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## VALIDITY OF BIOELECTRICAL IMPEDANCE ANALYSIS COMPARED TO HYDROSTATIC WEIGHING IN MEASURING BODY COMPOSITION OF MIDDLE-AGED WOMEN

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### ABSTRACT

**Bennis EA, Fatheree BJ, Mesang JN, Palmer DJ, Tauscheck EL.** Validity of Bioelectrical Impedance Analysis compared to Hydrostatic Weighing in Measuring Body Composition of Middle-Aged Women. *Journal of Undergraduate Kinesiology Research* 2006;2(1):41-48. **Purpose:** Two current methods for assessing total percent body fat among individuals are the Tanita Bioelectrical Impedance Analysis (BIA) device and hydrostatic underwater weighing. The purpose of this study was to determine the validity of the Tanita Bioelectrical Impedance Analysis device when compared with Hydrostatic Weighing in measuring body composition among women ages 18 to 45. **Methods:** We recruited 13 between the ages of 18 and 45 from the Eau Claire, Chippewa Valley area for our study. The subjects were of various physical activity levels ranging from inactive to highly active; however, highly trained women, those who participated in two or more high intensity exercise sessions per week, were excluded from the study. After being introduced to the testing procedures, subjects were measured using the Tanita Bioelectrical Impedance device and hydrostatic weighing to determine their percent body fat. After hydrostatic weighing, subject's residual lung volume was measured using the EXERTECH RV system in order to calculate percent body fat. All subjects underwent multiple trials of hydrostatic weighing and Tanita BIA measurements in order to ensure validity. All measurements procedures were conducted on the same day for each subject. This study compares the validity of the Tanita Bioelectrical Impedance Analysis device to hydrostatic weighing using a sample t-test. **Results:** The results of our study show that there is a significant difference between body fat percent as determined by the Tanita BIA device and hydrostatic weighing among women between the ages of 18 and 45. **Conclusion:** Results are important because BIA devices are becoming more popular and widely used. It is essential for health and fitness professionals to realize results from this tool should not be considered valid.

**Key Words:** Female, Underwater Weighing, Fat-Free Mass, Leg-to-Leg BIA, Percent Body Fat Assessment

## INTRODUCTION

Obesity in the United States has risen to almost an epidemic level over the last few years, and shows no signs of slowing down. Approximately 127 million people in the United States are overweight, 60 million of which are obese. There are numerous health issues associated with being overweight and obesity that many are probably not aware of. Diabetes, hyperlipidemia, high cholesterol, metabolic syndrome, hypertension, and cardiovascular disease are just some of the more prominent diseases that may arise from being overweight or obese. That is why it is important for people to strive for, or maintain a healthy body weight and be able to monitor their body composition in a safe and easy manner.

Many individuals concerned with fitness and body fat content often use some means of body composition assessment. In doing such an assessment, total percent body fat in an individual can be determined. One method of assessing body fat percentage is the Tanita Bioelectrical Impedance Analysis (BIA) device. Introduced in the 1960s, the BIA is a quick, non-invasive technique commonly used in health and fitness industries (1). Percent body fat determined by BIA is accomplished by conducting a harmless electrical current throughout the body (2). The resistance within the body of the individual to this current measures the electrical impedance (2). This conductive pathway of electric current directly correlates to the percentage of water in the body, which is higher in lean body mass than in fat mass (2). A developed regression equation is used to estimate lean mass and water volume within the body (3).

Research has been conducted in order to determine the validity of BIA. These studies look at comparing BIA results to those found using hydrostatic weighing. Hydrostatic weighing is used as a comparison model because it has long been considered the “gold standard” for determining body fat percentage (4). A study conducted by Demura, Sato, and Kitabayashi concludes the Tanita BIA device tended to overestimate the percent total body fat with the test-retest reliability of the device being 0.995 (5). Another study, conducted by Civar, Aktop, Tercan, Ozdol, and Ozer, finds the results determined by Tanita to be highly comparable with those of hydrostatic weighing (1). In this study, body fat percentage was estimated at  $11.63 \pm 2.42$  with underwater weighing and  $11.82 \pm 2.39$  with leg-to-leg bioelectrical impedance. The study concludes the confidence intervals are small enough to be considered to have no systematic difference (1). A study performed by Utter, Nieman, Ward, and Butterworth, which focuses on obese and non-obese women also concludes there is no significant difference when comparing the Tanita BIA device to hydrostatic weighing (6). A study conducted by Bosy-Westphal, Danielzik, Dorhofer, Piccoli, and Muller focuses on BIA accuracy across different age ranges. They stated that there is evidence that BIA can be accurately used with sex-specific regression equations in the age range of 12 to 94 years old (7). Through the research we have looked at, we have found the data has been somewhat inconsistent for how much of a difference there is between the two techniques for determining percent total body fat, if any at all. We believe that more work needs to be done in this area of study. This investigation aims to determine the validity of the Tanita BIA device as compared to hydrostatic weighing in measuring percent body fat among women ages 18 to 45. It is hypothesized that a woman's percent body fat as determined by the Tanita BIA device will not differ significantly from that determined by hydrostatic weighing.

## METHODS

Hydrostatic weighing and Tanita Bioelectrical Impedance Analysis testing were conducted on the same day for each individual subject.

### Subjects

We recruited 13 women between the ages of 18 and 45 from the Eau Claire, Chippewa Valley area. Subjects were categorized as being active or inactive. As this study was directed toward the average

population, highly trained women were not included. Highly trained women were those who participated in two or more high intensity exercise sessions per week. We categorized women as active or inactive based on the US Surgeon General's recommendations for physical activity. Those who participated in 30 minutes of moderately intense physical activity most days of the week were considered active, and those who did not were considered inactive. This study was approved by the institutional review board of the University of Wisconsin – Eau Claire. All subjects signed a letter of informed consent before the study.

**Table 1. Descriptive data of the subjects.**

	N	Minimum	Maximum	Mean	SD
Weight (kg)	13	60	81	67.0	5.0
Height (in)	13	53	70	63.0	5.3
Age (yrs)	13	20	46	27.2	8.7

### Instrumentation

After researchers explained testing procedures, subjects were measured using hydrostatic weighing and the Tanita Bioelectrical Impedance device (Tanita Inc., Tokyo, Japan, Model BF-522) to determine their percent body fat. The Tanita BIA device also measures the subject's body weight. Height measurements were taken using a basic wall tape measure. In addition, the subject's residual lung volume was measured using the EXERTECH RV (Dresbach, MN) system. In order to ensure validity and reliability of the study, all subjects underwent five to ten trials of hydrostatic underwater weighing and five Tanita BIA measurements. The mode of each measurement will be used as the final value. All measurement procedures, including hydrostatic weighing, residual lung volume, and Tanita BIA, were conducted on the same day for each subject. Tanita BIA testing was conducted prior to residual lung volume measurements and hydrostatic weighing. Subjects wore swimsuits for all testing procedures except residual lung volume testing.

### Procedures

#### Tanita Bioelectrical Impedance

The Tanita bioelectrical impedance analysis device (Tanita Inc., Tokyo, Japan, Model BF-522) was used for the assessment of percent body fat among the subjects. Each subject was given a set of written pre-testing guidelines to adhere to before her designated testing date. The guidelines included the following: (a) no food or drink 4 hours prior to the test; (b) no vigorous exercise 12 hours prior the test; (c) empty bladder 30 minutes prior to testing; (d) no alcohol consumption 48 hours before the test; (e) no diuretic or caffeine medications 7 days prior to the test; (f) no smoking for 3 hours prior to testing; (g) no testing clients who perceive they are retaining water during that stage of their menstrual cycle; (h) limit consumption of liquids to 1% of body weight 2 hours prior to the test; and (i) avoid foods that cause excessive amounts of intestinal gas. Along with these guidelines, we asked that the subjects wear swimsuits for all testing procedures to ensure validity. Tanita BIA measurements began with the technician entering the subject's age, gender, and height into the device. Subjects were measured by the Tanita BIA device while standing erect, with clean bare feet, on the analyzer's footpads. The device's electrodes are in the form of stainless steel footpads mounted on the top surface of a platform scale. A 50kHz current is applied and impedance is measured through the legs and lower trunk of the subject. The subject's percent body fat is determined by the Tanita BIA device according to the way in which this current passes through the body. The Tanita BIA device uses an unknown prediction equation to calculate the subject's percent body fat.

#### Hydrostatic Weighing

Hydrostatic weighing measurement procedures began by obtaining a dry weight of the subject in a swimsuit using a scale. The subject's height and weight were measured and recorded by the

technician. Prior to administering the test, the circulating pump of the cylindrical hydrostatic weighing tank must be turned off. The technician checked for this and then went on to record the water temperature of the tank. The water temperature is used to assess the density of the water. The PVC plastic chair was calibrated before each test while it was unloaded and at 0.0 kg. Each subject showered prior to entering the hydrostatic weighing tank for testing. The subject entered the tank and got completely wet, removing all air bubbles from their swimsuit. Before each measurement, the subjects sat in the chair with their head out of the water, took a deep breath, exhaled approximately one-half tidal volume into the air, and submerged their head beneath the water while they made a forced maximal exhalation. While performing this procedure, the subject must stay in the chair keeping their body parts from touching the tank walls. When the subject has expelled as much air as possible, the technician records their underwater weight. This procedure was repeated 5 to 10 times until a fairly consistent underwater weight was recorded. Percent body fat was then determined using the average of two Lohman Formulas.

### Residual Lung Volume

Following hydrostatic weighing, each subject underwent a residual lung volume analysis. This is done to produce the exact residual lung volume of each subject, and provide the highest amount of accuracy for hydrostatic weighing. The EXERTECH RV System (Dresbach, MN) was used to determine each subject's residual lung volume. After calibrating the EXERTECH RV System the following steps must be taken in order to get an accurate residual lung volume reading:

- a) Flush the bag twice prior to testing. On the third time filling the bag push in the calibrated syringe pump handle so the bag contains 4.5 – 5.0 Liters of pure oxygen.
- b) Push this measured volume into the bag for re-breathing.
- c) Attach a clean mouthpiece onto the mouth port of the slider valve, and place a nose clip on the subject.
- d) Lower the penlift lever and press the record button as the subject seals her lips around the mouthpiece.
- e) Instruct the subject to take in a deep breath and exhale slowly as fully as possible. Instruct the subject to signal when she has expelled all of her air.
- f) Once she signals push the handle of the slider valve in to connect the subject to the re-breathing bag. She should now breathe deeply until equilibrium occurs.

### **Statistical Analysis**

This study compares the validity of the Tanita Bioelectrical Impedance Analysis device to hydrostatic weighing using a sample t-test. Paired t-tests were performed to compare mean differences in percent body fat between hydrostatic weighing and the Tanita BIA device. The sample size of the study was determined by the number of subjects we were able to recruit for the study. The level of significance was set at  $p < 0.05$ .

### Dependent Variable

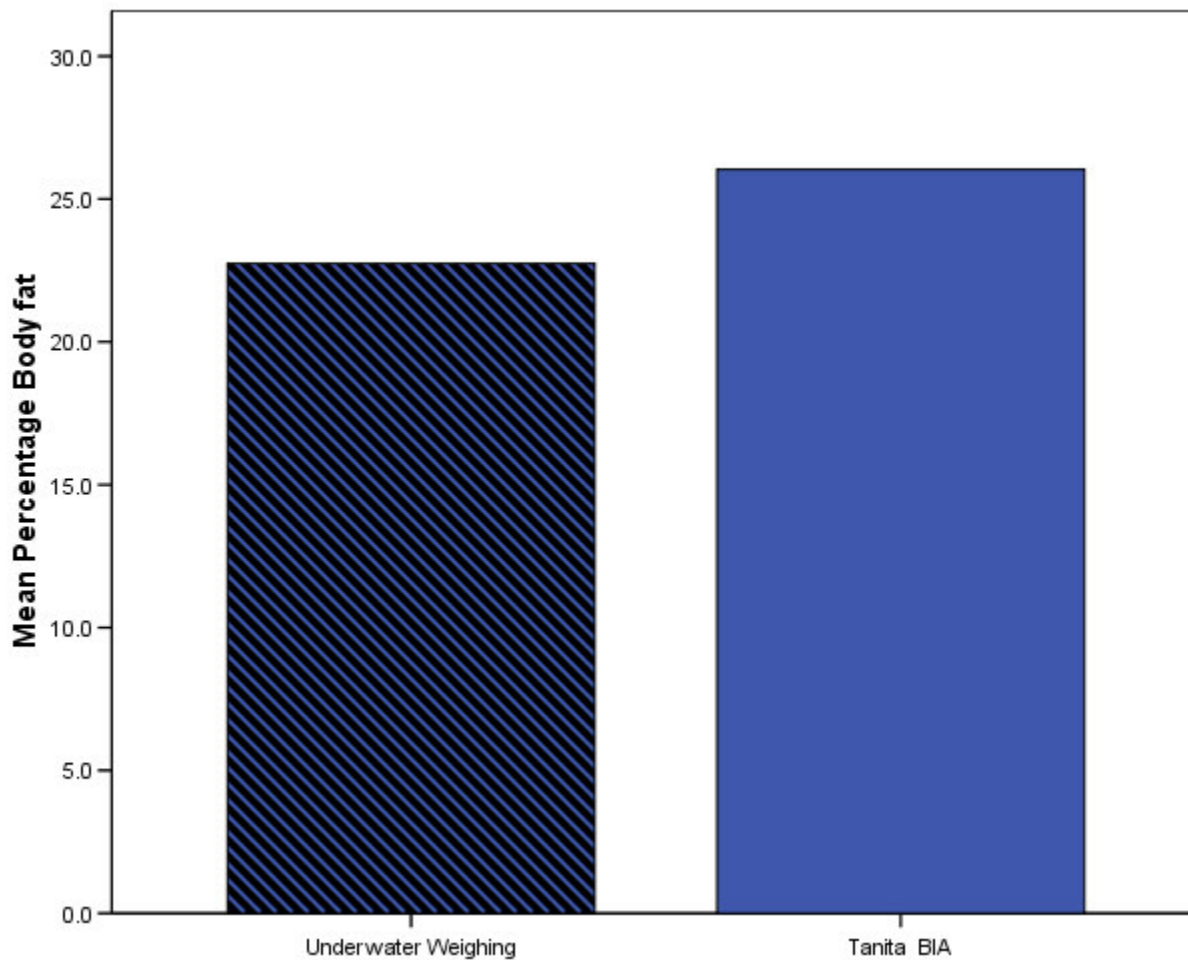
The dependent variable in this study is the individual percent body fat as determined by the Tanita BIA device.

### Independent Variable

Independent variables in this study include the individual percent body fat as determined by hydrostatic weighing and the Tanita BIA device.

### **RESULTS**

Significant differences exist ( $p < 0.05$ ) between body fat percent determined by the Tanita BIA device ( $m = 26.0$ ) and hydrostatic weighing ( $m = 22.8$ ),  $t(13) = -2.762$ ,  $p = 0.017$ . The Tanita BIA device overestimated percent body fat of our subjects by 3.2 percent, on average.



**Figure 1. Mean Percentage Body Fat Comparison**

## DISCUSSION

Based on the results of the study we will accept the null hypothesis, which states that there is a significant difference between body fat percent as determined by the Tanita BIA and hydrostatic weighing. Significant differences exist ( $m=3.28$ ) between body fat percent determined by the Tanita BIA ( $m=26.03$ ) and hydrostatic weighing ( $m=22.75$ ).

These significant differences suggest that the Tanita BIA device does not provide valid measurements of percent body fat for pre-menopausal women.

Previous studies have shown that BIA devices provide valid measurements of percent body fat when compared to alternative methods. Demura, Sato and Kitabayashi conducted a similar study and determined that the Tanita BIA slightly overestimates percent body fat ( $m=1.28$ ), but the differences are statistically insignificant (5). Another study, conducted by Civar, Aktop, Tercan, Ozdol, and Ozer concludes that the results determined by Tanita BIA are highly comparable with those of hydrostatic weighing ( $m=0.19$ ) (1). The mean differences of these three recent studies are shown in table 2.

**Table 2. Mean Differences of Studies**

Author	BIA	Hydrostatic	Difference
Demura (2004)	19.5	18.3	1.2
Civar (2006)	11.8	11.6	0.2
Fatheree (2006)	26.0	22.8	3.2

It is possible that inaccuracies in either Tanita BIA device and/or hydrostatic weighing contributed to the variation in the difference in percent body fat measurements by the Tanita BIA device and hydrostatic weighing. Although hydrostatic weighing is generally considered to be the “gold standard” for determining body fat percentage, the method involves multiple measurements including water temperature, atmospheric temperature and pressure, nitrogen analyzer calibrations, force sensor calibrations, subjects’ residual lung volume, and underwater weighing itself. With each measurement, inaccuracies can occur that can contribute to the overall error in estimating body density and percent body fat. The validity of hydrostatic weighing is dependent on an absence of mechanical or technical dysfunctions. All equipment used in our study was of good quality and functioning correctly. Inaccuracies can also occur among the researchers. Researchers need to be experienced in order to conduct hydrostatic weighing correctly in order to ensure minimal error. All researchers in this study had past experience in conducting or were previously introduced to hydrostatic weighing, Tanita BIA device, and residual lung volume assessments. Incorrectly zeroing in the chair by the researchers can significantly affect measurements causing error as well. However, this did not occur in our study. The greatest source of error in determining percent body fat comes from errors in measuring residual lung volume.

Inaccuracies in measuring residual lung volume (RLV) cause the greatest source of error in calculating body volume. Techniques for measuring RLV require specialized equipment and trained personnel. The standard error of estimate for predicting RLV ranges between  $\pm 325$  to 500 mL; this can then lead to error in predicting percent body fat of about  $\pm 2.5$  percent or more (8). In addition, according to McArdle, “Not accounting for residual lung volume causes the computed body density value to decrease because the lungs’ air volume contributes to buoyancy (lighter underwater weight) without affecting body mass. A lower body density makes a person “fatter” when converting body density to percent body fat (8). In our study, residual lung volume was taken into consideration and accurately measured using the EXERTECH RV System.

Subjects can also contribute to inaccurate percent body fat measurements taken by the Tanita BIA device and hydrostatic weighing. At least one day prior to their test date, we provided each of our subjects with strict pre-testing guidelines to abide by. We believe all subjects adhered to these guidelines based on an honor system. Subjects can also contribute to inaccuracies during hydrostatic weighing. The subject must make a forced maximal exhalation while submerged under water in the hydrostatic weighing tank. Failure by the subject to make a forced maximal exhalation can affect measurements, in particular underwater weight; therefore, causing inconsistent and/or inaccurate measurements for body density and percent body fat. We must also consider inaccuracies with methods for assessing body density when measuring percent body fat.

Applying constant density values for fat free and fat tissues can produce errors in measuring percent body fat among individuals. The density values for fat free and fat tissues are generalized, average values for young and middle-aged adults; however, these variables vary among individuals and groups. These differences limit the accuracy of determining percent body fat from whole body density. In our study, we used the body density formula that appropriately corresponded to our subjects. The body density formula we used was the average of two Lohman formulas, which is suited for women. The Tanita BIA device uses mysterious unknown formulas to determine percent



body fat. These formulas, like other constant density values for fat free and fat tissues, do not take population specific characteristics into consideration, which may lead to inaccurate or invalid results.

Future research comparing the validity of the Tanita BIA device to hydrostatic weighing can still be conducted in order to support our results. Future studies that may be conducted may possibly look at different groups of individuals including different genders, ethnic groups, athletes, the obese, etc. Other future research that could be conducted in order to assess the validity of the Tanita BIA device could include comparing this method to other methods of assessing percent body fat such as skin fold analysis, air displacement plethysmography, and dual-energy x-ray absorptiometry.

Our results are important to individuals concerned with body composition, particularly those aiming to alter their physical appearance. As BIA devices are becoming more available to the general public it is important that the accuracy and validity be addressed. These devices are becoming popular because they are easy to use, quick, noninvasive, and relatively inexpensive. Based on our findings BIA does not provide an accurate assessment of percent body fat for pre-menopausal, untrained women. Interestingly, our research shows that the Tanita BIA device consistently overestimates percent body fat and results should not be considered valid. This contradicts results from previous research studies that claim there is no significant difference between percent body fat measurements as determined by BIA devices and hydrostatic weighing. One factor that affects the Tanita leg-to-leg BIA device is the distribution of the individual's adiposity. The gynoid fat pattern is common among women, which is characterized by excess weight in the lower extremities, hip and thigh regions. Because this particular BIA device sends the electrical current through the legs it tends to overestimate the women's overall percent body fat. The Tanita BIA device significantly overestimates percent body fat in pre-menopausal, untrained women and should not be used as a valid tool for assessment.

## CONCLUSIONS

In disagreement with previous research, our study shows that there is a significant difference between body fat percent as determined by the Tanita BIA device and hydrostatic weighing among women between the ages of 18 and 45. The significant difference found suggests that the Tanita BIA device consistently overestimates overall percent body fat in women. The most valid and reliable instrument used to measure percent body fat continues to be hydrostatic weighing.

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