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COMPARISON OF BODY COMPOSITION ASSESSMENT IN WOMEN USING SKINFOLD THICKNESS EQUATIONS, BIOELECTRICAL IMPEDANCE ANALYSIS AND UNDERWATER WEIGHING

Key words: body composition, hydrostatic weighing, densitometry, skinfold, bioelectrical impedance analysis.

ABSTRACT

The aims of this study were to assess the validity of four skinfold equations and bioelectrical impedance analysis and underwater weighing (UWW) in female college students. The subjects were 30 female students of physical education from the Shahid Chamran University of Ahvaz, Iran, aged 22-26 years (mean age = 22.73 ± 0.908 years, body height = 1.63 ± 0.043 m, body mass = 21.87 ± 2.62 kg/m^2). Relative body fat percent (%BF) based on underwater weighing was used as the validity criterion. Each participant's %BF was assessed via the UWW on the basis of bioelectrical impedance and four skin fold equations. Body density and percent body fatness were determined using four commonly used skinfold thickness measurements: Jackson-Pollock (J-P) 3- and 7-site tests; Durnin--Womersley (D-W) 4-site test; and Sloan 2-site test (S). The statistical analysis used the Pearson correlation coefficient and paired sample $T_{test,}$ standard error of the estimate (SEE) and total error (TE). The analysis results revealed no significant differences with skinfold measurements using the Durnin-Womersley test (P = 0.117, r = 0.947, SEE = 1.4709, TE = 1.5112). Statistically significant differences were found between the BIA and Sloan test, Jackson-Pollock 3-site and 7-site test results and hydrostatic weighing results. The achieved results revealed that the Durnin-Womersley 4-site test was the most precise body fat estimation method.

INTRODUCTION

Body composition is one of five components of physical fitness. Estimation of body composition is important for athletes as an indicator of their fitness and health [17]. Using body composition measurements one can monitor preseason and postseason changes, and also track weight loss or gain as indicators of poor health or eating disorders [5, 17]. The monitoring of body fat is especially important in female athletes because of their increased risk for developing symptoms of the female athlete triad: disordered eating behaviors, amenorrhea and osteoporosis [1, 5]. Early identification of these potentially serious disorders is crucial for an athlete to prevent harmful diseases or injury [1, 5].

Underwater (hydrostatic) weighing (UWW) has long been considered the "gold standard" in body composition testing [7]. UWW has been used in multiple studies either being compared to another method of body composition measurement or used as a reference measure [4]. Despite its widespread use, UWW has many limitations such as expensive equipment, time-consuming measurement (30-60 minutes depending on residual volume measurement) and the necessity to submerge the head under the water [7]. One of the limitations of

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hydrostatic weighing is the problem of measuring residual volume. Researchers compared dilution and plethysmography and found that residual volume was estimated to be lower when the subject was submerged than when out of the water. The consequence of errors in measuring residual volume becomes crucial in examination of athletes.

Therefore, alternative methods of body composition assessment that are easier and safer to administer have been developed. One such technique involves the use of skinfold calipers to measure subcutaneous fat at various anatomic sites. Although widely used in laboratory and field settings, the accuracy of this procedure is predicated upon the investigator's technical experience and training. Inter- and intra-individual variability associated with the selection of skinfold sites, size/depth of the skinfold measurement and time delay in reading the calipers have all been shown to markedly reduce the accuracy of this procedure [5]. In the hands of highly trained and experienced testers the error associated with the use of skinfolds to predict body fatness is less than 3% [12]. However, inter-individual variability remains a major source of error associated with this technique. Clearly the accurate assessment of body composition using skinfold calipers requires specially trained and experienced personnel [12]. This has somewhat limited the widespread application of skinfold assessment as a field-based tool and has led to the development of an alternative technique for the determination of body composition known as bioelectrical impedance analysis (BIA). This procedure takes very little time, is easy to administer, requires no specialized training and is non-invasive. The basic premise of this technique is that lean tissue acts as an electrical conductor while fat resists the transmission of the electrical impulse. Equations that utilize electrical impedance to estimate the percent of body fat have been developed for athletes, adults and children [11, 13].

One popular misinterpretation of statistics in sport and exercise science is the use of the correlation coefficient, particularly evident in validity studies, when one measurement technique is compared with another. The inevitable generation of a high correlation coefficient, usually the PMCC, convinces the researcher that the results from the two measurements are in agreement.

Unfortunately, the correlation coefficient does not indicate agreement but merely the strength of relationship between the two variables. Bland and Altman (1986) provide five reasons why correlation coefficients are inappropriate for assessing agreement. Firstly, perfect agreement takes place if all the data points lie along the line of equality, but a perfect correlation will be found if all the data points lie along any straight line. Secondly, a change in the scale of measurement will not affect the measurement but does have ramifications for the agreement. Furthermore, the correlation coefficients are greatly affected by the range of data points in the sample. A mass of data points grouped together can generate a low correlation, but when several lower and upper influential observations are placed in the sample, the correlation coefficient can dramatically increase. Fourthly, a test of significance does not help in the interpretation of agreement and, lastly, even data points which are in poor agreement can produce high correlations.

The purpose of the present study was to examine three different statistical techniques to validate two common field methods of body fat measurement, BIA and SKF, against the criterion laboratory-based measure, UWW.

METHODS

Subjects

The subjects were 30 female college students of physical education from Shahid Chamran University of Ahvaz in Iran, aged 22-26 years. Subjects' profiles are shown in Table 2. Each subject was provided with a list of pretest procedures (i.e., no alcohol, caffeine, food or exercise 12 hours prior to testing) before the test date. The procedures as well as potential benefits and risks were explained before obtaining written informed consent from each participant.

Test protocol

Percent body fat was estimated from body density (BD) as determined by standardized hydrostatic weighing with correction for residual lung volume (RV). Residual lung volume was measured using the oxygen dilution method by Wilmore [18]. Residual lung volume was determined on land with the subject seated in a position similar to that assumed during UWW. The average of similar scores (within 0.11) from two to three trials was used as the representative RV. For determination of underwater weight, each participant sat on a chair suspended from four load cells in a pool of water with the temperature of 35Cº. When the participant was completely submerged and at maximum exhalation, underwater weights were recorded to the nearest 0.002 kg from a digital display. Five repeated underwater weights were obtained for each participant, and the average of the highest three weights – as these are indicative of maximum exhalation – was used to calculate body density corrected for residual volume. This model assumes the density of body fat to be 0.9 g/cm^3. D_b was converted to %BF utilizing the Siri [15] equation:

$$\%BF_{UWW} = (4.95/BD - 4.5) \times 100$$

$$D_b = \frac{BW}{\frac{BW - UWW}{D_{H_2O}} - (RV + 0.1L)}$$

Skinfold measurement

Seven skinfold sites (triceps, biceps, chest, subscapula, abdomen, suprailiac, thigh) were measured in rotating order three times each on the right side of the body to the nearest 0.5 mm; the median value was used for analysis [9]. Each skinfold was grasped firmly with the thumb and the index finger holding the caliper perpendicular to the fold approximately one centimeter away from the thumb and the finger [12]. The measurement sites were identified following Jackson and Pollock [6]. All skinfold measures were taken by one tester.

Data from the skinfold measurements were utilized in four different skinfold equations. The first and third skinfold equations were converted from body density (D_b) to %BF via the Siri equation: Siri = (4.95/BD – 4. 5) × 100 (Siri W. 1961). The four different skinfold equation used for this study are given below (Table 1).

To verify the accuracy of skinfold thickness measurements, criterion-related concurrent validity and intraclass reliability were calculated. Criterion-related concurrent validity was measured by comparing skinfold measurements taken by the tester with those taken by an expert in skinfold measurement. Five women were tested at the same time of day by both measurers, with the newer tester always measuring prior to the experienced tester. The validity coefficients between testers for each skinfold measurement were above r = 0.80, which is recommended in order to substitute the tester for the experienced technician [13]: triceps, r = 0.97; biceps, r = 0.97; chest, r = 0.95; subscapula, r = 0.94; abdomen, r = 0.89; suprailiac, r = 0.92, thigh, r = 0.96.

Intraclass reliability was calculated for the three trials at all four skinfold sites by calculating a mean square representing the total of changes in the mean and error [16]. This was done to measure the repeatability or consistency of the tester's ability to take skinfold measurements. All of the trials were highly correlated: triceps, r = 0.97; biceps, r = 0.99; chest, r = 0.99; subscapula, r = 0.98; abdomen, r = 0.98; suprailiac, r = 0.98; and thigh, r = 0.99. The coefficient of variation was computed for each subject's skinfold thickness results by dividing the standard deviation by the mean and multiplying by 100 [2].

Table 1. Skinfold equations for predicting body density cross-validated against underwater weighing

SF- UWW	Equations
S	BD_1 = 1/0764 – (0/0008 × superiliac) – (0/00088 × triceps)
$(J\text{-}P)_1$	BD_2 = 1/099492 – 0/0009929 (X) + 0/0000023 $(X)^2$ – 0/0001392 (age), where X is the sum of the triceps, thigh and suprailiac skinfolds in mm.
D-W	BD_3 = 1/599 0717 log (X), where X is the sum of triceps, biceps, superiliac and subscapula skinfolds in mm.
$(J\text{-}P)_2$	BD_4 = 1/0970-0/00046971 (X) + 0/00000056 $(X)^2$ – 0/00012828 (age), where X is the sum of triceps, chest, abdomen, suprailiac, subaxilla, subscapula and thigh skinfolds in mm.

S – Sloan 2-site test [13, 15]; $(J\text{-}P)_1$ – Jackson-Pollock 3-site test [13]; D-W – Durnin-Womersley 4-site test [2]; $(J\text{-}P)_2$ – Jackson-Pollock 3- and 7-site test [13].

Bioelectrical impedance analysis

Bioelectrical impedance analysis (BIA) is a commonly used method for estimating body composition. Since the advent of the first commercially available devices in the mid-1980s the method has become popular owing to its ease of use, portability of the equipment and its relatively low cost compared to some of the other methods of body composition analysis. It is familiar in the consumer market as a simple instrument for estimating body fat.

Statistical analysis

Means and standard deviations were calculated for each variable of interest. Validity coefficients (*R*) and standard error of the estimate (SEE) were calculated. The predicted error sum of squares statistic was used as a means of internal validation. The mean difference, total error and standard error between skin fold predicted and hydrostatically-determined percent body fatness for each bioelectrical impedance and skinfold equation were calculated using the cross validation procedures of Lohman. Total error (TE) was determined as:

$$TE = \sqrt{\sum [predicted - actual]^2 / n}$$

where M_P is the skinfold predicted body fatness and M_m is the hydrostatically-determined value [16]. The standard error of the estimate was calculated as SEE = (SD) $[1–r^2]^{½}$, where SD is the SD of the UWW procedure. T-test for paired observations was used to calculate differences between skinfold and hydrostatically-determined percent body fatness for each skinfold equation. A *p* value < 0.05 was considered statistically significant. All other data were analyzed using SPSS 14.0 for Windows.

Paired t-tests were also performed to determine statistically significant differences between measurement methods for collegiate female students. In all analyses, an alpha level of $p < 0.05$ was set a priori.

RESULTS

Body composition profiles of the subjects (n = 30) calculated from body weight (kg), height (cm), age (years), BMI (kg/m^2) and hydrostatically determined body density, are shown in Table 2. These values are equivalent to the average of the adult population.

Table 2. Subjects' profiles

Variable	Mean ± SD
Body height (cm)	163 ± 4.3
Body weight (kg)	56.96 ± 4.91
Age (years)	22.73 ± 0.90
BMI (kg/m^2)	21.87 ± 2.62

For the college female students the mean UWW, BIA and SKF body fat scores were 27.72, 24.22, 20.06, 20.82, 27.72 and 26.12, respectively.

Table 3. Percentage of body fat

Variable	Mean ± SD	Minimum	Maximum
$\%BF_{UWW}$	27.72 ± 4.56	18.44	35.63
BIA	24.22 ± 3.08	17.20	29.30
$\%BF_1$	20.06 ± 2.85	15.47	29.17
$\%BF_2$	20.82 ± 3.71	13.20	27.34
$\%BF_3$	27.72 ± 4.56	17.95	35.26
$\%BF_4$	26.12 ± 4.50	18.75	32.27

Percentage body fat (%BF) estimates and measurements in the cross-validation group $\%BF_{UWW}$

The paired sample t-tests showed significant differences ($p < 0.05$) in the percentage body fat between UWW and BIA, and between UWW and SKF equations for the collegiate female students. Correlation data from Table 3 and 4 reveal high correlation coefficients between both SKF and BIA body fat scores and UWW for the collegiate females.

The Pearson product moment correlations for body fat percentages in college female students between the methods were high, ranging from 0.77 to 0.94 ($p < 0.05$). The standard error of estimate for BIA and equations obtained using data from the collegiate females were 1/94, 1/99, 2/17, 1/47 and 2/007, respectively.

Table 4. Comparison means %BF of skinfold measurement method and BIA with UWW (paired sample t-tests)

	%BF (BIA - UWW)	%BF (S - UWW)	%BF ((J-P)$_1$ - UWW)	%BF ((D-W) - UWW)	%BF ((J-P)$_2$ - UWW)
T	–6.588	13.075	14.130	1.615	4.231
P	0.00	0.00	0.00	0.117	0.00

Table 5. Pearson correlation coefficients for skinfold techniques and BIA

%BF (UWW - X)	BIA	Sloan	Jackson-Pollock (1)	Durnin-Womersley	Jackson-Pollock (2)
R	0/777	0.716	0.810	0.947	0.895
R^2	0/604	0.513	0.656	0.896	0.801
TE	4/5155	8.28	7.28	1.51	2.59
SEE	1/941	1.99	2.17	1.47	2.007

DISCUSSION

The correlation coefficients between SKF, BIA and UWW data for females support the argument that a high correlation between variables is not a rationale for a high level of agreement between methods. Table 3 indicates that the relationship between the three methods is high, and similar findings were obtained by Maughan (1993), who studied a smaller sample of 50 female and male volunteers [10]. The sample correlation obtained by Maughan (1993) of r = 0.83 for BIA and UWW was accepted as a valid indicator that BIA could be used instead of UWW [10]. However, in this study, the percentage fat assessed by the BIA method was shown to be significantly higher ($p < 0.05$) when compared with the hydrostatic weighing and skinfold thickness measurements for both male and female athletes. The percentage body fat measures for both female and male athletes were significantly different between the UWW and BIA methods, whereas for the UWW and SKF scores only the females were shown to have significantly different levels of percentage body fat ($p < 0.05$) [17]. Despite the findings of significance and non-significance between methodologies, this statistic does not provide a measure of agreement between methods.

In the case of athletes, prediction of body fat by the BIA method may result in a linear regression analysis predicting a score that has been adjusted to the group mean. Therefore, lean individuals such as endurance athletes will be regressed up towards the mean, resulting in an overestimation of the body fat. Similarly, other researchers have indicated the limitation of BIA with population extremes, in which fat-free mass is underestimated in thinner, and overestimated in obese, subjects. This artefact could be due to the percentage of fat-free mass hydration in the obese being higher than in normal subjects and lower than in lean subjects. Consequently, obese subjects have more expanded extra cellular space in their adipose tissue and more fat in their muscles and around their body organs, which is interpreted by BIA as a higher lean body mass.

Skinfold measurements are frequently used in the field to assess body composition; however, few equations have been designed for collegiate female athletes. Our purpose was to develop a skinfold model for the female collegiate athlete using UWW as a criterion measure. We determined that a model containing only weight and triceps, biceps, superiliac and subscapula skinfolds is sufficient for accurate determination of FFM.

When comparing the skinfold equation estimates for the percentage of body fat, statistically significant differences were noted between the Durnin-Womersley and UWW test results (Table 2). Only one other study could be found that has examined skin fold equations data using the Durnin-Womersley method. The model showed a validity coefficient in the D-W and UWW of R = 0.94 and an SEE of 1.4 kg. Adding this 1.4 kg to the mean FFM and calculating the change in body fat indicates that the SEE is equivalent to the prediction error of a little fat. In contrast, a 4-site skinfold equation (validated against underwater weighing) suggested for use on female athletes aged 18 to 25 years has an SEE of a little fat.

As all of these are appropriate, the method selection will depend upon factors such as time for test administration, costs, equipment maintenance, ability to accommodate people with limitations, ability to monitor changes over time, and ease of use [3]. The skinfold regression equation and BIA methods have a poor predictive capability at the extreme limits of the population studied.

There is the need for specific equations for populations which are otherwise homogeneous in terms of age, physiological status and exercise performance. This study provided a sample group that was homogeneous in terms of age and sporting activity and therefore examined skinfold equations data using the Durnin and Womersley method [12]. This study provides evidence that the strength of a correlation does not indicate agreement between two methods. In future, reliability and validity studies should examine the absolute differences between two variables and calculate limits of agreement around which a practitioner can appreciate the precision of the methodologies.

In conclusion, the percentage of body fat determined from two of the four skinfold equations and bioelectrical impedance analysis (BIA) used in this study were comparable with the underwater weighing (UWW), i.e. the criterion measure. The skinfold equations and BIA using UWW as the criterion provided a significantly lower %BF than the other methods tested. Since the UWW is not readily available for testing at all facilities, the use of the Durnin and Womersley equation was shown to be most appropriate to estimate body fat in physical education female students from the Shahid Chamran University of Ahvaz.

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