COMPARISON OF SKINFOLD AND BIOELECTRICAL IMPEDANCE ANALYSIS WITH DUAL-ENERGY X-RAY ABSORPTIOMETRY FOR BODY COMPOSITION ANALYSIS IN COLLEGE STUDENTS

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ABSTRACT

Dual-energy x-ray absorptiometry (DXA) can provide precise measurement of soft tissue composition with minimal radiation exposure. However, having access to DXA is very costly and limited, and other noninvasive and more accessible techniques such as bioelectrical impedance analysis (BIA) and skinfold measurements are commonly used by clinicians. The purpose of this study was to compare body composition examined with BIA and 3-sites skinfold analysis to the results examined with DXA, and develop body fat prediction equations for BIA and skinfold measurements, using DXA data as the criterion ***Design:*** *Cross sectional.* ***Subjects:*** *Sixty three college age students (28 male, 35 female) aged 18 to 27 participated in the study.* ***Results:*** *Body fat percentage measured with DXA is significantly higher than those measured with skinfold (p = .01) and BIA (p = .01). However, body fat percentage measured with DXA is highly correlated with those measured with skinfold (r = .895; p = .01) and BIA (r = .875; p = .01). The DXA criterion regression equations were created for skinfold and BIA: DXA%BF=4.65 + 0.43 * S3SF (sum of 3 site skinfold); DXA%BF=3.79 + 1.09 * BIA%BF. The new regression equations were further validated using 75/25% subjects cross validation.* ***Conclusion:*** *Skinfold and BIA measurements significantly underestimate body fat percentage compared to DXA in healthy college students. Adjustments are necessary to accurately predict body fat percentage when using skinfold or BIA at a clinical setting. To accommodate the higher body fat percentage measured with the gold standard such as DXA, the results from this study suggest the need for the current %BF standards and norms for healthy young adults to be adjusted upward.*

Key words: Body composition, DXA, Skinfold, BIA, Equations

Introduction

With an estimated 34.9% adult obesity rate in the United States, body composition evaluation during health screenings and physical examination is an important methodology for physical therapists to categorize health risk and prescribe appropriate exercise interventions.[1] Body mass index (BMI) is commonly used to classify individuals into different health risk categories because it does not require any equipment and can be rapidly calculated. However, using BMI as an expression of percent body fat has been shown to be inaccurate and may lead to bias in evaluating health outcomes.[2] Hydrostatic weighing (underwater weighing) has long been the gold standard of in vivo body composition measurement.[3] This technique requires expensive equipment and is not feasible for many clinical and educational settings. Moreover, subject and examiner errors can often occur without extensive practice.

Many skinfold measurement techniques and equations were developed to produce accurate estimates of percent body fat in many populations.[3] For example, American College of Sports Medicine (ACSM) suggests 3-site or 7-site formula for both men and women to calculate body density, and many population-specific formulas to convert body density to percent body fat.[3] However, factors such as poor technique of an inexperienced examiner can contribute to measurement errors.[3]

Bioelectrical impedance analysis (BIA) is another widely used body composition technique which is based on the speed of electrical current conduction through different types of body tissue. BIA is a reliable, noninvasive, and rapidly performed body composition technique.[4] It is suggested that the accuracy of BIA testing is similar to skinfold testing with a normal/similar hydration level and if proper testing protocols are followed.[5,6] In addition, BIA machine is also inexpensive and portable, ideal for non-hospital settings such as fitness facilities. However, due to the differences in body water distribution, BIA testing may not be valid when testing obese individuals.[7]

In 1988, Dual Energy X-Ray Absorptiometry (DXA) was approved by the food and drug administration.[8] DXA provides precise measurement of bone mineral content (BMC) and soft tissue composition,[9-17] and has shown positive agreement with Magnetic Resonance Imaging (MRI), Computed Tomography (CT), and multi-compartment models.[14,15,18-22] Additionally, DXA is now recognized as the new gold standard for measuring body composition in the United States by the Centers for Disease Control and Prevention (CDC). In 2013, DXA was the method used to determine body composition for the National Health and Nutrition Examination Survey (NHANES).[23,24] According to the CDC's body composition procedures manual for 2013-2014, the CDC plans to use the data obtained from DXA scans to gain:

> Nationally representative data on total and regional bone mineral content, lean mass, fat mass, and percent fat overall and for age, gender, and racial/ethnic groups; estimates of obesity, defined as an excess of body fat; data to study the association between body composition and other health conditions and risk factors, such as cardiovascular disease, diabetes, hypertension, physical activity, and dietary patterns; estimates of the prevalence of osteoporosis and low bone mass; and the first estimates of the prevalence of vertebral fractures and abdominal aortic calcification.[24]

In view of DXA's superior accuracy, it should be used to measure body composition whenever possible. Despite this, there are a number of reasons why other methods such as Skinfold and BIA are still more prevalently used. One limitation to using DXA is the expense of the machine itself and the cost to have a DXA scan performed. In addition, there is concern that certain individuals may not fit appropriately on the scanning table due to either height or width. However, research has shown that there are interventions available to accommodate such individuals.[25,26]

In recent years, a number of studies have explored the relationship between Skinfold, BIA, and DXA measurements.[27-36] Owing to underwater weighing no longer being the reference standard and lack of agreement between Skinfold and DXA or BIA with DXA, some of these studies have attempted to determine new prediction equations to modify either Skinfold or BIA measurements using DXA as the criterion.[27-35] These studies used various populations including children, professional athletes, the obese, those with special medical conditions, or the general population with large age ranges.[27-35] However, it is not clear if percent body fat measured with skinfold and BIA is similar to those measured with DXA in healthy college students. The main purpose of this study was to evaluate the accuracy of BIA and skinfold body fat measurement in comparison to the data from DXA in college students. The secondary purpose was to develop body fat prediction equations for BIA and skinfold measurement, using DXA data as the criterion.

Method

Design

Cross Sectional design was used for this study. All testing was performed at the 0.05 level of significance.

Participants

Sixty-three healthy, mostly active, college age students (28 males and 35 females ages 18 to 27) volunteered to be the subjects. Based on body mass index (BMI) analysis, volunteers who were obese (BMI $\geq$ 30) or underweight (BMI $<$ 18.5), and females who were pregnant or had the possibility of being pregnant were excluded from the study. Self-reported activity levels of participants were categorized using the following three point scale: 2 - Very active individuals were exercising at an intensity of $\geq$8 METS at least 3 to 5 days per week for sessions of at least 30 minutes each, 1 - moderately active individuals were exercising at 4 to 7 METS at least 3 days a week for sessions of at least 30 minutes each, and 0 - non-active individuals were performing activities at intensities of $\leq$3 METS. All participants signed a written informed consent in accordance with the policies and procedures of the University Human Subjects Institutional Review Board.

Participants were required to wear athletic clothing (ie: shorts, t-shirt, sports bra) with no metal at the day of testing. Participant's body weight and height were first measured using a medical balance beam scale. Height and weight measurements were taken without shoes with weight being measured to the nearest 0.5 pounds and height the nearest 0.5 inch. Subjects were informed not to perform exercise within several hours prior to the measurement because of factors such as dehydration, increased vascular perfusion, warming of muscle tissue, increased skin temperature, and sweating. Those factors can impact the accuracy of the measurements.

Skinfolds

Skinfolds from chest, abdomen, and thigh were examined for males. Skinfolds from triceps, suprailiac, and thigh were examined for females. Body density was calculated for males and females with separate equations based on American College of Sports Medicine's (ACSM) guidelines (2014).[3] Body density was converted to body fat percentage based on sex, age, and ethnicity.[3] A minimum of two skinfolds were measured at each site to the nearest 0.5mm.

Bioelectrical impedance analysis

BIA was analyzed with a bioimpedance analyzer (BIA): BIA 450 (Biodynamics Corp. Shoreline WA). The subject was positioned in supine on a non-conductive surface in an anatomical position with limbs slightly abducted (to avoid skin contact) and palms down. Each subject's personal information was entered into the data set of the BIA 450 including sex, age, height (inches), and weight (pounds). Skin sites were cleaned with an alcohol prep pad and allowed to dry. Four surface electrodes were placed on the right side of the body: dorsal surface of right wrist between radial and ulnar styloid processes, dorsal surface of right hand at space between second and third MCP, anterior surface of right ankle between medial and lateral malleoli, and anterior surface of right foot at space between first and second MTP joints. The subjects were asked to remain still and breathe normally.

Dual Energy X-Ray Absorptiometry

DXA analysis (Hologic QDR 4500 X-ray Bone Densitometer Bedford, MA) was used for body composition analysis. The DXA was calibrated before each screening using a spine core calibration block. The subject was asked to remove all metal and/or jewelry prior to scanning, and positioned in supine on the scanning table in an anatomical position with limbs slightly abducted (to avoid contacting the torso) and palms down. The legs and feet were positioned in slight internal rotation and held lightly with an elastic band. The subjects were instructed to stay still during the scanning process. The total scan time was 6 minutes.

Reliability

All three body composition measurements were conducted in series in a single session. All measurements were taken by a single examiner to ensure consistency. Test/re-test reliability data was collected from 10 male and 10 female volunteers, and measurements were conducted in single sessions 24 hours apart.

Data Analysis

The IBM Statistical Package for Social Sciences (SPSS) version 21 was used for all statistical analysis.[32] All testing was performed at the 0.05 level of significance. Descriptive statistics were performed on all variables. Correlation analysis was performed to determine significant variables and relationships between DXA and skinfold and between DXA and BIA. Bland Altman Plotts were performed to identify any systematic or proportional biases within the data sets. Simple linear regression analysis was performed for the creation of the adjusted formulas for skinfold and BIA for the general population, as well as gender specific equations for skinfold and BIA using DXA as the criterion. The new regression equations were further validated using 75/25% subjects cross validation.

Results

For the main effects, body fat percentage was significantly different ($p<.01$) among different body composition testing: skinfold (17.64%), BIA (20.70%), and DXA (26.27%)(Table 1). Female subjects have a significantly larger ($p < .01$) body fat percentage than male subjects (25.62% vs. 16.43%).The Descriptive statistics for ethnicity and fitness number are presented in Table 2. Our sample was mostly Caucasian (85.7%), but did include representation from other ethnic groups including Hispanic (11.1%), African American (1.6%), and Indian (non-Native American) (1.6%). The fitness composition of the participants included 8 non-active, 20 moderately active, and 35 very active individuals as defined by our fitness number scale. Twenty participants were assessed twice for test-retest reproducibility. Their 24 hour test-retest intraclass correlation coefficient (ICC) ranged from .991** to .997** across the three body composition analysis tools (Table 3).

Table 1 Descriptive Statistics (N=63)

Variable	Mean±s.d.	Range
AGE	21.86± 2.20	9
HEIGHT (in.)	67.51± 4.25	18
WEIGHT (lbs.)	153.71± 28.08	114.5
BMI	23.55± 2.55	10.78
SKINFOLDBF	17.64± 6.69	24.29 (4.5% to 28.79%)
BIABF	20.70± 5.68	25.6 (10.1% to 35.7%)
DXABF	26.27±7.04	31.4 (12.5% to 43.9%)

SKINFOLDBF: Skinfold body fat percentage. BIABF: BIA body fat percentage. DXABF: DXA body fat percentage.

Table 2: Ethnicity and Fitness Number (N=63)

Variable	Frequency
Caucasian	54
Hispanic	7
African American	1
Indian	1
Non-Active FN=0	8
Mod Active FN=1	20
Very Active FN=2	35

FN: Fitness Number

Table 3: Test-Retest Correlations (N=20)

Measurement	**Pearson Correlation**
Skinfold 1 and 2	.994**
BIA 1 and 2	.991**
DXA 1 and 2	.997**

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations between significant variables are presented in Table 4. Skinfold, BIA, and DXA were all highly correlated. Fitness level/Number also significantly correlated to all body fat percentages and sum of the three skinfold variables. BMI did not significantly correlate to any variable. Sum of the three skinfolds highly correlated with DXA body fat percentage *r* = .893**, with gender specific correlations of *r* =.912** for males and *r* =.795** for females

Table 4: Correlations (N=63)

		FitnessNumber	BMI	SKINFOLDBF	BIABF	DXABF	Sum3SkFold
FitnessNumber	Pearson Correlation	1	-.022	-.475**	-.466**	-.543**	-.521**
	Sig. (2-tailed)		.862	.000	.000	.000	.000
BMI	Pearson Correlation	-.022	1	-.099	-.039	.008	.205
	Sig. (2-tailed)	.862	.442	.759	.949	.108	.115
SKINFOLDBF	Pearson Correlation	-.475**	-.099	1	.827**	.895**	.917**
	Sig. (2-tailed)	.000	.442	.000	.000	.000	.000
BIABF	Pearson Correlation	-.466**	-.039	.827**	1	.875**	.750**
	Sig. (2-tailed)	.000	.759	.000	.000	.000	.000

DXABF	Pearson Correlation	-.543**	.008	.895**	.875**	1	.893**
	Sig. (2-tailed)	.000	.949	.000	.000	.000	.000
Sum3SkFold	Pearson Correlation	-.521**	.205	.917**	.750**	.893**	1
	Sig. (2-tailed)	.000	.108	.000	.000	.000	.000

**. Correlation is significant at the 0.01 level (2-tailed). Sum3SkFold: Sum of the 3 skinfold sites

Bland Altman Plots demonstrate that BIA body fat percentage showed better levels of agreement with the DXA difference than skinfold body fat percentage (Fig. 1-2). BIA is a more stable and consistent model to use rather than the skinfolds. Figure 1 displays Bland Altman Plot between skinfold and DXA difference using mean difference (Mean difference = -8.62; 95% CI = -14.81 to -2.43) for the whole sample (N=63). Figure 2 displays Bland Altman Plot between BIA and DXA difference using mean difference (Mean difference = -5.57; 95% CI = -12.31 to 1.17) for the whole sample (N=63). T-test shows no significant difference between skinfold and DXA, and between BIA and DXA, demonstrating no proportional bias between the two measurements.

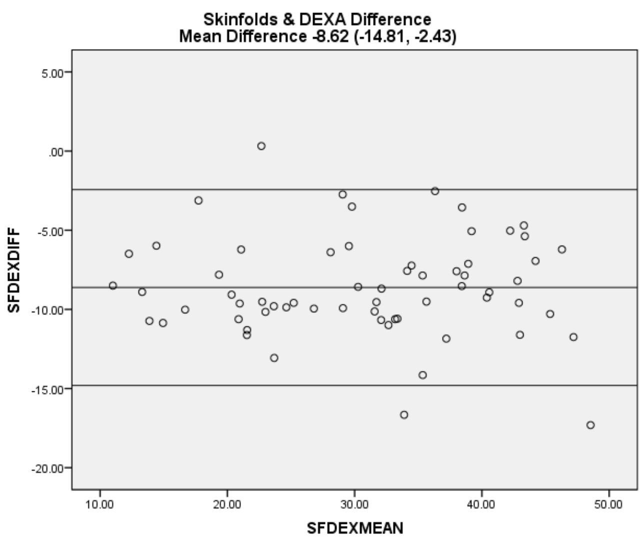

Figure 1: Bland Altman Plot for Skinfold and DXA by mean difference

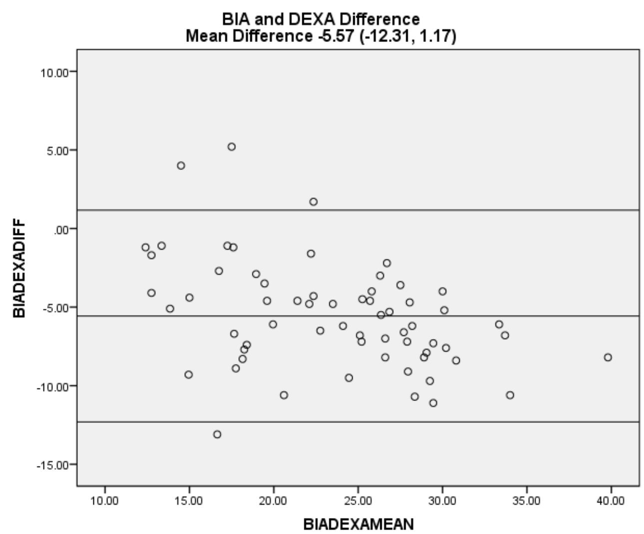

Figure 2: Bland Altman Plot for BIA and DXA by mean difference

From our sample of 63 participants, DXA body fat percentage was predicted from the sum of the three skinfolds using simple linear regression analysis: DXA%BF=4.65 + 0.43 * S3SF (sum of 3 site skinfold). The slope of the regression line was significantly greater than zero, indicating that DXA body fat percentage tends to increase as sum of the three skinfolds increases (Slope = 0.43;95% CI = 0.34 to 0.47; t_{60} = 12.54; $P < 0.000$; Y = 4.65 + 0.43X; r^2 = 0.797). Similarly, DXA body fat percentage was predicted from BIA body fat percentage using simple linear regression analysis: DXA%BF = 3.79 + 1.09 * BIA%BF. The slope of the regression line was significantly greater than zero, indicating DXA body fat percentage tends to increase as BIA body fat percentage increases (Slope =3.79; 95% CI = 0.38 to 0.49; t_{61} = 15.47; $P < 0.000$; Y = 3.79 + 1.09X; r^2 = 0.766).

Considering potential gender difference, separate regression analysis was performed for male and female subjects. From 28 male participants, DXA body fat percentage was predicted from the sum of three skinfolds using simple linear regression analysis: DXA%BF = 5.54 + 0.38 * S3SF. The slope of the regression line was significantly greater than zero, indicating that DXA body fat percentage tends to increase as sum of the three skinfolds increases(Slope = 5.54; 95% CI = 0.31 to 0.45; t_{26} = 11.31; $P < 0.000$; Y = 5.54 + 0.38X; r^2 = 0.831). In addition, DXA body fat percentage was predicted from BIA body fat percentage using simple linear regression analysis: DXA%BF = 5.59 + 0.94 * BIA%BF. The slope of the regression line was significantly greater than zero, indicating that DXA body fat percentage tends to increase as BIA body fat percentage increases (Slope = 5.95; 95% CI = 0.56 to 1.32; t_{26} = 5.1; $P < 0.000$; Y = 5.95 + 0.94X; r^2 = 0.5). The same analyses were performed for 35 female participants. DXA body fat percentage was predicted from the sum of three skinfolds using simple linear regression analysis: DXA%BF = 9.15 + 0.37 * S3SF. The slope of the regression line was significantly greater than zero, indicating that DXA body fat percentage tends to increase as sum of the three skinfolds increases (Slope = 9.15; 95% CI = 0.27 to 0.47; t_{33} = 7.53; $P < 0.000$; Y = 9.15 + 0.37X; r^2 = 0.63). DXA body fat percentage was predicted from BIA body fat percentage using simple linear regression analysis: DXA%BF = 2.81 + 1.13 * BIA%BF. The slope of the regression line was significantly greater than zero, indicating that DXA body fat percentage tends to increase as BIA body fat percentage increases (Slope = 2.81; 95% CI = 0.89 to 1.38; t_{33} = 9.3; $P < 0.000$; Y = 2.81 + 1.13X; r^2 = 0.72).

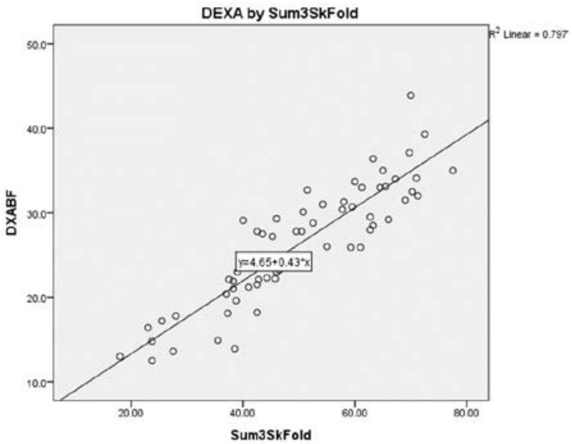

Figure 3: Simple linear regression using sum of the three skinfolds to predict DXA body fat percentage (N=63)

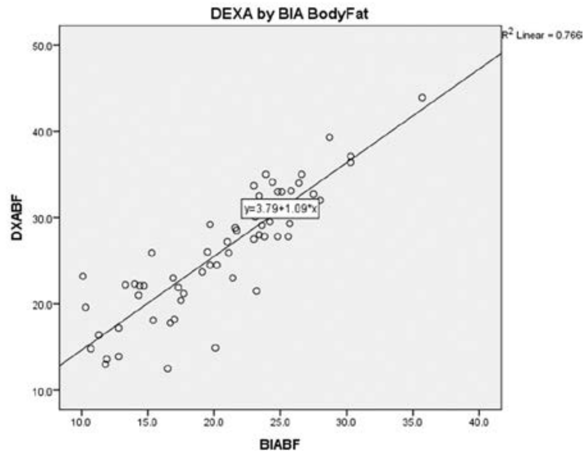

Figure 4: Simple linear regression using BIA body fat percentage to predict DXA body fat percentage (N = 63

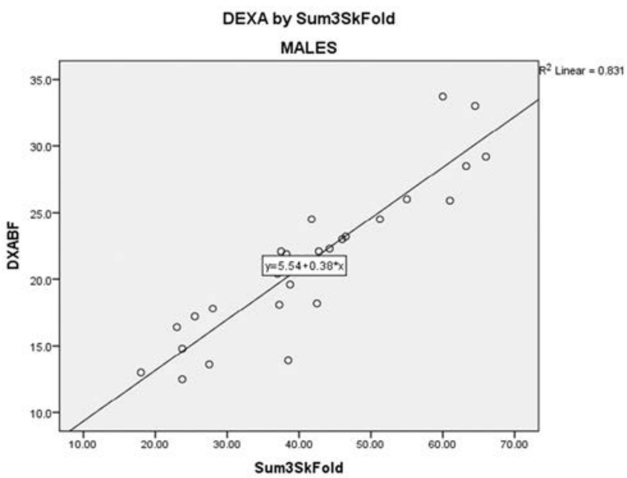

Figure 5: Simple linear regression using sum of the three skinfolds to predict DXA body fat percentage in males (N=28)

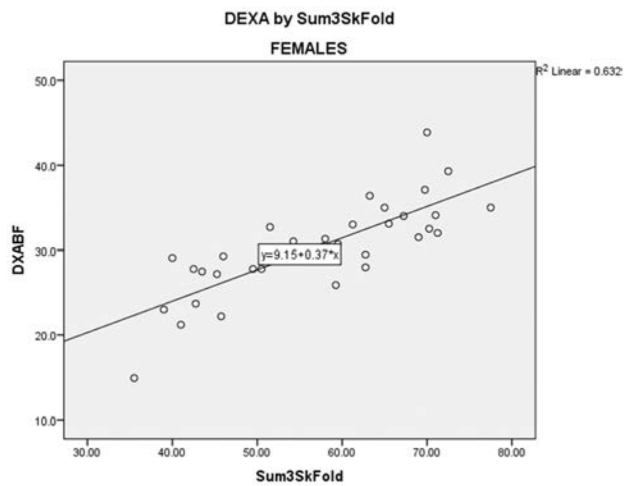

Figure 6: Simple linear regression using sum of the three skinfolds to predict DXA body fat percentage in females (N=35)

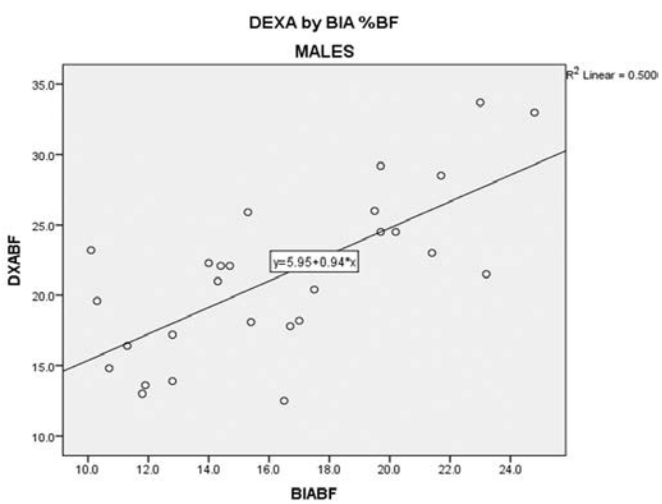

Figure 7: Simple linear regression using BIA body fat percentage to predict DXA body fat percentage in males (N = 28)

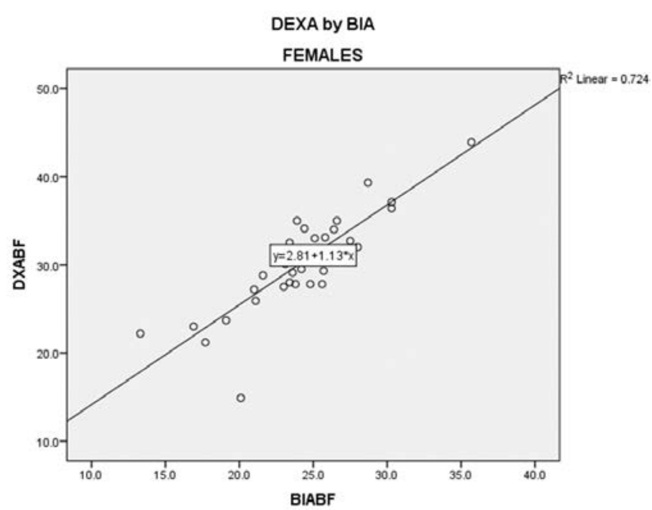

Figure 8: Simple linear regression using BIA body fat percentage to predict DXA body fat percentage in females (N = 35)

Due to the sample size, cross validation for the prediction equations was only performed for all 63 subjects. Regression equations were compared between 25% and 75% of the total participants. For skinfold to DXA prediction, cross validation returned (r = .886, r^2 = .785) for 25% of the sample, which is similar to (r = .874, r^2 = .764) for 75% of the sample. For BIA prediction, cross validation returned (r = .889, r^2 = .79) for 25% of the sample, and returned (r = .875, r^2 = .764) for the 75% of the sample.

Discussion

The main purpose of this study was to examine the relationship between skinfold, BIA, and DXA measurements in relation to body fat percentage in a healthy college age population. The results indicate that significantly higher body fat percentages occurred with DXA measurements as compared to measurements performed using skinfold or BIA. These findings are consistent with the findings from Ball et al. (2004), and Harley et al. (2008).[32-34] However, the subject population of this current study is different from those prior reports. The age of their subject ranges from 18-62 year old males[32], 18-55 year old females[33], and 20-31 year old male professional rugby players[34]. The subjects of the current study ranges from 18-27 years old and they are not professional athletes. In other words, the data for the current study can better represent a specific population: collage age individuals who are not professional athletes.

Another difference between the current study and prior reports is the method for skinfold measurement. Harley et al. (2009) used 9-site skinfold analysis, and Ball et al. (2004) used both 3-site and 7-site skinfold analysis for both men and women. The current study used the Jackson Pollock 3-site equation because it is a more practical approach in a clinical setting. Moreover, Ball et al. (2004) compared both 3-site and 7-site skinfold testing and found the 3-site skinfold measurement a better predictor for body fat percentage measured with DXA. The results obtained identified the need for adjustments to be made when measuring body composition if Skinfold or BIA measurements were used with this specific population.

High Intraclass correlations of all three methods demonstrate high levels of consistency by the examiner and assessment tools. This decreases the chance of error or variability, particularly with the skinfold method. Although DXA, skinfold, and BIA body fat percentages were all highly correlated as stated earlier, each was significantly different from the other. The data from DXA is better correlated with the sum of the three skinfolds than with the body fat percentage converted from skinfold equations and body density formulas. This finding is also consistent with Ball et al. (2004)[33], who also found a better correlation between DXA and skinfold using the sum of the 3-site measures. Without going through 2 sets of conversion (from skinfold to body density and from body density to body fat percentage), there is a lesser chance for errors to occur during the process. In addition, it is also more convenient for clinicians in a practical setting.

Validity of the equations was analyzed for the general skinfold and BIA equations, using 75/25% cross validation. The r and r^2 values returned by each model indicate that the agreement between the models is excellent and the general equations generated for skinfold and BIA are valid and applicable to college-age adults. However, our sample size was not large enough to perform cross validation analysis for gender specific equations. Further study with a larger sample size for each gender would be beneficial.

When comparing DXA body fat percentage of our healthy college-age subjects to what is commonly identified as normal values for males and females, the subjects were categorized as “poor” or worse.[3] As demonstrated in Table 1, skinfold body fat percentage had a range of 4.5% to 28.79% whereas DXA body fat percentage had a range of 12.5% to 43.9%. According to ACSM fitness categories based on body composition for males ages 20-29: Excellent range is 7.9% to 10.5%, Good range is 11.5% to 14.8, Fair range is 15.8% to 18.6%, Poor rang is 19.7% to 23.3%, and Very Poor range is 24.9% to 33.4%.[3] The average DXA measurement for males was 21.35% categorizing this sample of healthy mostly active and physically fit individuals into the “Poor” category. According to ACSM fitness categories based on body composition for females ages 20-29: Excellent range is 15.1% to 16.8%, Good range is 17.6% to 19.8%, Fair range is 20.6% to 23.4%, Poor range is 24.2% to 28.2%, and Very Poor range is 30.5% to 38.6%.[3] Average DXA measurement for females was 30.19%

categorizing this sample of healthy, mostly active and physically fit individuals between “Poor” and “Very Poor” categories. This study is in agreement with (Ball et al, 2004) that there is a need to re-examine the normative values of body fat percentage using accurate measurements, newer technique (such as DXA), and update the literature and recommendation accordingly.

With more and more involvement in health promotion, the result of this current study can assist physical therapists to properly conduct health screening, categorize health risk, as well as determine appropriate exercise interventions. DXA provides valid and reliable data on bone mineral density and body composition. However, body composition testing with DXA is very costly and not readily available in most facilities. BIA and Skinfold testing are more available and less expensive; however, those tests underestimate body fat percentage in the healthy young adult population and provide inaccurate information for health analyses and exercise prescriptions. The importance of the new regression equations in this study is to provide physical therapists with the means to gain accurate body composition measurement in the absence of DXA.

There are some limitations for this study. The majority of the subjects are young Caucasians (87%). Therefore, the result may not be applicable for other age populations and/or ethnic groups. In addition, 75/25% cross validation for those gender specific regression equations could not be performed due to the small sample size. Further research is needed to investigate prediction equations over other age ranges and specific ethnic populations. A larger sample size would also be beneficial in future studies.

Conclusion

Skinfold and BIA measurements significantly underestimate percent body fat compared to DXA measurements for body composition. It is recommended that DXA be used for body composition analysis. However, if unable to obtain DXA measurements, adjustment equations for skinfold and BIA should be utilized to maintain accuracy of measurement. Body composition charts depicting normal/healthy values should also be adjusted based on DXA measurements to better classify individuals in regards to health and exercise prescription.

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