Comparison of Bioelectrical Impedance Analysis with Dual Energy X-ray Absorptiometry in Obese Women

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Abstract

Background: Bioelectrical Impedance Analysis (BIA) is simple, inexpensive, portable, safe and relatively accurate means of assessing body composition. However, there were many reports in that the error of BIA was increased in extremely obese subjects. This study was conducted to assess the accuracy of BIA in obese women and to investigate factors that influence the error of BIA in obese women.

Methods: 173 Health obese women (ages 21 to 49 years; BMI $\geq$25 kg/m^2) underwent BIA and dual energy X-ray absorptiometry (DEXA). The accuracy of BIA was assessed by Pearson correlation and Bland-Altman analysis. Factors that influence the error of BIA were investigated by Pearson correlation, one-way ANOVA, and multiple regression analysis.

Results: In obese women, the correlations between estimates of BIA and DEXA were highly significant (r = 0.838~0.910). Compared with DEXA, BIA was highly accurate for fat mass [[ΔFM (BIA-DEXA): 0.5kg (95% confidence interval: -3.8~4.8)], but BIA overestimated fat free mass [ΔFM (BIA-DEXA): 2.8kg (-1.9~7.5; 95% confidence interval)]. As adiposity was increasing, BIA overestimated fat free mass and underestimated fat mass. Increasing of waist circumference decreased the error of BIA occurred by increasing of adiposity.

Conclusion: In obese women, the correlations and agreements between estimates of BIA and DEXA were highly significant. However, the amount and distribution of body fat had influence on the error of BIA.

Key Words: Bioelectrical Impedance Analysis, Dual Energy X-ray Absorptiometry, Body Composition, Fat mass, Fat Free Mass, Obesity

Introduction

The syndrome of obesity is the state involving a metabolic disorder caused by the excessively increased body fat. However, WHO defines the obesity through the Body Mass Index as most studies on dynamics do.[1)2)] Unfortunately, using BMI we cannot draw a clear boundary line between Body Fat and

Fat Free Mass because it cannot directly determine the status of Body Composition. For instance, when the BMI increased, it can be the case that the adipose tissue has increased or on the contrary the case that the muscle has risen in its amount. Body Fat and Fat Free Mass affect the health and diseases in different ways so some accurate and highly reproducible measurement methods of Body Composition is necessary. Relatively accurate methods include Computerized axial Tomography(CT), Magnetic Resonance Imaging, Dual Energy X-ray Absorptiomety(DEXA), Underwater Weight measurement and Neutron Activation Analysis. But these methods are difficult to use in a clinic; the equipment is expensive and the measurement involves complex processes, massive facilities, and skilled technicians.

The BIA is relatively accurate and simple where its method analyzing the Body Composition has been developed as not expensive, easily transportable, safe and easy to use in a clinic.[3] BIA determines the impedance of body tissues sending small communicational currents across the body. Of all body compositions, the only compositions capable of conveying the electric currents are the body water and electrolyte that is melted in the water. Therefore, through the measurement of the impedance, it is possible to measure the Total Body Water (TBW) and predict the FFM on the presumption that TBW makes up a particular portion (usually 73%) of FFM.[4] FM can be calculated by subtracting the estimated FFM from the weight. In the last 20 years, many studies reported that in the grownups with normal weight, the measurement results of BIA showed high agreements without any big accidental errors with those of DEXA or Underwater Weight Measurement, more accurate methods assessing body composition,[5)6)7)8] but with fatness increasing, the BIA overestimated the FFM while underestimating the FM.[9)10)11] Neovious et al.[12] reported that in the women with abdominal obesity, BIA evaluated the FM 5% less than DEXA and the values increase in proportion to the increase of FM. However, in a recent report in Korea,[13] FFM and FM indicated high correlations in obese adults when analyzed by BIA and DEXA and there were no error differences associated with the increase of weight between the two methods. This result is significantly different from those of previous studies.

In this respect, we conducted comparison analysis on the FM and FFM in obese women measured by DEXA and BIA to verify the accuracy of BIA measurement and identify the factors affecting the errors in BIA. In this study, we used DEXA as a barometer test method which has reportedly been proved for its validity and known to hardly produce biased results caused by differences of age, gender, race, amount of physical activity and %FM.[14]

Methods

1. Study Subjects

This study used and analyzed the data on the 21 to 49-years-old obese women who had participated in a clinic experiment targeting the development of health care food at a research center in Seoul in 2006. BMIs of all subjects were above 25 kg/m^2, the criteria in diagnosing the obesity of WHO's Asia-Pacific Obesity Guidelines.[15)] The excluded people's list was written out through the preliminary survey and selecting examination carried out before the clinic experiment. The list of the excluded includes; the hypertensive whose blood pressures go above 150/90mmHg or who are taking diuretics, diabetics whose fasting plasma glucose is above 126mg/dl or who are taking oral hypoglycemic agents or insulin, patients who have a problem with the thyroid function or was diagnosed with thyroid disorder, the mentally ill suffering from depression, schizophrenia, alcohol and drug abuse, those who were diagnosed with a cancer or got treatment for a cancer in the recent 5 years, patients who have undergone an surgical operation in the recent 6 months, women who are pregnant or breast-feeding, women who have participated in a commercial program for obesity, or taken a obesity cure or diet food in the recent 3 months.

2. Study Methods

1) Anthropometry

The anthropometry and body composition measurement was conducted by the same research team and preliminarily trained nurses took the measurement. Fast for more than 8 hours, the lightly clothed subjects were measured for all their body parts and body compositions. Before the measurement, they were asked to urinate. All the estimates were not rounded off and taken down to one decimal place. Height and weight were measured with an auto weight and height measure (Dong-Sahn Jenix, DS-102, Korea). The BMI was obtained from the body weight(kg) divided by height in square meters. The waist circumference was tape-measured on the L12 site below the rib and the middle section of the uppermost site of the iliac crest.

2) Measurement of Body Composition

DEXA(GE, LUNAR prodigy, USA) and BIA(Jawon Medical, ZEUS 9.9, Korea) were used to measure body composition and leans body mass. The DEXA subjects were lying comfortably on a table and got scans from tip to toe for about 10 to 20 minutes. The BIA device with output current of 180 uA and frequencies of 1 to 1000 kHz uses total 8 electrodes - 2 at the hands and 2 at the feet – in the measurement. The subjects had fasted for more than 8 hours and inputted their gender, age, and height when the measurement started. They stood bare-foot on the distinguished areas including the electrodes with their legs spread out a little bit and lightly held the electrode handles with their arms stretched down following the measuring process. The Fat Mass and Fat Free Mass were calculated by the estimated formula embedded in the device. To analyze the errors using BIA and DEXA, we obtained the measurement difference between FFM (BIA-DEXA) and FM(BIA-DEXA) measured by both methods. If the difference turns out positive numbers, it means BIA's overestimating of both FFM and FM when compared with DEXA while underestimating both body compositions if the negative numbers.

4. Statistical Analysis

To assess the accordance between BIA and DEXA estimates, we conducted the correlation analysis and Bland-Altman analysis.[16)] To analyze the factors influencing the errors of BIA, we assessed the correlations between the differences of the two methods and other variables. And, to exclude the biggest effect of % body fat imposed on the BIA errors, we performed one-way ANOVA making a stratification of % body fat (average of measurement differences of DEXA and BIA) into 3 groups according to the tripartite numbers and Duncan test as a post-analysis. Multi-regression analysis was carried out on the age, % body fat and waist circumference regarding the BIA-DEXA measurement differences. For all the statistical data processes, we used 'SPSS 12.0 for Windows' to find out there was a meaningful difference when $P < 0.05$.

Results

1. Characteristics of the Subjects

Average age of the subjects(n = 173) was 35.2 ± 6.4. They had average BMI of 27.9 ± 2.4 kg/m^2 and average waist

Table 1. Baseline characteristics of subjects (n = 173)

Variable	Mean(SD)
Age (years)	35.2 (6.4)
Height (cm)	159.8 (5.4)
Weight (kg)	71.4 (7.9)
Body mass index (kg/m^2)	27.9 (2.4)
Waist circumference (cm)	90.4 (6.9)
DEXA body fat (%)	35.2 (4.6)
BIA body fat (%)	34.3 (2.8)
DEXA Fat Mass (kg)	24.1 (5.2)
BIA Fat Mass (kg)	24.6 (4.4)
DEXA Fat Free Mass (kg)	43.9 (4.4)
BIA Fat Free Mass (kg)	46.8 (4.1)

DEXA: Dual Energy X-ray Absorptiometry, BIA: Bioelectrical Impedance circumference of 90.4 ± 6.9 cm. DEXA measurement showed average % body fat of 35.2 ± 4.6 % while BIA showed 34.3 ± 2.8%. Average % body fat was 24.1 ± 5.2 kg with DEXA and 24.6 ± 4.4 kg with BIA. DEXA indicated the 43.9 ± 4.4 kg of FFM while BIA, 46.8 ± 4.1 kg (Table 1).

2. Accordance of Measurement time

Strong correlations were shown between DEXA and BIA with stronger correlations for FM (r = 0.091) than for FFM (r = 0.083) (Fig. 1). The FM measurement difference between BIA and DEXA was 0.5 kg (95% trust section: -3.8 ~ 4.8), a small 1kg difference, but FM estimates with BIA tended to fall as the FM increases (Fig. 1A). For the measurement of FFM, BIA showed overestimation by 2.8kg (-0.9~7.5; 95% trust section) higher than DEXA. But no tendency was found associated with the measurement differences of FFM between the two analysis methods.

3. Analysis of Factors affecting BIA errors

In the correlation analysis of BIA-DEXA measurement differences and anthropology variables, % body fat showed the strongest correlations with the differences. The % body fat had negative correlation (r = -0.570) with the differences of Fat Mass while positive correlation (r = 0.545) with the FFM. The same correlations were observed in the weight, BMI and BMF as in % body fat but the waist circumferences didn't show any meaningful correlations with the BIA-DEXA measurement differences. Age

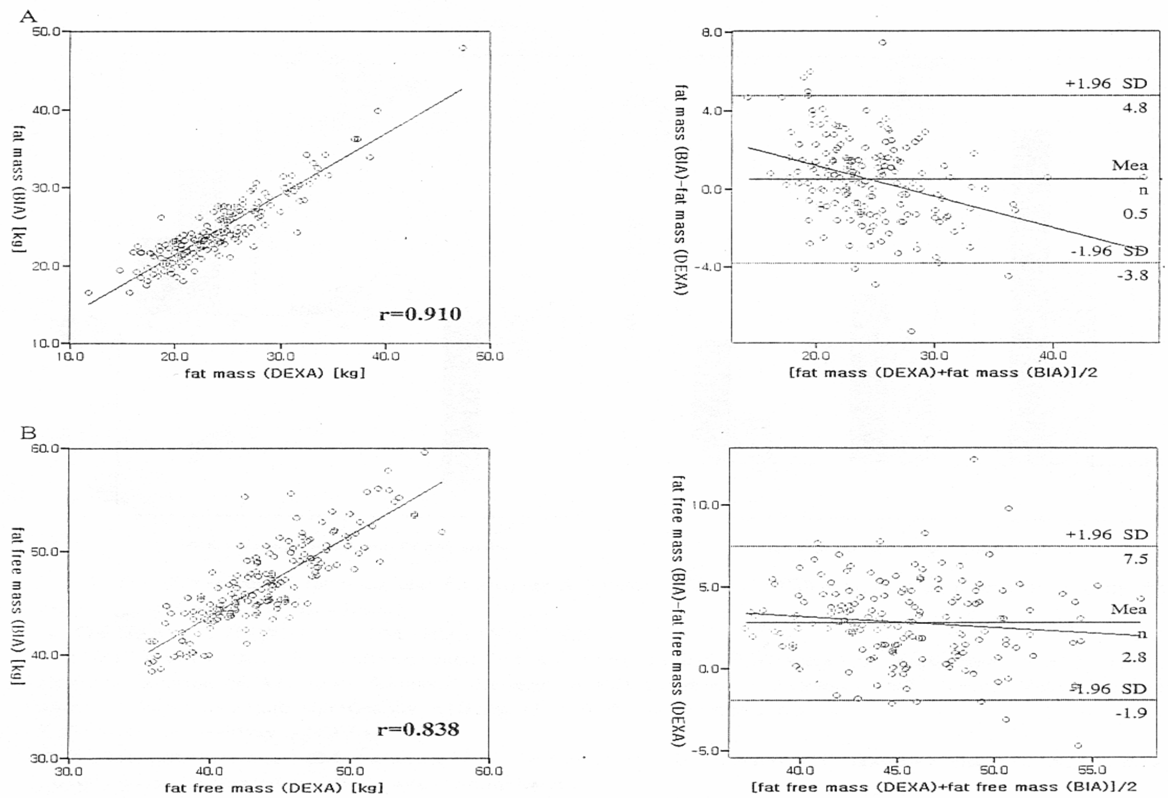

Fig. 1. Scatter plot (left) and Bland-Altman plot (right) of fat mass (A), fat free mass(Fat Free Mass) (B) by dual energy X-ray absorptiometry (DEXA) and bioelectrical impedance analysis (BIA)

Table 2. Correlation coefficients between differences of DEXA-BIA estimates and related variables.

	ΔFM (BIA-DEXA)	ΔFFM (BIA-DEXA)
Age	0.140	-0.223
Height	0.041	0.062
Weight	-0.119	0.195
Body mass index	-0.188	0.207
Waist circumference	-0.085	0.087
%BIA body fat†	-0.570	0.545
Fat Mass†	-0.344	0.372
Fat free mass†	0.190	-0.115

* $P < 0.05$ by Pearson's correlation.

† Average of estimates of DEXA and BIA.

FM, Fat Mass; FFM, fat free mass; BIA, bioelectrical impedance analysis; DEXA, dual energy X-ray absorptiometry.

didn't have any correlations with FM differences but a weak correlation with FFM differences (Table 2). We conducted On-way ANOVA on the waist circumferences (T1: 75.9~87.1cm, T2: 87.2~92.4cm, T3: 92.5~119.0) regarding BIA-DEXA measurement differences by making a stratification of % body fat into 3 groups (T1: 24.0~33.1%, T2: 33.2~36.1%, T3: 36.2~45.4%) according to tripartite numbers.

Different from the correlation analysis results that didn't show any meaningful correlations, the increased waist circumferences reduced BIA errors that had increased in proportion to %BF increase compared with DEXA. In the groups of low %BF, as the waist circumferences increased, BIA overestimated FM compared with DEXA. And this tendency was most prominent in the low %BF group (T1) while not so significant in the middle group (T2) (Fig. 2).

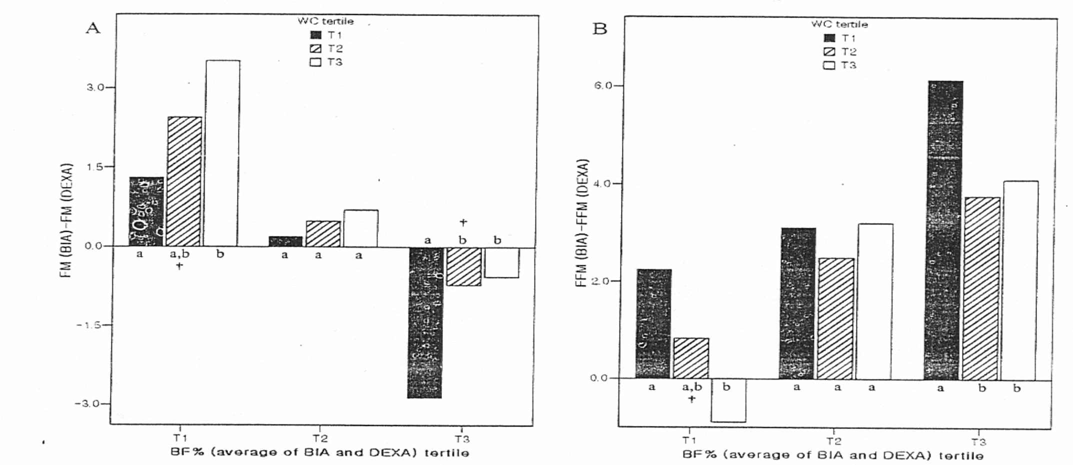

Fig. 2. The differences of Fat Mass and fat free mass between BIA and DEXA according to tertiles of %body fat and waist circumference.*

A. FM (BIA)-FM(DEXA), B. FFM (BIA)-FFM (DEXA)

* It was observed that BIA underestimated FM and overestimated FFM according to increase of %BF tertile. However, increase of WC tertile decreased the error of BIA occurred by increase of %BF tertile. Values marked with a different letter are significantly different ($P < 0.05$) by Duncan's test.

† $P < 0.05$ by one-way ANOVA

%BF, body fat percentage; FM, Fat Mass; FFM, fat free mass; BIA, bioelectrical impedance analysis; DEXA, dual energy X-ray absorptiometry; WC, waist circumference

Table 3. Results of multiple regression analysis on the differences of estimates between BIA and DEXA

∆FM (BIA-DEXA)				∆FFM (BIA-DEXA)			
	β	SE	P-value		β	SE	P-value
Constant	6.708	1.834	< 0.001	Constant	-2.919	2.106	0.168
Age	0.014	0.020	0.482	Age	-0.052	0.024	0.030
%BF*	-0.486	0.046	< 0.001	%BF*	0.505	0.053	< 0.001
WC	0.112	0.023	< 0.001	WC	-0.110	0.027	< 0.001

* Average of estimates of DEXA and BIA.

FM, Fat Mass; FFM, fat free mass; BIA, bioelectrical impedance analysis; DEXA, dual energy X-ray absorptiometry; WC, waist circumference; %BF, body fat percentage

When Multi-regression Analysis was performed on the age, %BF and waist circumference concerning BIA-DEXA measurement differences; for the difference between FMs, %BF (β = -0.486) and waist circumference (β = 0.112) had a significant correlation statistically, for the difference between FFMs, %BF (β = 0.505), waist circumference (β = -0.110) and age (β = -0.052) altogether had strong correlations; the direction of the correlation between waist circumference and age was opposite to that of %BF (Table 3).

Discussion

In this study, based on DEXA measurement for obese women, we tried to verify a BIA product developed by a domestic company and identify the factors that affect BIA test errors. Study results showed BIA estimates had correlations with DEXA [r = 0.910 (FM), 0.838 (FFM)]. When compared with DEXA, BIA showed high agreement in FM [∆ FM (BIA-DEXA): 0.5 kg (95% trust section: -3.8 ~ 4.8)], but in FFM, BIA assessment was 2.8kg (-1.9~7.5: 95% trust section) higher than DEXA. The most prominent variable that influences the BIA errors was %BF and the waist circumference also had effects on the errors.

Han, Sang-hyuk et al.[13] reported that in the obese adult population comprised mainly women, BIA estimated the FFM by average 2.8kg (-1.9~7.5: 95% trust section) higher than DEXA. He also added the average BIA-DEXA difference in measurement of FM was -0.2kg (-4.8~4.4: 95% trust section), a similar result with our report. However, different from our study results, BIA-DEXA differences did not appeared in accordance with the FM increase. Neovius et al. reported that BIA underestimated the %BF as %BF increased in women who had abdominal obesity, an agreement with our report but with 5.0% of BIA-DEXA measurement difference, his study showed higher error ratios. These study to study differences are considered to be caused by the varied conditions of study scale, characteristics and different estimated formulas of the BIA products employed in those studies. In a study of overweighing males,[17] BIA products adopting Multi-frequencies assessed the %BF 7.0% less than DEXA (-0.4~13.6: 95% trust section), while the same products showed only 1.7% (-5.6~9.0: 95% trust section) higher measurement when the frequency method was switched to Single-frequency. Other Single-frequency BIA devices, on the contrary, showed 1.2% (-8.3~10.7: 95% trust section) higher measurement. These results indicate different kinds of BIA devices with different frequency types result in different BIA estimates.

BIA, in reality, measures just the TBW(Total Body Water) and on the assumption that the ratio of FFM and TBW is consistent, it estimates FFM and calculates FM by subtracting the FFM from the body weight. However, when the FM increases, TBW will also increase relatively to FFM.[18][19] When the estimated formula for normal people assuming the ratio of FFM and TBW is consistent is applied to obese people with this relatively increased TBW, FFM in the obese is overestimated whereas the FM is underestimated. And in these obese people, the relative amount of Extracellular Fluid (ECF) to TBW increases.[18] The 50 kHz frequency dominant in BIA cannot perforate the surface of cell so the BIA devices that use 50 kHz single frequency actually measure the ECF and parts of Intracellular Fluid (ICF) rather than the TBW.[20] In addition, even in the Multi-frequency BIA devices, the impedance against the current going through ICF is higher than in case of ECF. The main culprit can be the impedance generated while the current passes through the cell membrane. Different types and amounts of electrolytes melted into both fluids can also be the cause.[21][22] Therefore the relatively higher amount of ECF in obese people can contribute to the overestimation of FFM even when Multi-frequency devices are used.

In this study, we reaffirmed that the circumference of waist - indirect indicator of BF distributions as well as FM - can affect the BIA measurement errors.[20] BIA assumes that the human body consists of conductors of cylinder shape with the same cross section. But the real arms, legs, and trunk have different values of cross section, and the impedance is proportional to length and inversely proportional to the cross section. So, the arms and legs having a relatively small cross section contribute to the impedance more than the trunk which is short and has a relatively big cross section. Arms and legs make up only 4% and 17% of the body weight while comprising 47% and 50% of the total impedance respectively. Meanwhile, the trunk takes up 50% of the weight but only 5~12% of the impedance.[23] Hence the changes of FM in the trunk are not sensitive to BIA and, as a result, with the same increase of FM, BIA errors should be determined by the location of body fat storage. And the age didn't affect the BIA errors in measurement of FM but showed a weak negative correlation with the measurement of FFM, which may be translated as the fat gathers to the center of body with aging.

There were several limitations in this study. First, the study used the DEXA as a criterion. Although this method has been proved for its validation[24)25)] and many other studies also used this method as a barometer in comparison study of BIA accuracy,[11)12)17)] we can not jump to a conclusion that DEXA is an absolutely accurate method. Second, this study used only one time of DEXA and BIA measurement, failing to meet the requirement of using the data from two or three times of measurements to minimize the errors. And despite the possibility of errors triggered by women's menstruation cycles, the cycles were not taken into consideration. Third, since this study was conducted only for the health but obese women in their 20 – 40s who had participated in the experiment for the development of health-care food, the results of this study can not be generalized to be applied to other obese public.

When the BIA method of the device used in this study compared with DEXA, it presented strong correlations between the measurement values of obese women and high agreements with DEXA in average FM. However, the BIA errors were observed to increase and decrease according to the amount and distribution of FM. Accordingly, when interpreting the BIA test results of obese women, the FM amount and distribution will also have to be considered.

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