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Comparison of Multi-Frequency Bioelectrical Impedance and Dual-Energy X-Ray Absorptiometry to Assess Body Composition in College-Aged Adults

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ABSTRACT

International Journal of Exercise Science 13(4): 1595-1604, 2020. The purpose of this study was to evaluate the validity of whole body percent fat (%BF) and segmental fat-free mass (FFM) using multi-frequency bioelectrical impedance analysis (MF-BIA) and dual-energy x-ray absorptiometry (DEXA) in college-aged adults. Sixty-two participants male (n = 32) and female (n = 30) completed MF-BIA and DEXA measurements following established pre-test guidelines. %BF and segmental FFM (right arm, left arm, trunk, right leg, and left leg) were collected and analyzed. The MF-BIA significantly ($p < 0.05$) underestimated %BF for all participants, females, and males compared to DEXA. In addition, MF-BIA significantly ($p < 0.05$) underestimated FFM in the arms and legs in all participants and males with the exception of the left arm in all subjects while significantly overestimating FFM in the trunk. In females, the MF-BIA overestimated FFM in the arms and trunk while significantly ($p < 0.05$) underestimating FFM in the legs. Difference plots also indicated that the underestimation of FFM from MF-BIA in the arms and legs increased as the amount of FFM increased. Thus, our findings suggested that the MF-BIA may not be accurate for measuring whole %BF and segmental FFM in the college-aged population.

KEY WORDS: percent body fat, segmental fat-free mass, males, females

INTRODUCTION

The ability to accurately measure whole body percent fat (%BF) and fat-free mass (FFM) is important because of the established association between high amounts of body fat, a variety of disease processes, and overall physical fitness (2, 5, 20). Dual-energy X-ray absorptiometry (DEXA) and multi-frequency bioelectrical impedance (MF-BIA) are two techniques that have become increasingly popular and are used measure %BF, FFM, and segmental FFM. The DEXA is an accepted reference method for the estimation of %BF and segmental FFM mass, and it has been widely compared to other criterion techniques such hydrostatic weighing, computerized tomography (CT), and magnetic resonance imaging (MRI) (7, 11, 14, 19). There are multiple disadvantages, however, for DEXA scans which include its limited access, expensiveness, and the requirement of a pregnancy test.

MF-BIA is also a valid method of body composition analysis for certain populations, and it is widely available, non-invasive, inexpensive, and can test numerous people quickly and efficiently when compared to other techniques. Specifically, the MF-BIA measures the resistance to an electrical current, with the least resistance (R) offered by FFM due to its high-water content (13). Low-level frequencies rely on the conducive properties of extracellular water (ECW) while high-level frequencies rely on both intracellular water (ICW) and ECW conductive properties (10). The difference between low and high frequencies is related to their respective abilities to penetrate cell membranes. At low frequencies, currents cannot penetrate the cell wall and remain in the extracellular fluid, thus providing an estimate of ECW. High frequencies are able to pass through the cell membrane, thereby providing an estimate of total body water (ECW + ICW). The volume of water determines the width of the passage through which the electricity flows which is represented by impedance (Z). Impedance and resistance values differ between 2 and 3 Ω, thus the two terms are often used synonymously (16). The difference between resistance (R) and impedance (Z) values is due to reactance (X), which is considered negligible at low frequencies but increases at higher frequencies ($Z^2 = R^2 + X^2$). The MF-BIA typically uses 8-electrodes and measures the impedance of electrical currents at multiple frequencies to estimate body composition (5, 6). Advanced MF-BIA techniques have the ability to also measure impedance and resistance separately across 5 different cylinders within the human body which allow for whole and segmental (legs, arms, and trunk) FFM analysis (9).

The results of the comparison of fat mass (FM), FFM, and segmental FFM while comparing DEXA and MF-BIA, however, have remained conflicting. For example, multiple studies have shown MF-BIA underestimates FM and overestimates FFM (4, 5, 9, 13, 21, 22, 23). In contrast, other studies demonstrated that MF-BIA overestimates FM and underestimates FFM (11, 14, 17, 20, 24). There have also been inconsistent results with examination of segmental FM and FFM. Some studies show that the MF-BIA overestimates appendicular FM while others showed an underestimation of appendicular FM and FFM (1, 5, 9, 18). Due to conflicting findings found in these previous studies (1, 4, 5, 9, 11, 13, 14, 17, 18, 20-24) additional data using other MF-BIA and DEXA models are needed to clarify previous findings. Therefore, the purpose of this study was to compare %BF and segmental FFM between the MF-BIA and the Hologic Horizon Wi DEXA in healthy college-aged adults. Based on previous findings (1, 4, 5, 9, 13, 18, 21, 22, 23), we hypothesized that the MF-BIA would underestimate %BF, overestimate FFM in the arms and legs, and underestimate FFM in the trunk.

METHODS

Participants

Sixty-two participants were recruited to participate in the study through verbal proposal to Kinesiology and Physical Education classes at Northern Illinois University and flyers posted in various locations throughout the university. Participant characteristics are presented in Table 1. Females were required to pass a pregnancy test, and those with positive tests were excluded from the study. Other exclusion criteria included metal implants in the body, body mass > 158 kilograms, < 18 years old or > 29 years old, and any type of respiratory illness. An *a priori* power analysis using G*Power 3.1 (Düsseldorf, Germany) indicated a sample size of at least 62 was required to achieve power (1-β) of 0.80 with an effect size of 0.3 and alpha of 0.05. All participants completed a written informed consent form prior to participation, and the Institutional Review Board at Northern Illinois University approved the protocol. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science.

Table 1. Participant characteristics.

	All	Males	Females
n	62	32	30
Age (years)	22.3±2.5	22.6±2.6	21.9±2.4
Height (cm)	169.1±7.6	174.9±6.6	164.0±5.0
Weight (kg)	75.5±17.4	80.3±16.8	70.5±16.8
BMI (kg/m^2)	26.3±5.0	26.5±4.4	26.1±5.7

Protocol

Participants completed two sessions: screening and assessment. Upon arrival to the screening session, participants completed an initial screening questionnaire that included demographic questions such as age, gender, and having metal implants. Height and body mass were measured to the nearest centimeter and kilogram using a Detecto clinical scale (Model 238W; MO, USA). Body mass index (BMI) was then determined by dividing body mass in kilograms by height in meters squared. Participants who met all inclusion criteria and qualified for participation in the study were scheduled for a time to come back for testing within seven days. All participants were instructed and given a document of proper guidelines to follow for the day prior to and the day of testing to ensure consistency of variables that would affect the results. Specifically, subjects were instructed to: 1) refrain from eating for at least five hours prior to testing but no more than 12 hours, 2) not exercise within eight hours prior to testing, 3) not consume large amounts of liquids within four hours prior to testing, 4) not consume caffeine or other diuretics within three hours prior to testing, 5) not consume alcohol within 12 hours prior to testing, and 6) not shower directly prior to testing.

For the assessment visit, participants were asked to fill out a pre-testing questionnaire to ensure all guidelines were followed. A pregnancy test was administered to female participants to determine eligibility. Male subjects were then asked to void all contents of their bladder, females already having done so during the pregnancy test. Subjects were asked to wear minimal clothing for MF-BIA procedures. All piercings, jewelry, and other metallic objects were removed prior to testing. Body mass was measured to the nearest tenth of a kilogram with the InBody 520 to ensure consistency and accuracy.

Total and segmental body composition was estimated with the InBody 520 (Version 520DM-1520; Biospace, Inc., Los Angeles, CA, USA). Participants remained standing for 15 minutes prior to testing to allow for normal circulation of blood and fluid movement according to the manufacturer's guidelines (3). Participants were asked to wipe his or her hands and feet prior to stepping onto the electrodes of the InBody 520. The participant was asked to grab hold of the hand electrodes with his or her thumbs in proper placement over the electrodes, arms at an approximately 45-degree angle to the torso and stand upright with good posture. The InBody 520 system measured total and segmental body composition across the whole body and segments (arms, legs, and trunk) at 5, 50, and 500kHz. The average assessment time was approximately 90 seconds, and the participants were instructed to step off the machine once the test was completed.

The Hologic Horizon Wi DEXA (Software version 5.6.0.1; Hologic Inc., Marlborough, MA, USA) was used as the criterion measure for total and segmental body composition. The participant was placed within the scanning rectangle on the DEXA with proper arm and foot placement, positioned at the subject's side and slightly pronated with his or her fingers pointed straight. The subject's toes were pointed up and their feet were held together by a plastic strap to eliminate movement throughout the scan. Once the subject was in position, the subject was instructed to remain as still as possible for the duration of the scan. The average assessment time was approximately 6 minutes.

Statistical Analysis

%BF and segmental FFM (right arm, left arm, left leg, right leg, and trunk) were determined for all subjects (n = 62), males (n = 32), and females (n =30). Linear regressions were used to determine the standard error of estimate (SEE) and correlation coefficient (r) values of the InBody 520 compared with the DEXA. Proper statistical procedures were followed for linear regressions which included assessing normality (P-P plot), linearity (r = 0.96), homoscedasticity (scatterplot of residuals), and multicollinearity (VIF < 10). Constant error (CE) was determined as the differences between the InBody 520 and DEXA (CE=DEXA-InBody 520). Total error (TE) was determined as $\text{TE}=\sqrt{\sum(\text{DEXA-InBody 520})^2/n}$. Mean body composition measures from the DEXA and InBody 520 were compared using paired-sample t-tests. Difference plots (12) were used to identify the 95% limits of agreement between the InBody 520 and DEXA. All significant values were determined using an alpha level of 0.05.

RESULTS

Linear regression assumptions were met prior to analysis through visual analysis of P-P plots and scatterplot of residuals as well as assessment of linearity (r = 0.96) and VIF = 1.0. Linear regression analyses showed a significant (p < 0.05) relationship between %BF from the DEXA and InBody 520 for all subjects, males and females (Table 2). Paired-sample t-tests for means showed that the InBody 520 significantly underestimated %BF in all participants, males and females and therefore FFM.

Table 2. Comparison of %BF between DEXA and InBody 520 in all participants, males, and females.

	DEXA %BF	InBody 520 %BF	*r*	CE	SEE	TE
All (n = 62)	27.4 ± 9.5	23.6 ± 10.5*	0.96	3.79	2.50	4.72
Males (n = 32)	21.5 ± 5.6	17.6 ± 6.7*	0.94	3.87	1.93	4.50
Females (n = 30)	33.6 ± 8.8	29.9 ± 10.2*	0.95	3.70	2.78	4.95

DEXA= Dual-energy X-ray absorptiometry; %BF=Percent body fat (mean ± SD); *= statistically significant differences (p < 0.05) from DEXA; r= correlation coefficient from linear regression); CE= Constant error (CE=DEXA-InBody 520); SEE= Standard error of estimate; TE= Total error (TE = $\sqrt{\sum(\text{DEXA} - \text{InBody 520})^2/n}$).

The difference plot showed no significant (p = 0.06) relationship (Figure 1).

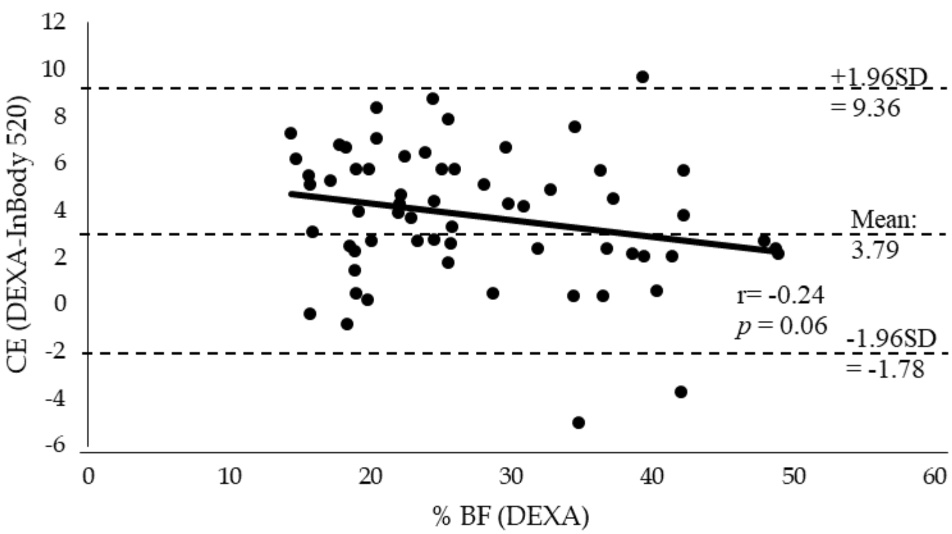

Figure 1. Difference plot showing the relationship of the constant error (CE) and %BF from the DEXA in all subjects (n = 62).

Results from linear regression analyses are presented in Table 3. There were significant (p < 0.05) correlations between the DEXA and InBody 520 for segmental FFM which included right arm, left arm, trunk, right leg, and left leg for all participants, males, and females. In all of the participants, the InBody 520 overestimated FFM in the trunk and underestimated FFM in the right arm, left arm, right leg, and left leg. All of the results of the paired sample t-tests were significant (p < 0.05) with the exception of the left arm. In the male participants, the InBody 520 significantly underestimated FFM in the right arm, left arm, right leg, and left leg while significantly overestimating FFM in the trunk. In addition, the InBody 520 overestimated FFM in the right arm, left arm, and trunk while underestimating FFM in the right leg and left leg in female subjects; however, only the left arm, right leg, and left leg paired-sample t-tests were significant ($p < 0.05$).

Table 3. Comparison of segmental FFM between DEXA and InBody 520 in all participants, males, and females.

	DEXA	InBody 520	*r*	CE	SEE	TE
All (n=62)						
Right arm (kg)	3.39 ± 1.12	3.24 ± 0.90*	0.87	0.15	0.56	0.57
Left arm (kg)	3.22 ± 1.04	3.21 ± 0.90	0.93	0.01	0.39	0.39
Trunk (kg)	24.88 ± 5.11	25.66 ± 5.27*	0.96	-0.78	1.46	1.04
Right leg (kg)	9.17 ± 2.00	8.48 ± 1.63*	0.93	0.70	0.75	1.04
Left leg (kg)	8.96 ± 1.98	8.44 ± 1.64*	0.91	0.52	0.81	0.96
Males (n=32)						
Right arm (kg)	4.28 ± 0.82	3.88 ± 0.68*	0.69	0.40	0.60	0.71
Left arm (kg)	4.07 ± 0.64	3.84 ± 0.67*	0.86	0.21	0.22	0.40
Trunk (kg)	28.24 ± 4.14	28.40 ± 3.97*	0.94	-1.16	1.54	1.89
Right leg (kg)	10.39 ± 1.70	9.57 ± 1.34*	0.90	0.82	0.77	1.12
Left leg (kg)	10.16 ± 1.68	9.55 ± 1.34*	0.88	0.61	0.81	1.00
Females (n=30)						
Right arm (kg)	2.44 ± 0.33	2.55 ± 0.50	0.71	-0.11	0.24	0.36
Left arm (kg)	2.32 ± 0.45	2.52 ± 0.52*	0.79	-0.20	0.28	0.61
Trunk (kg)	21.30 ± 3.30	21.68 ± 3.12	0.91	-0.38	1.41	1.42
Right leg (kg)	7.87 ± 1.39	7.33 ± 0.97*	0.84	0.56	0.76	0.95
Left leg (kg)	7.67 ± 1.37	7.26 ± 0.95*	0.81	0.42	0.82	0.91

DEXA= Dual-energy X-ray absorptiometry; *= statistically significant differences ($p < 0.05$) from DEXA (from the results of a paired-sample t-test); *r*= correlation coefficient from linear regression; CE= Constant error (CE=DEXA- InBody 520); SEE= Standard error of estimate; TE= Total error (TE = $\sqrt{\sum(\text{DEXA} - \text{InBody 520})^2/n}$).

Difference plots (Figure 2) showed positive relationships between constant error and segmental FFM (right arm, left arms, trunk, right leg, and left leg) for all participants indicating that the InBody 520 displayed a tendency to underestimate FFM at higher levels of FFM. All relationships were significant ($p < 0.05$) with the exception of the trunk ($p = 0.76$) indicating that the individual error was the same throughout the range.

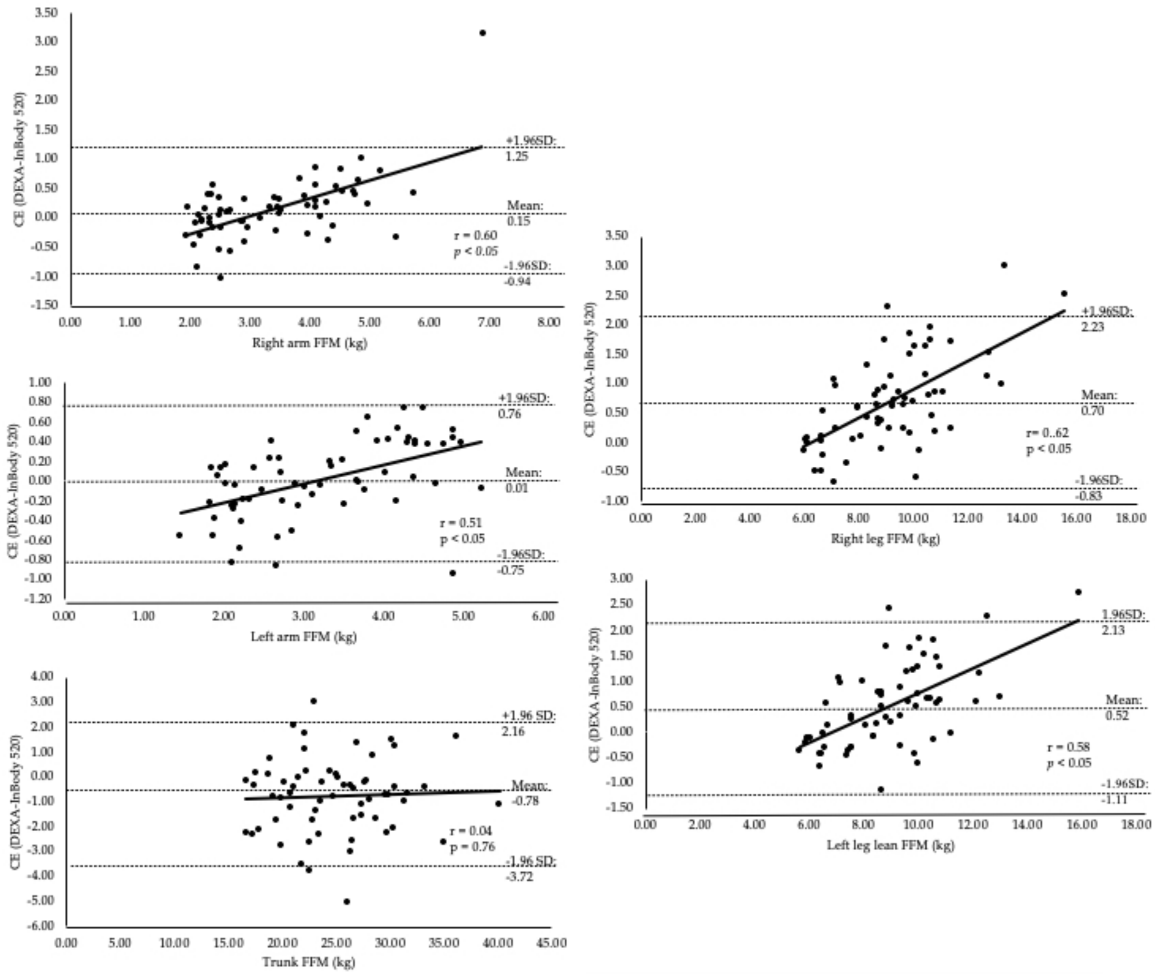

Figure 2. Difference plots showing the comparison between constant error (CE) and DEXA segmental FFM (right arm, left arm, trunk, right leg, and left leg in all subjects) (n = 62).

DISCUSSION

Body composition assessment is an important diagnostic and evaluative tool used to identify nutritional status within and between populations, obesity, and overall health in men and women. Over the last two decades, there has been an increasing amount of studies that focused on the validity of BIA (4, 7, 9, 13, 21). Most studies have focused on total FM versus FFM; however, recent studies have begun to compare segmental FM and FFM. In congruency, most studies have either focused on a broader age range rather than college-aged adults. Therefore, the current study sought out to examine the validity of %BF along with segmental FFM in healthy college-aged students.

One principle finding in the present study was that the MF-BIA overall consistently underestimated %BF regardless of gender compared with the DEXA. It is important to note that the mean BMI for all participants (26.3 ± 5.0), males (26.5 ± 4.4), and females (26.1 ±5.7) was considered slightly overweight. Wang et al. (23) also reported that the MF-BIA significantly underestimated FM in both overweight men and women. In another comparable study (13), the MF-BIA underestimated %BF compared to the DEXA by 2.1% ($p < 0.001$) in the total participant group for the same age range. In college-athletes, it has also been reported that the MF-BIA underestimated %BF (5, 9). In contrast, Ling et al. (14) reported the MF-BIA overestimated %BF relative to the DEXA. The study also found that the overestimation of %BF appeared to increase with in increasing BMI (14). Sun et al. (21) reported significant differences between the MF-BIA and DEXA when subjects were stratified according to their %BF. It was reported that the MF-BIA overestimated %BF by 3.56% for subjects whose %BF was < 20%, underestimated %BF by 2.65% for subjects whose %BF was > 30%, and no disagreement in %BF for subjects whose %BF was between 20% and 30%. The same relationship was reported when partitioning the %BF groups into genders (21). The discrepancies may be due to different age ranges in participants. Sun et al. (21) used a larger age range (19-60 years old) and Ling et al. (14) used participants with an average age of 61.2 for females and 63.5 for males. In addition, the InBody 520 uses FFM, but it cannot distinguish between bone mineral components of FFM from impedance measurements. The InBody 520 uses an equation based on DEXA normative values established from the general population (9). The DEXA, on the other hand, distinguishes the FFM and bone mineral content (13). If there are discrepancies with FFM, the FM would be affected and thus %BF. The DEXA and the InBody 520 also assume that the FFM has a hydration of 73%; however, there may be systematic differences with regards to adiposity, gender, and body size, and fitness-level (11, 22).

The present study found that the MF-BIA significantly ($p < 0.05$) underestimated FFM in both of the arms and legs while overestimating FFM in the trunk in all participants and males relative to the DEXA with the exception of the left arm in all participants. For females, the MF-BIA compared to the DEXA overestimated FFM in the arms and trunk while underestimating FFM in the legs. These results are similar to previous studies. One study found that within the female participants there no significant differences in the arms ($p = 0.371$) yet significant differences in the legs ($p = 0.049$) (9). There are two studies that were consistent with the results in the current study which demonstrated an underestimation of segmental FFM in the arms and legs by the MF-BIA compared to the DEXA (5, 14). The difference plots in the current study also suggest that the MF-BIA is more likely to underestimate FFM in the arms and legs compared with the DEXA. This has also been seen in both college-aged athletes and non-athletes in previous studies (5, 9, 11, 24). Differences in physical activity may have a different distribution of the FFM and FM in the trunk, arms, and legs (21).

A primary limitation that the current study had was the lack of a hydration status measurement. Although there were strict pre-testing guidelines with regards to food and beverage consumption and exercising, there was no exact measurement to determine whether or not they had proper hydration. Acute changes in hydration status would ultimately affect both DEXA and InBody 520 measurements. Lastly, there was no test-retest reliability performed during the study due to time constraints. The study relied on other research studies that stated the Hologic DEXA and InBody 520 had excellent test-retest reliability agreement.

In conclusion, one should use caution while using the InBody 520. Additional research is needed on both the InBody 520 and Hologic DEXA to determine whether or not certain body sizes can affect the results of %BF and segmental FFM. As body composition equipment becomes more available and popular, more research is needed on the segmental body composition component to ensure both reliability and validity.

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