SKINFOLD METHOD VS DUAL-ENERGY X-RAY ABSORPTIOMETRY TO ASSESS BODY COMPOSITION IN NORMAL AND OBESE WOMEN

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ABSTRACT
SKINFOLD METHOD VS DUAL-ENERGY X-RAY ABSORPTIOMETRY TO ASSESS BODY COMPOSITION IN NORMAL AND OBESE WOMEN. Martim F. Bottaro, Vivian H. Heyward, Ricardo F. A. Bezerra, And Dale R. Wagner. JEPonline. 2002;5(2):11-18. Fat-free body density varies among population subgroups, which could lead to errors when estimating relative body fat (%BF) from generalized prediction equations and conversion formulas. Thus, this study was conducted to determine the applicability and validity of previously published skinfold (SKF) equations for estimating the %BF of 44 Brazilian women (20 to 40 y old). Reference measures of %BF were obtained with dual energy x-ray absorptiometry (DXA). Jackson et al. sum of 3 (ΣSKF) and 7 (ΣSKF) equations were used to predict body density (Db). The Siri formula and the Heyward and Stolarczyk formula specific to Hispanic women were used to convert Db to %BF. When used with the Siri formula, the Σ3SKF and Σ7SKF equations estimated %BF with an acceptable prediction error (SEE= 2.76 and 3.29 %BF, respectively), but both equations significantly underestimated average %BF by 2.82 and 2.67 %BF, respectively. The mean differences were reduced (Σ3SKF=1.46 %BF and Σ7SKF=1.33 %BF), but remained statistically significant (p<0.05), when the Heyward and Stolarczyk conversion formula was used. However, these differences were not significant when the analysis was limited to a sub-sample of non-obese (<30 %BF) women (n=32). The %BF of young, non-obese, Brazilian women can be accurately estimated using the Jackson et al. Σ3SKF and Σ7SKF equations with the Heyward and Stolarczyk Db-conversion formula. However, these SKF equations should not be used to assess the %BF of obese, Brazilian women.

Key Words: Obesity, Fat mass, Ethnicity, Hispanic
INTRODUCTION

Since athletic performance is partially influenced by the ratio of one’s fat mass (FM) to fat-free mass (FFM), most athletes are concerned with their body composition. However, the concern over one’s body fat percentage (%BF) should not be limited to just athletes. An accurate assessment of one’s body composition is important for all individuals, as %BF is closely related to one’s health and well-being. According to the American College of Sports Medicine (1), obesity is associated with increased risk for the development of cardiovascular disease, hypertension, diabetes, specific types of cancer and other chronic diseases. In addition to, there is some evidence that in populations undergoing rapid cultural and lifestyle change, individuals may be vulnerable to the development of high levels of fatness and its complications (2). Cultural changes in countries such as Brazil may foretell physiological changes with huge public health implications. The Brazilian National Institute of Nutrition (3) has reported that almost seven million adults are obese, which constituted a doubling in number during the last 15 years.

Traditionally, the classic two-component model (4,5), that separates the gross body mass into FM and FFM, has been used to obtain reference measures of body composition. This model relies on certain assumptions about tissue densities and relative distributions of water, protein, and mineral in the fat-free body.

The proportions of water, protein and mineral in the fat-free body, and thus the overall density of the fat-free body (FFBd) vary with age, gender, ethnicity, level of body fatness and physical activity level (6-8). Actual variations from the assumed FFBd value may result in a systematic error in estimating %BF. Thus, while the two-component model provides accurate %BF estimates for white males, from whom these assumptions were derived, it may not be suitable for use in population subgroups where the FFBd varies from the assumed value.

Ethnicity is one of the characteristics of subgroups that may violate the assumptions of the two-component model. For example, the FFBd of black women (1.106 g/cm$^3$) and Hispanic women (1.105 g/cm$^3$) is greater than the assumed value of 1.100 g/cm$^3$ due to their higher relative bone mineral content (9-11). Therefore, experts in the field of body composition (12,13) recommend using prediction equations only after they have been cross-validated for a specific population subgroup. Most of the body composition prediction equations in use today have been developed for North American populations of European descent. For populations of other ethnic or racial origins, these equations may lack predictive validity. Such subgroups are not as well defined. For example, most Brazilians are of mixed European, African, and Amerindian ancestry, and as such are a homogeneous amalgamation of three continents (14).

In Brazil, generalized skinfold (SKF) prediction equations for estimating body density (Db), have been used (15,16). However, these prediction equations have not been cross-validated for Brazilian men and women. There is a need to cross-validate existing body composition prediction equations to determine their applicability to the Brazilian population. Thus, this study was conducted to determine the applicability and predictive accuracy of the SKF field method and selected prediction equations for estimating the body composition of Brazilian women.

METHODS

Subjects
This study was approved by the Institutional Review Board of the University of New Mexico and by the Research Review Board of the Catholic University of Brasilia in Brazil. Forty-four women from the Brasilia area, between the ages of 20 and 40 years, participated in the study on a volunteer basis. The women were selected at random from the respondents to fliers distributed to health clubs, social clubs, public offices, and by word-of-mouth. The subjects were informed of the purpose, procedures, possible discomforts, risks, and benefits of the study prior to giving an informed written consent.

Questionnaires on health history and physical activity (17) were used to collect descriptive data and to define the participants’ menstrual cycles. Women who experienced water retention during the menstrual cycle were
scheduled for testing at a time when they perceived themselves to be at their usual body weight. Thus, the effects of water retention on body weight and total Db (18) were minimized. The participants were excluded from the study if they had not been eumenorrheic during the previous year. The women were also screened for medical conditions that may alter body composition. Contraindications included certain cancers, hypertension, cardiovascular diseases, renal or liver diseases, and muscular dystrophy.

Setting
All testing was conducted at the Clinica de Endocrinologia e Metabologia (Endocrinology and Metabolism Clinic) in Brasilia, Brazil.

Procedures
The women were instructed not to eat within 4 hr, drink alcohol within 48 hr, or exercise within 12 hr prior to arrival at the clinic. Upon arrival, all participants gave written informed consent and filled out the questionnaires. They then submitted to the following tests in the order indicated: height (HT), body mass (BM), SKF, and dual energy x-ray absorptiometry (DXA). Following the tests, the participants received oral and written interpretations of the results.

Height (HT) and Body Mass (BM)
The HT and BM were measured with the participants shoeless, wearing shorts and T-shirts. The BM was recorded to the nearest 0.1 kg on a medical beam scale (Filizzola, Sao Paulo, SP, Brazil). HT was measured to the nearest 0.1 cm at mid-inspiration using a wall-mounted stadiometer (Accustat, Ross Laboratories, Columbus, OH) while the subject stood erect with arms relaxed at the sides. The average of the two measurements was recorded.

Skinfold (SKF) Method
A Lange SKF caliper (Cambridge Scientific Industries, Cambridge, MD) was used to measure SKF thickness to the nearest 0.5 mm. The SKF sites were marked with a surgical marking pen. All SKFs were taken on the right side of the body, and the same technician took a minimum of two measurements at each site in a rotational order. The average of two measurements within 10% of each other was recorded as the SKF thickness for that site.

SKF measurements were used to cross-validate the sum of 3 (Σ3SKF) and sum of 7 (Σ7SKF) equations of Jackson et al. (16). The following sites were measured as described by Jackson and Pollock (20): chest, midaxillary, triceps, subscapular, abdominal, suprailiac, and thigh.

Dual-Energy X-ray Absorptiometry (DXA)
Total body fat, fat-free soft tissue, and bone mineral ash measurements were obtained with a Lunar DPX-IQ whole-body scanner (Lunar Radiation Corporation, Madison, WI, U.S.A., software version 4.6 A). The DXA was calibrated prior to testing with a known calibration marker, according to the manufacturer’s guidelines. Total body scans took 10 to 20 minutes, depending on the size of the participant. Fully clothed with all metal objects removed, each participant laid motionless in a supine position with arms at her side during the entire scan. The total radiation was 0.1 µG, which is equivalent to 1/20th of an average dental x-ray. The %BF measurement was based on an extrapolation of fatness from the ratio of soft tissue attenuation of two x-ray energies in pixels not containing bone (21).

DXA was used to obtain a reference measure of %BF in this study. Previous researchers have found good agreement between the %BF estimated from DXA and that obtained from multicomponent body composition models (22-25). These same researchers (20-23) concluded that DXA was a better predictor of %BF than other reference methods, such as hydrostatic weighing and isotope dilution, used in conjunction with two-component models.

Statistical Analyses
Regression analysis [Statistical Package for the Social Sciences (SPSS 8.0)] was used to assess the predictive accuracy of the Jackson et al. (16) generalized Σ3SKF and Σ7SKF equations using the formulas of Siri (5) and Heyward and Stolarczyk (12) to convert Db to %BF. Regression analysis assumes that the independent variables, as well as the dependent variables, are normally distributed. Extreme cases (outliers), if not excluded from the analysis, may spuriously inflate both the standard error of estimate (SEE) and the multiple correlation
coefficients (26). For this reason, univariate outliers were identified and removed from subsequent analyses. Univariate outliers were defined as standardized Z scores in excess of 3.29 standard deviations from the mean for that variable (\(Z > \pm 3.29\)) (26).

Each SKF equation was evaluated using the cross-validation criteria developed by Lohman (13). The means and the standard deviations of FFM and %BF of the reference method (DXA) and predicted FFM and %BF from each equation were compared using a dependent t-test. The correlation between the reference and the predicted %BF (\(r_{xy}\)), \(r^2\), and SEE, as well as the correlation between reference %BF and residual scores for all subjects (\(r_{y,res}\)) were examined (26). Residual scores were calculated for each participant by subtracting the predicted %BF from the respective reference measure. The residuals were analyzed using a variation of the Bland and Altman (28) method to determine the percentage of participants whose %BF was correctly estimated within \(\pm 3.5\) %BF.

Additionally, the slopes and intercepts for the line of best fit were determined for each equation. Each slope was tested to determine whether it was statistically different from 1.0 (\(p \leq 0.05\)). Each intercept was tested to determine whether it was statistically different from zero (\(p \leq 0.05\)). Also, an attempt was made to reduce the threats to external validity by selecting women from the Brasilia area. In 2000, the population of Brasilia was approximately 2.0 million (19). With the birth of Brasilia in 1960, people from all regions, ages, and socioeconomic ranks of Brazil moved into the city. “Brasilia, located in the state of Goias, became the symbol of the unification of all regions of Brazil” (14). Thus, Brasilia is one city that probably best represents the Brazilian population.

RESULTS

The physical characteristics of the participants (n=44) are presented in Table 1. Initial screening of the data revealed that all variables were normally distributed, and no statistical outliers were found (\(Z < \pm 3.29\)). Therefore, all subjects were included in the subsequent analyses.

Results of the cross-validation analysis of skinfold prediction equations are presented in Table 2. The %BF estimated from the Jackson et al. (16) \(\Sigma 3SKF\) equations was initially obtained using the Siri (5) two-component model to convert Db to %BF. These estimates were compared to the %BF obtained from the reference method, DXA. The relationship between reference and estimated %BF for the \(\Sigma 3SKF\) equation is presented in Figure 1. The SEE for each equation was acceptable, not exceeding the 3.5 %BF criterion (13). However, the \(\Sigma 3SKF\) and \(\Sigma 7SKF\) equations significantly (\(p < 0.01\)) underestimated average %BF\(_{DXA}\) in this sample by 2.82 %BF and 2.67 %BF, respectively. Furthermore, although the intercepts for the equations did not differ significantly from zero, the slopes were significantly different from one (\(p < 0.05\)).

The correlations between residuals scores (%BF\(_{DXA}\) - %BF\(_{SKF}\)) and average of both methods (%BF\(_{DXA}\) + %BF\(_{SKF}\)/2) were significant for both \(\Sigma 3SKF\) and \(\Sigma 7SKF\) equations (\(r_{y,res} = 0.79\) and 0.80, respectively, \(p < 0.01\)), indicating that these equations tended to systematically overestimate %BF in leaner subjects and underestimate

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>29.39 ± 5.52</td>
<td>20 to 40</td>
</tr>
<tr>
<td>(HT^4) (cm)</td>
<td>163.20 ± 5.85</td>
<td>152.5 to 174.5</td>
</tr>
<tr>
<td>(BM^2) (kg)</td>
<td>56.19 ± 6.16</td>
<td>45.8 to 72.8</td>
</tr>
<tr>
<td>(WHR^3)</td>
<td>0.795 ± 0.045</td>
<td>0.701 to 0.868</td>
</tr>
<tr>
<td>(TBM/FFM^4) (%)</td>
<td>7.48 ± 0.76</td>
<td>6.11 to 9.79</td>
</tr>
<tr>
<td>(%BF_{DXA}^5)</td>
<td>26.25 ± 5.87</td>
<td>14.60 to 39.60</td>
</tr>
<tr>
<td>(\Sigma 3SKF^6) (mm)</td>
<td>58.34 ± 11.82</td>
<td>36.50 to 88.00</td>
</tr>
<tr>
<td>(\Sigma 7SKF^7) (mm)</td>
<td>119.85 ± 24.05</td>
<td>73.00 to 167.50</td>
</tr>
</tbody>
</table>

\(^{1}\)HT, standing height; \(^{2}\)BM, body mass; \(^{3}\)WHR, waist to hip ratio; \(^{4}\)TBM/FFM, total bone mineral relative to fat-free mass \(^{5}\)\(\%BF_{DXA}\), relative body fat obtained from dual energy x-ray absorptiometry; \(^{6}\)\(\Sigma 3SKF\), sum of three skinfolds; \(^{7}\)\(\Sigma 7SKF\), sum of seven skinfolds
%BF in fatter subjects (Figure 2). In addition, the %BF of individuals was accurately estimated within ±3.5 %BF for less than two-thirds of the sample (60% for Σ3SKF and 57% for Σ7SKF).

Table 2. Cross-validation of the Jackson et al. (14) SKF equations on Brazilian women (N=44)

<table>
<thead>
<tr>
<th>Equation</th>
<th>Mean (%BF)</th>
<th>$r_{y,y'}$</th>
<th>t</th>
<th>SEE (%BF)</th>
<th>Slope</th>
<th>±3.5%BF</th>
<th>±3.5%BF</th>
</tr>
</thead>
<tbody>
<tr>
<td>DXA</td>
<td>26.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Σ3SKF (Siri)</td>
<td>23.43</td>
<td>0.87**</td>
<td>6.24**</td>
<td>2.76</td>
<td>1.32**</td>
<td>60%</td>
<td></td>
</tr>
<tr>
<td>Σ7SKF (Siri)</td>
<td>23.58</td>
<td>0.83**</td>
<td>5.14**</td>
<td>3.29</td>
<td>1.31**</td>
<td>57%</td>
<td></td>
</tr>
<tr>
<td>Σ3SKF (H&amp;S)</td>
<td>24.79</td>
<td>0.89**</td>
<td>3.22**</td>
<td>2.75</td>
<td>1.34**</td>
<td>75%</td>
<td></td>
</tr>
<tr>
<td>Σ7SKF (H&amp;S)</td>
<td>24.92</td>
<td>0.83**</td>
<td>2.54*</td>
<td>3.28</td>
<td>1.33**</td>
<td>70%</td>
<td></td>
</tr>
</tbody>
</table>

1Σ3SKF, sum of 3 skinfolds; Σ7SKF, sum of 7 skinfolds; Siri, conversion formula of Siri (5); H&S, population-specific conversion formula for Hispanic women of Heyward and Stolarczyk (12); $r_{y,y'}$, correlation between the reference and predicted percent body fat
±3.5%BF, percentage of subjects who were accurately estimated within ±3.5% body fat; DXA, dual energy x-ray absorptiometry
* P ≤ 0.05; ** P ≤ 0.01

**DISCUSSION**

The SKF prediction equations examined for cross-validation in this study were the Σ3SKF and Σ7SKF equations developed by Jackson et al. (16). When compared to %BF$_{DXA}$, the average %BF obtained from the two SKF equations was significantly underestimated. However, Heyward and Stolarczyk (12) suggested that the SKF method should not be used to assess the body composition of obese individuals. Thus, a separate analysis to evaluate the validity of the SKF equations on just the non-obese (<30 %BF) sub-sample (n=32) of women in this study was also done. Results from this analysis indicated that the average difference between %BF$_{DXA}$ and %BF$_{SKF}$ was reduced from 2.82 %BF and 2.67 %BF to 1.67 %BF and 1.20 %BF, respectively, for the Σ3SKF and Σ7SKF equations. Although these differences were small, they were still statistically significant ($p<0.05$).

The tendency for the Σ3SKF and Σ7SKF equations to systematically underestimate %BF in Brazilian women may be explained, in part, by examining the relative total body mineral of this sample. Stolarczyk et al. (11) assessed the body composition of young (20-39 yr), Hispanic women (n=29) and reported that their average relative total body mineral is 7.4% of the FFM. The relative body mineral of the Brazilian women in this study

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Figure 1. Relationship between the relative body fat (%BF) measured from DXA and that estimated from Σ3 SKF. %BF was estimated using the Siri (5) conversion formula. Dashed line is line of identity, and solid line is regression line.

Figure 2. Analysis of the individual residual %BF scores for the Σ3 SKF using the Siri (5) conversion formula. An SEE within ±3.5% BF is considered “good” when evaluating the predicted accuracy of %BF measurements (13).
(7.48% FFM) was similar to that reported by Stolarczyk et al. (11). This value is greater than that assumed (6.8% FFM) for the Siri (5) two-component model. Thus, the overall FFBd of premenopausal, Brazilian women was also greater than the assumed value (1.100 g/cm³), thereby producing a systematic underestimation of \%BF_{DXA} when the Siri (5) two-component model was used to convert Db to \%BF.

Based on Stolarczyk et al.’s (11) findings, Heyward and Stolarczyk (10) developed a population-specific two-component model conversion formula for estimating \%BF from Db for Hispanic women: \%BF=4.87/ Db - 4.41. This formula assumes a FFBd of 1.105 g/cm³. The authors recommended using this formula to estimate \%BF from hydrostatically measured Db, as well as Db predicted by the Jackson ΣSKF equations. Thus, the predictive accuracy of this population-specific conversion formula was tested for the total sample (n = 44) in the present study. The mean differences (\%BF_{DXA} vs. \%BF_{SKF}) were reduced from the 2.82 \%BF and 2.67 \%BF obtained with the Siri (5) conversion formula to 1.46 \%BF and 1.33 \%BF for the Σ3SKF and Σ7SKF equations, respectively; however, the differences remained statistically significant (P < 0.05). Also, the prediction error (SEE) for each equation did not change significantly from the original analysis that used the Siri (5) conversion formula (Table 2).

Table 3. Cross-validation of the Jackson et al. (16) SKF equations¹ using a population-specific body density conversion formula (12) on a sub-sample of non-obese (<30% body fat) Brazilian women (n=32)

<table>
<thead>
<tr>
<th>Equation</th>
<th>Mean (%BF)</th>
<th>(r_{y,y'})²</th>
<th>(t)</th>
<th>SEE (%BF)</th>
<th>Slope</th>
<th>±3.5%BF³</th>
</tr>
</thead>
<tbody>
<tr>
<td>DXA⁴</td>
<td>23.46</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Σ3SKF</td>
<td>23.17</td>
<td>0.81**</td>
<td>-0.72</td>
<td>2.31</td>
<td>1.11</td>
<td>87%</td>
</tr>
<tr>
<td>Σ7SKF</td>
<td>23.63</td>
<td>0.76**</td>
<td>0.39</td>
<td>2.54</td>
<td>1.02</td>
<td>87%</td>
</tr>
</tbody>
</table>

¹Σ3SKF, sum of 3 skinfolds; Σ7SKF, sum of 7 skinfolds
²\(r_{y,y'}\), correlation between the reference and predicted percent body fat
³±3.5%BF, percentage of subjects who were accurately estimated within ±3.5% body fat
⁴DXA, dual energy x-ray absorptiometry

* \(p \leq 0.05\); ** \(p \leq 0.01\)

However, when the population-specific conversion formula for Hispanic women (12) was applied to only the nonobese subsample of women (n = 32) in the present study, each of the cross-validation criteria (13) was met (Table 3). The relationship between reference and predicted \%BF for the Σ3SKF equation applied to a nonobese sample is presented in Figure 3. The differences between average \%BF_{DXA} and \%BF estimated by the Σ3SKF (0.29 \%BF) and Σ7SKF (0.17% BF) equations were small and not significant. In addition, nearly all (87%) of the subjects were accurately estimated within ±3.5 %BF for both the Σ3SKF and Σ7SKF equations (Figure 4).

Based on these findings, it appears that the Σ3SKF and Σ7SKF equations of Jackson et al. (16) yield an accurate estimate of \%BF in healthy, non-obese, Brazilian women when these SKF equations are used in conjunction with a population-specific conversion formula for Hispanic women (12). Although either SKF equation may be used, the Σ3SKF is more practical given that it requires measuring

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![Figure 3. Relationship between the relative body fat (%BF) measured from DXA and that estimated from Σ3 SKF using a sub-sample of nonobese women. %BF was estimated using the Hispanic (12) conversion formula. Dashed line is line of identity, and solid line is regression line.](image-url)
only three SKF sites compared to seven sites. However, results from the present study indicated that these SKF equations should not be used to assess body composition of Brazilian women who are obese (≥30 %BF). Thus, future studies need to be done in order to explore how adiposity and fat distribution affect the predictive accuracy of others body composition field methods, especially the bioimpedance method.

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