4C model in tracking %FM and FM changes, with coefficients of correlation ranging from 0.65 to 0.56 and FFM changes ranging from 0.72 to 0.73. The accuracy data of the anthropometric methods to estimate %FM and FFM changes are presented in Figure 2. Similar results to those obtained for %FM were found for absolute FM changes (JP: $R^2 = 0.36$, SEE = 1.35 kg; Ev7SKF: $R^2 = 0.40$, SEE = 1.31 kg; Ev3SKF: $R^2 = 0.42$, SEE = 1.29 kg). All the regression lines did not differ from the line of identity because the slopes and intercepts were not different from 1 and 0, respectively ($p > 0.05$).

The agreement between the 4C model and the other methods is shown in Figure 3. The 95% limits of agreement ranged from −3.4 to 3.6 for %FM, from −2.7 to 2.5 for FM, and from −2.5 to 2.7 for FFM. For %FM and FM changes, a significant trend was found between the difference of each anthropometric method and the 4C model with the mean of the methods ($p < 0.01$), except in detecting FFM changes ($p > 0.05$). Bland-Altman plots of %FM and FFM changes are shown in Figure 3.

The relation of FFM hydration and density on body composition differences was investigated to determine the association of the between-body composition measures and the 4C model. None of those changes were significantly related with the differences obtained between body composition variables from each anthropometric model and the 4C model ($p > 0.05$); that is, the differences between the SKF-based models and the 4C model in tracking %FM, FM, and FFM are not dependent on the magnitude of the FFM hydration and density changes.

The relationship between the differences in %FM, absolute FM, and FFM using each method and the reference method with BW changes were tested. No association was found between BW changes and the difference between the reference 4C model and the 3 anthropometric models ($p > 0.05$). Thus, body composition differences of each equation and the reference model did not depend on the magnitude of BW change ($p > 0.05$).

In addition, no association was found between absolute trunk FM changes, obtained by DXA, and the differences of absolute FM changes obtained by each method against the reference absolute FM changes ($p > 0.05$). Therefore, the

differences between the SKF-based methods and the 4C model in tracking absolute FM are not dependent on the magnitude of the trunk FM changes.

Discussion

The primary goal of this study was to examine the validity of anthropometric-based methods for measuring changes in body composition at baseline and before a competition in elite judo athletes using a molecular 4C reference model. Four-component models provide more accurate estimates of body composition than the other methods used to estimate body composition (26), and thus this study is unique in its approach. To our knowledge, studies have validated measures of body composition across weight loss in overweight or obese subjects by comparing them with the reference 4C model (1,13,14,32) and to DXA (11,44), but only 2 studies validated SKF-based models to track body composition in an athletic population (23,40).

van Marken Lichtenbelt et al. (40) examined the ability of various body composition methods using a 4C model as the reference method to detect changes in FM and FFM in 27 male bodybuilders after a period of exercise and androgenic-anabolic steroids. In this study, the authors used the Durnin and Womersly equation (10) and concluded that only the 3C model (incorporating BD as measured from underwater weighing and TBW as measured by deuterium dilution) could serve as an alternative for the 4C model if accurate measurements of body composition change are needed. The study of Kilduff et al. (23) validated the JP 7-site SKF equation in detecting body composition changes in highly trained athletes. These authors used underwater weighing as the criterion method, with the underlying assumptions inherent in such a model to test the effect of chromium supplementation on FFM. The findings of their study demonstrated that the JP equation was sensitive in quantifying acute changes in FFM after chromium supplementation to a similar level of more expensive techniques such as ADP and underwater weighing. Although no mean differences were observed in our models in estimating %FM, FM, and FFM changes when compared with the reference method, the equations were not sensitive enough to accurately predict body composition changes before a competition.

The cross-sectional data analysis indicates that both models developed by Ev overestimated FM and %FM and underestimated FFM at baseline and before the competition, respectively, whereas no significant cross-sectional differences were found using the JP equation. At baseline, FFM hydration in the present study was approximately 72%, decreasing to approximately 71% before the competition, values that differ from the assumed hydration status (73.8%) based on chemical cadavers (4). These findings may explain the observed and significant decrease in the DFFM because water presents the lowest density value (0.9937 g/mL) when compared with the remaining FFM components (mineral osseous: 2.982 g/mL; Ms: 3.317 g/mL; and protein: 1.34 g/mL), thus increasing the overall DFFM. Although no cross-sectional differences were found between DFFM observed and the assumed DFFM (1.1 g/mL), a significant increase of 0.003 g/mL was found. These findings may explain the similar mean values for %FM, FM, and FFM at both moments using the JP equation when compared with the 4C model. Because the conversion of BD to %FM was based on the assumed value of 1.1 g/mL for the DFFM, this underlying assumption was met at baseline and before the competition.

The models developed by Evans et al. used a 4C model as the reference method, whereas Jackson and Pollock used a 2C model as the criterion method. Therefore, we were expecting a better accuracy of the former models in predicting FM both cross-sectionally and longitudinally. We advance biological and methodologic errors to address this issue. The equations developed by Ev were not perfectly balanced by sex and race across the sport groups, and results may not have captured sport by sex by race interactions (12). Also, the type of athletic training was different from our judo male athletes and showed a higher variability (i.e., football, distance running, gymnastics), which may have affected the results in terms of fat patterning and SKF site selection. This variability in body morphology would support the use of prediction equation based on SKF sites representing the entire body, but our findings when the 3SKF model was used showed a similar accuracy as using 7 sites in our top-level judoists. Another methodologic issue that we need to point out as a potential factor for the cross-sectional differences found between the Ev models and the 4C model is the adipometer characteristics used in our study to perform the SKF measurements. Evans' models were developed using a Holtain adipometer, whereas a Lange calliper was used by Jackson and Pollock (22), the same used in our study. According to these authors, the Harpenden calliper tends to give smaller SKF values when compared with the Lange caliper (34). We observed at baseline and before the competition that Ev equations tend to overestimate FM. The recognition of a tendency for a higher value of the SKF when a Lange caliper is used, may explain the %FM and FM overestimation obtained at both moments using Ev models when compared with the reference method. It is worth mentioning that this is the first study that validates the models developed by Ev, whereas the JP equation, although developed in a sample of normal and overweight men ranging in age from 18 to 61 years, has been extensively validated in several samples of male athletes (5,12,21,33,36,38,45). Considering the effect of body size on body composition, Kraemer et al. (24) indicated that body mass index (BMI) is not an accurate measure or representation of body fat in a sample of athletes from the National Football League. In the present study, we also observed that BMI changes explained approximately 29% of %FM changes estimated by the reference model with a standard error of estimation of 1.9% (data not shown). Therefore, we expanded the results of Kraemer et al. (24) by pointing out BMI

inaccuracy to detect longitudinal changes in %FM in elite judo athletes.

In our study, a similar accuracy was found using the 3 anthropometric models. The slopes and intercepts for FM, %FM, and FFM changes using the 3 models were not different from 1 and 0, respectively, when the 4C model was used as the reference. This would indicate a good accuracy for these models. However, in considering the data from the agreement analysis, both methods had a wide range for the 95% confidence interval, indicating a reduced individual accuracy. Furthermore, a significant trend, that is, a significant correlation between the mean changes observed between each anthropometric model and the 4C model and the difference between both methods, was found for FM and %FM. In other words, the fact that there were no differences between mean FM and %FM changes estimated by the 4C model and the SKF-based methods is most likely because these models overestimated in subjects who lost less FM and underestimated in subjects who lost more FM. This result underscores the notion that these methods are not sensitive enough to accurately track these measures at an individual level of changes in body adiposity. However, for tracking FFM, no trend was found between the difference and the mean of the methods, indicating a better accuracy in detecting individual changes in the amounts of FFM.

Furthermore, it is important to note that the SKF measurement has an underlying biological error because of differences in individual fat distribution patterns and the relationship between subcutaneous and internal body fat (25,27). In line with these concerns, Watts et al. (43), using a sample of obese children who underwent an exercise training program, showed that changes in SKF collected from the abdominal region did not predict changes in DXA-derived abdominal FM, and the correlation between these measures was modest ($r = 0.39$). However, in our sample of athletes, a very strong association ($r = 0.86$, $p < 0.001$) was found between changes in the sum of trunk SKF (midaxilar, subscapular, chest, supra iliac, and abdominal) and in trunk absolute FM changes. Moreover, in our study, the differences between the SKF-based models and the reference method in detecting adiposity were not dependent on the magnitude of the absolute trunk FM obtained by the regional DXA measurements as a gross indicator of both subcutaneous and visceral adipose tissue. Considering these results, we may speculate that some assumptions used to overcome the biological variability of using SKF-based measurements to predict FMmay have a reduced impact in an athletic sample when compared with other populations, in particular obese and elderly subjects.

Although the above findings are based on the assumption that differences between clinical estimates of FM and %FM from the reference 4C model resulted from error in the alternative method estimation, absolute FM from the reference model is not without error. It has been suggested that the increased error associated with the greater number of measurements contributing to FM estimation with the 4C model may negate its greater theoretic accuracy (16). The present investigation presents a propagation of measurement error of 0.8% of BW, which is very close to the results obtained by Friedl et al. (16). These authors indicated a low (<0.8% of BW) within-subjects *SD* for replicate FM measurements, similar to that derived with other indirect methods based on fewer measurements, concluding that propagation of measurement error is not a significant problem.

In conclusion, the major findings of this study revealed that SKF-based equations did not accurately track body composition changes in elite judo athletes. Overall, the models based on 3- and 7-site SKF presented a similar and poor individual accuracy in the detection of adiposity changes, although a better performance for tracking FFM changes was found. Therefore, small physiologic changes in body composition are not accurately detected by these models in highly trained judo athletes.

Practical Applications

On the basis of the results of this study, we see that SKF-based models may not be useful in the field setting for tracking FM and FFM changes in elite judo athletes, and use of clinical methods that control for the variability in the FFM composition are needed, particularly if a target body composition is desired before a competition.

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