To the Graduate Council:

I am submitting herewith a thesis written by Allison Kellie Wallis entitled "The effect of physical activity levels on body composition assessment in young women." I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Human Performance and Sport Studies.

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The Effect of Physical Activity Levels on Body Composition Assessment in Young Women

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Allison Kellie Wallis

August 2002

DEDICATION

This thesis is dedicated to my parents, Gary and Linda Wallis, and my fiancé Chuck Kohstall. Thank you for all of your support, encouragement, guidance, and patience throughout this entire process. You have helped me to become who I am today and have inspired me in so many ways. Thank you for believing in me and pushing me to do my best. I am forever grateful.

ACKNOWLEDGMENTS

The author wishes to express her thanks and gratitude to several people for their assistance throughout various stages of this study.

My advisor, Dr. Dixie Lee Thompson: Thank you so much for your dedication and early morning sacrifices. Thank you for pushing me to complete a thesis and helping me realize my research abilities. Your guidance with the writing of this document has been extremely beneficial and I greatly appreciate the number of hours spent editing this document.

Dr. Edward T. Howley and Dr. David R. Bassett, Jr.: Thank you for serving as members of my committee and guiding me through the world of exercise physiology.

Abigail Geslani, MS: Thank you for all of your help with testing during those early morning hours. I couldn't have done it without you.

Mike Neuman, MS: Thank you so much for all of your help with the statistical analyses used in this study.

Chuck Kohstall: Thank you so much for standing by me throughout this entire process. Your encouragement was extremely motivating; you kept me going through the ups and downs of research and helped me see the light at the end of the tunnel. Thank you for being my shoulder to lean on and my best friend. I love you.

To my family and friends, thanks for believing in me and encouraging me to never give up.

Lastly, special thanks to all of the young women who volunteered to participate in this study. Without all of you, this thesis would not have been possible.

ABSTRACT

The main objective of this study was to determine which activity mode of a foot-to-foot bioelectrical impedance analyzer (BIA) provides the best estimate of body composition as compared to Lohman's 3-compartment (3-C) model in young women. Study participants were 60 young females (23.3 ± 4.8 y) that were classified into one of three aerobic activity groups (less active (LA), moderately active (MA), or highly active (HA)) based on reported physical activity. Body fat percentage (%BF) was estimated in both the BIA "athlete" and "adult" mode of the Tanita® TBF-305. Body density (D_b) via underwater weighing and bone mineral via a whole-body DXA (Lunar DPX-NT) scan were used to compute the 3-C estimate of %BF. A one-way analysis of variance (ANOVA) showed significant differences ($p<0.05$) in aerobic activity between the three groups, in addition to significant differences ($p<0.05$) in height and body mass in the LA and MA groups compared to the HA women. The MA women also had significantly ($p<0.05$) lower bone mineral content compared to the HA group. For the LA women, there was no significant difference between the 3-C estimate of %BF and that from the BIA adult mode (28.8 ± 1.1% vs. 30.7 ± 1.09, respectively). For the MA women, the BIA athlete mode and the 3-C model yielded similar results (21.1 ± 0.92% vs. 20.7 ± 1.05%, respectively), while the BIA adult mode provided significantly higher estimates (29.3 ± 1.04%). For the HA women, both the BIA athlete (20.9 ± 0.94%) and BIA adult (31.2 ± 1.07%) estimates were significantly higher than the 3-C criterion value (17.3 ± 1.07%). Each of the %BF estimates from the two BIA modes were moderately correlated with the %BF estimate of Lohman's 3-C model for all three activity groups (r = 0.59-

0.77). In conclusion, the BIA adult mode appears to be an acceptable alternative for body composition assessment in less active young women, while the BIA athlete mode can be used to estimate %BF in young women that participate in 2 to 10 hours of aerobic exercise per week, however in extremely active women (i.e., 10 or more hours of aerobic exercise per week), both the athlete and adult mode overestimate %BF.

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CHAPTER 1

INTRODUCTION

Over the years, a great deal of emphasis has been placed on body fatness due to its relevance in both health and performance. Predicted body fat values are often used in conjunction with other health factors to determine an individual's overall risk of disease and future health consequences. Body fatness can also impact athletic performance. Excessive body weight and/or fatness can inhibit an athlete's abilities in a number of sports, especially those that require large amounts of power, speed, and strength (50). Many people often interchange the terms body fatness and body composition, however body composition extends beyond the idea that the body is made up of fat mass (FM) and fat-free (lean) mass (FFM). The FFM component of body composition can be broken down into individual components: mineral, water, and protein. With methods to assess these individual FFM components, a more accurate estimation of percent body fat will result.

Underwater (hydrostatic) weighing (UWW) is often viewed as the gold standard of body composition assessment. UWW has been found to provide fairly accurate estimates of body fatness when performed correctly (9, 28, 32). Although UWW is often considered a criterion measure, it is not free of problems. A number of studies have found the density of FFM (D_{FFM}) varies among people of different ages and ethnicities. Regardless of the 2-compartment (2-C) model used in conjunction with UWW, if the individual being tested does not have the D_{FFM}

assumed by the model, the estimation of %BF will be inaccurate. UWW can also take a large amount of practice for a technician to master and may be difficult for the subject to perform: exhaling maximally while being completely submerged. Another possible measurement error in percent body fat with UWW is the measurement of residual volume; "for every 100 ml error in residual volume, percent fat will be in error by ~0.7 percent fat units" (17).

As stated previously, body composition is often generalized into two parts: fat mass (FM) and fat-free mass (FFM). Currently, there are a number of methods available that assess body composition using these two "general" compartments to calculate percent body fat (the proportion of the total body weight that is fat tissue). Unfortunately, a number of these two-compartment models (e.g. Siri, Brozek, etc.) were developed solely on the cadaver dissection of a few white males and thus have significant room for error since they do not account for individual differences in the components of fat-free mass: mineral, water, and protein. As technology has advanced, a number of multi-compartment models have been developed that correct for different FFM components, thus reducing the error in estimation of body fat.

In addition to being used as a "stand alone" measure, UWW's determination of total body density is often used as a component in a number of multi-compartment models. The addition of bone mineral from a dual energy X-ray absorptiometry (DXA) scan to UWW's total body density has been shown to increase the accuracy of the estimation of body fatness (29). Total body mineral has been found to account for approximately 6% of FFM and also has the highest density of all of the FFM components (34). Past studies have proposed that a variation of 1% of bone mineral can alter the density of FFM so significantly that estimates of body fat are altered 4-5% (32, 52). Although a number of researchers feel that traditional 2-compartment models may not be significantly different from multi-component models for a number of young adults, a substantial number of individuals lie at the extremes of the range for bone mineral density (BMD), bone mineral content (BMC), and/or density of the FFM, thus causing under or overestimations in their %BF when using 2-compartment models (12). Thus, the addition of bone mineral density to the body fat equation can be extremely important.

Lohman's 3-compartment (3-C) model accounts for both total body mineral and total body density (via UWW) and will be used as the criterion in this study. It is highly possible that women in this study may differ significantly in bone mineral density due to their diverse activity levels. There is a considerable chance that some of the "highly active" women may lie at either extreme of the bone density spectrum: very low bone mineral density as a result of intense training conditions and possible amenorrhea, or extremely high bone mineral density as a result of the heavy training loads. Thus, the use of Lohman's 3-C model as the criterion measure is key to reducing possible error that may occur in the measurement of percent body fat for this study's population.

Although multi-compartment models appear to be extremely accurate, they are often very time-consuming and difficult to administer, especially to the general public. "Techniques with high accuracy, suitable for use as reference methods, are of value in the research settings, but are not easily applicable to field studies of a large population" (53). Technology has quickly answered the need for quick and useful body composition assessment tools with a number of new devices, including the Tanita® TBF-305, a foot-to-foot device that estimates percent body fat through bioelectrical impedance (BIA). Bioelectrical impedance devices introduce a small current into the body and measure the resistance to flow (or impedance) based on the response of various tissues in the body, those that allow the current to flow through, and those that resist the current (14). Once impedance is measured, then FFM, FM, TBW, and percent body fat can be predicted.

The Tanita® uses a single frequency to estimate percent body fat. The electrical current is transmitted across a tissue bed and impedance is measured in relation to the transmission and conduction properties of the tissue (35). Tissues that contain a lot of water and electrolytes, such as blood and muscle, will allow the current to flow through, while tissues that contain low levels of water and electrolytes, such as adipose tissue (fat) and bone, will be highly resistive to the current (4, 14).

The Tanita® is currently being used in a number of diverse populations and settings, including clinician's offices, wellness centers, hospitals, fitness facilities, and private homes (48). Many researchers attribute the growing use of the Tanita® to a number of advantages it possesses. The Tanita® is extremely easy to use, requires very little skill to administer as the technician, eliminates the need for gel electrodes, and is extremely portable, noninvasive, and relatively inexpensive. One issue of concern with the Tanita® TBF-305 is that an individual must be classified as either an "athlete" or "adult" based on his/her activity level. Manufacturer's guidelines specifically classify an "athlete" as an individual who participates in recreational or professional sports for 10 or more hours each week and has been doing so for at least the past six months, has a resting heart rate at or below 60 beats per minute, and/or has competed in national and regional sporting events. These guidelines are based on the assumption that elite athletes usually have a body composition that falls well outside the normal "adult" range; thus, the "athlete" mode was created to more accurately assess athletes' percent body fat since they tend to be much leaner than the general population.

Although BIA devices, including the Tanita®, are extremely quick and practical to use, a debate still exists over their accuracy and precision in estimating body fatness, especially when dealing with diverse populations. Unfortunately, very little is known regarding the usefulness of the Tanita® when assessing body composition in women of different activity levels. Although techniques like the Tanita® are easier to administer, their efficacy still needs to be established in a number of populations. The primary objective of this study is to determine whether the Tanita® TBF-305 bioelectrical impedance analyzer accurately estimates body composition in highly active, moderately active, and less active young women.

Purpose

The purpose of this study is to determine which activity mode (athlete vs. adult) of the Tanita® best estimates body composition in young women of varying activity levels when compared to the Lohman's 3-compartment model. Subjects will be divided into three activity categories according to their responses to a physical activity questionnaire: less active (individuals who participate in aerobic exercise two hours or less per week), moderately active (individuals who participate in more than 2 but less than 10 hours of aerobic exercise per week), or highly active (individuals who participate in aerobic exercise 10 hours or more per week).

Hypotheses

1. The Tanita® will most accurately estimate highly active women in the "athlete" mode when compared to Lohman's 3-compartment model.
2. The less active women will be best estimated with the Tanita's "adult" mode compared to Lohman's 3-compartment model.
3. The moderately active women will be most accurately assessed with the Tanita's "athlete" mode compared to Lohman's 3-compartment model.

CHAPTER 2

REVIEW OF LITERATURE

Body composition assessment has been around for decades, but in the last ten to fifteen years, the number of techniques for estimating body fatness has increased dramatically. When choosing a given method for body composition assessment one must decide what factors are most important: accuracy and precision or feasibility and practicality. Some body composition methods are extremely reliable and produce accurate results when compared to a criterion method but tend to be very time-consuming, are often expensive, and may be difficult for the subject to perform. Others are quick and easy to administer, relatively inexpensive, and require little effort by the subject, yet may give inaccurate and unreliable results when compared to a criterion. Thus, one of the key concerns with body composition assessment is finding a method that is both accurate and feasible for a given population.

The biggest disadvantage surrounding body composition assessment is that there is only one direct method that can actually measure body composition, human cadaver dissection with chemical analysis. Little research has been done in this area and unfortunately the small amount that has been done focused on Caucasian males. This small amount of cadaver dissection data however, has been used to create prediction equations including those of Siri (44) and Brozek (8). These prediction equations have been applied to people of both sexes and various ethnic backgrounds despite interindividual differences. In recent years, a number of population-specific equations have been developed and body fat estimations have improved slightly for some of these populations, yet questions still exist regarding the validity of these new equations since they do not account for individual subject variation in different FFM components (12).

Two main avenues of body composition assessment have evolved from human dissection studies: indirect methods (e.g., underwater weighing, total body water, and potassium counting), and doubly indirect methods (e.g., skinfolds, bioelectrical impedance analysis, and anthropometry) (32). Indirect methods measure a variable(s) other than fat (e.g., body volume, underwater weight, etc.) and then make one or more quantitative assumptions about the relationship between the measured variable and the amount of fat (32). Doubly indirect methods use estimation equations derived from one of the previously described indirect methods (often underwater weighing) to estimate body fat. Virtually all of the indirect methods available assume the constancy of the fat-free mass. If a multi-compartment model is used, %BF estimation is then dependent on the individual components of the FFM.

Multi-Compartment Models

When assessing body composition, multi-compartment models account for a greater number of variables of the FFM, thus decreasing the error in %BF estimation. Researchers have even gone as far to say that the methods of "hydrodensitometry, hydrometry, and dual-energy x-ray absorptiometry are subject to measurement error and violation of basic assumptions underlying their use," and that none of these methods should be considered a 'gold standard' method for in vivo body composition assessment (23). It has been found that methods (e.g., hydrostatic weighing) that are based on the 2-compartment (2-C) model in which both FFM and FM have a constant density are limited, especially for individuals whose FFM density and hydration level differ from the assumed constants. Age and gender-related variability in the density of the FFM can lead to significant errors (>3%) when converting body density from UWW to %BF using 2-C models. Studies have shown that both men and women of various ethnicities (i.e., African-American, Hispanic, and American Indian) have higher FFM densities than the assumed value of 1.1 kg/L (23, 46). Thus, a number of prediction equations have been developed by researchers to estimate body fatness that are based on multi-compartment models that take into account population variation in the water, mineral, and protein content of the FFM.

Overall, the two most variable components of fat-free mass in the human body are total body water (TBW) and bone mineral, specifically bone mineral content (BMC). Knowledge of TBW and bone mineral provides an estimate of percent body fat based on a fewer number of generalizations, thus yielding a more accurate estimate compared to the traditional 2-C model that assumes both FFM and FM are of a constant density.

Withers et al. (56) analyzed the differences in the precision of measurement, standard error of measurement, and reliability of two-, three-, and four-compartment body composition models. The measurement of body density by underwater weighing in addition to the measurement of TBW via isotopic dilution were classified as 2-C models. Both the UWW and TBWs method analyzed by Withers et al. (56)

assume that FM and FFM have constant densities. Thus, if either of these two densities are not equal to their assumed values, body fat estimations will be incorrect. Biological variability in FFM as a whole in addition to individual FFM components is highly possible due to differences in age, gender, ethnicity, and physical training status (56). When individuals are assumed to have the constant density values for FFM and FM, studies have found underwater weighing to be fairly accurate when performed by experienced technicians, yielding an error of only approximately 1% (32). This error however can increase dramatically with individual variation in any of the FFM components. Withers et al. (56) found that errors associated with UWW body fat estimations in 436 men and women, age 20-94 years old, ranged from -6.4 to +6.7% when one of the FFM components increased or decreased from the assumed value. When a 2-C based TBW method was used to estimate %BF in this same population and one of the FFM components was altered, error in estimation ranged from -4.8 to +4.8% (56). These results emphasize that it is advantageous to use a multi-compartment model that accounts for one or more of the FFM components, if possible, in order to avoid sizeable individual errors in %BF estimation for those subjects that may lie at the extremes of the normal adult population for water, protein, and bone mineral (56).

Water has the lowest density, yet comprises the largest mass and volume of the FFM components. The most frequently used three-compartment (3-C) model is that of Siri (44), which combines the measurements of body density (via UWW) with TBW. Other 3-C models exist, including that of Lohman (29) that combines body density with the measurement of bone mineral. Three-compartment models are theoretically more valid than 2-C models since they do control for interindividual variability in one of the FFM components, yet they are not without assumptions (e.g., an assumed value for FM density, total mineral/protein ratio) (56). Lastly, four-compartment (4-C) models combine measurements of body density, total body water and bone mineral, thus controlling for variability in two of the FFM components. Withers et al. (56) found only a marginal increase in accuracy with the 4-C model compared to the 3-C models of Siri and Lohman when a group of 436 men and women age 20-94 served as subjects. This study also revealed identical standard error of measurement values of 0.7% body fat for both Lohman and Siri's 3-C models and Lohman's 4-C model. The authors attributed this result to the high reproducibility and reliability in the measurement of bone mineral.

Overall, the major advantage of three- and four-compartment models is their increased accuracy. Both methods account for individual biological variability in FFM density and some of the individual FFM components. Although multi-compartment models require more equipment, time, and tester expertise, "they represent the new 'gold standard' for profiling, monitoring change and serving as a criterion against which field methods can be validated" (56).

Arngrimsson and colleagues (3) recently examined the validity of body composition estimates via a 4-C model in Caucasian male and female middle and long-distance runners and matched controls. Twelve male (21.4 $\pm$ 1.9 years) and 10 female (21.1 $\pm$ 3.6 years) distance runners and 22 controls matched for age, height, weight, gender, and ethnicity participated in this study. The male and female runners had run 93.8 ± 21.5 and 78.9 ± 19.3 km/wk respectively, on average for the past 6 months, while the controls did less than 2 hours/wk of any exercise for the past 6 months. Body density via underwater weighing, total body water via deuterium oxide dilution, and bone mineral density via a DXA scan, were determined in each of the subjects. Body fat was estimated six different ways: DXA, a 2-C model using the Siri equation, a 2-C model using total body water, Siri's 3-C model that corrects for total body water, Lohman's 3-C model that corrects for bone mineral, and Lohman's 4-C model that corrects for both total body water and bone mineral.

In both the male and female runners and the matched controls, percent fat from body water, DXA, and both 3-C models differed significantly from the 4-C model, while the Siri 2-C model was not significantly different with α set at $p<0.05$. The mean difference of percent fat estimates was less than 1.5% for the Siri 2-C model compared with the 4-C model. The density of FFM was not significantly different from the assumed constant of 1.1 kg/L, except in the female controls which was believed to be a result of a lower body water to fat free mass ratio which was most likely related to having been tested during the follicular phase of their menstrual cycle. When the individual FFM components of water, protein, and mineral were analyzed against the assumed values of 73.8%, 19.4%, and 6.8%, respectively, the water fraction of the FFM was significantly lower and the protein fraction of the FFM was significantly higher in male runners, and in the male and female controls (3). The mineral fraction of the FFM was significantly lower in male (5.7 ± 0.3%) and female (6.3 $\pm$ 0.5%) runners, in addition to the male controls (6.0 $\pm$ 0.4%). Overall, this study found that the average density of FFM in male and female distance runners did not significantly differ from 1.1 kg/L even though the relative makeup of FFM differed from the assumed constants. Thus, the authors concluded that hydrostatic weighing appears to be a valid method of estimation of body fat in this population when compared to a 4-C model (3). The authors did however emphasize that UWW may not be an accurate measure for certain individuals whose density of FFM differs from the assumed value.

When 2-C based models are used to estimate body fat, it is assumed that the individual being measured differs from the reference body only in the amount of fat and not in the densities of the FFM and FM, or the individual contributions of the FFM components (24). If body density from UWW is placed in a multi-compartment equation or even in some cases a population-specific 2-C equation, error in body fat prediction can decrease significantly (24, 29). The 2-C equation that will be used in this study to estimate body fatness from UWW's measurement of body density was developed by Heyward & Stolarczyk (24) and is based on studies by Ortiz et al. (36) and Heymsfield et al. (20) that found Caucasian females age 20-80 had a FFM density of 1.097 kg/L, slightly lower than that of the assumed value of 1.1 kg/L (44). The equation is as follows (where D_b stands for body density):

$$\%BF = (5.01/D_b - 4.57) \times 100$$

The Role of Bone Mineral in Multi-Compartment Models

Bone mineral accounts for 5-6% of the total FFM (22, 29). Many researchers have suggested that bone mineral presents the highest degree of variability in the density of the FFM, contributing approximately 13-19% to the FFM density (32, 34, 40). Studies have also found the coefficient of variation for BMD in normal healthy subjects ranges from 10-20% (32, 34). Since total bone mineral density can be accurately measured with a whole-body dual-energy x-ray absorptiometry (DXA) scan, Lohman developed a 3-C model in 1986 that accounts for variation in bone mineral in order to provide a more accurate estimate of %BF than 2-C models. Lohman's 3-C model assumes the following densities: fat 0.9007 kg/L, mineral 3.037 kg/L, protein and water, 1.0486 kg/L. Lohman's 3-C model equation is as follows:

$$\% \text{ BF} = (6.386/D_b + 3.961\text{m} - 6.09) \times 100$$

where D_b stands for body density (usually determined via hydrostatic weighing), and m is equal to the total body mineral (osseous and non-osseous) as a fraction of body weight. In the present study, "m" will be calculated by multiplying the total bone mineral content (BMC) in kg by a factor of 1.25 and then dividing by the subject's body weight in kg. This technique has been previously verified and used by Salamone et al. (40).

A number of studies have examined the impact of bone mineral on FFM and the prediction of body fatness. Côté and Adams (12) investigated the impact of bone density on body composition predictions by hydrostatic weighing in two young adult female populations that varied significantly in total bone mineral density and bone mineral content. Twenty-six black and 26 white young adult, eumenorrheic women, age 18-30, participated in this study. Body density was assessed from underwater weighing, total body water was measured by deuterium oxide dilution, and BMC and BMD were measured with a Lunar DXA scan. Body fat was estimated with the Siri equation, total body water, sum of skinfolds, and an adjusted 2-C formula that assumes a lower FFM density of 1.095 kg/L. In addition, "several multi-compartment models that corrected for individual subject variation in measured BMC and TBW" were also used to predict %BF (12). The two groups were very similar in age, height, weight, and total skinfolds, yet the black women had significantly higher BMC and BMD than their white counterparts. Although there was a significant difference between the two groups in BMC and BMD, no significant differences were found between the percent body fat estimates of the two groups, yet the 4-C model revealed the lowest difference (1.7%) in %BF between the two groups. Within each group, percent body fat estimates from the 2-C models were not significantly different from those of the multi-compartment models. When data were analyzed on an individual basis, the Siri equation tended to substantially under- and over-predict percent body fat in individuals with very high and very low BMD, respectively. Thus, the authors concluded that it is important to account for bone mineral, if possible, when estimating percent body fat to correct for possible interindividual variability.

Ortiz et al. (36) also conducted a study that looked at the effect of bone mineral mass on body composition estimates in matched black and white females. Twenty-eight black (age 44.2 ± 15.2 years) and 28 white (43.6 ± 15.3 years) females served as subjects for this study. Subjects underwent anthropometric measures, dual-photon absorptiometry, deuterium oxide dilution, underwater weighing, and whole-body potassium counting. It should be noted that bone mineral was measured with dual-photon absorptiometry and not a DXA scan. The black females had 10-15% higher total bone mineral mass than their white counterparts, which contributed to a significantly higher FFM density for the black females. The authors concluded that 2-C based methods (i.e., underwater weighing) clearly need to be adjusted when applied to black females to account for their significantly greater BMC and BMD, and to avoid underestimations of percent body fat (36).

In another study, Thompson and Moreau (46), compared body fat estimates of black female athletes using the 2-C equations of Brozek et al. (8) and Schutte et al. (41), in addition to a 4-C model developed by Heymsfield et al. (22) that accounts for both total body water and bone mineral. Eleven black women collegiate athletes, age 20.6 ± 1.4 years participated in this study. Subjects underwent the following testing: underwater weighing, total body water assessment via deuterium oxide dilution, and dual energy x-ray absorptiometry. The Brozek et al. (8) equation assumes a FFM density of 1.1 kg/l, while the Schutte et al. (41) equation assumes a higher FFM density of 1.113 kg/l, which was developed for black males since bone density tends to be higher in blacks than whites (46). The results showed similar values for %BF from the 4-C model and the Schutte et al. prediction equation, while the Brozek model significantly underestimated body fatness (approximately 3%) compared to the 4-C model. The average FFM density for this group of subjects was 1.109 ± 0.002 kg/l, which was significantly higher than the assumed value of 1.1 kg/l, which the authors attributed to the subjects' higher bone mineral. Lastly, the authors recommend that when estimating body fatness in a group of similar athletes, one should measure body density, total body water, and bone mineral, if possible, to account for potential biological variability.

In a similar study, Bunt et al. (9) examined the variability in BMC in four sites of the body (lumbar vertebrae, radius shaft, femoral neck, and distal radius) and body density among 89 females (mean age 25.1 ± 5.3 years) of varying activity levels and menstrual status. The subjects were classified as follows: 18 eumenorrheic inactive controls, 25 recreational runners, 7 collegiate runners, 21 body builders, 14 swimmers, and 4 collegiate amenorrheic runners (no menses in the previous year). Subjects underwent underwater weighing with simultaneous measurement of residual volume, a Lunar DXA whole-body scan in addition to the four sites listed above, and the sum of four skinfolds (subscapula, abdomen, thigh, and calf) to estimate body fatness. When body fatness via UWW was adjusted for bone mineral with Lohman's 3-C model, the majority of the subjects' body fat changed by less than 1.0% compared to the UWW-%BF values, yet larger errors did occur with a few subjects whose BMC was unusually low (i.e., amenorrheic runners) or high (i.e., body builders). Thus, the researchers concluded that variability in BMC in some select groups of young adult females can significantly contribute to variability of body density independent of body fatness (9).

Modlesky et al. (34) conducted a study in which they hoped to determine the influence of BMC on percent fat estimates from a 4-C model with two different DXA scans, specifically a Hologic QRR 1000/W and a DPX-L Lunar. Modlesky and colleagues suspected that a deviation in bone mineral of 1% FFM would alter predicted body fat percentages by 5%, thus these researchers were curious to see how reliable bone mineral measurements were across different DXA devices. Fourteen healthy men (13 Caucasian and 1 Asian), and 10 healthy women (9 Caucasian and 1 Asian) mean age 26.7 $\pm$ 6.0 years, took part in this study. Each subject's body density was determined from underwater weighing and simultaneous measurement of residual volume, while total body water was measured with deuterium oxide dilution, and BMC and BMD were each measured with the Hologic and Lunar DXAs. Differences in BMC, BMD and %BF estimates from Lohman's 4-C model were compared between the two DXA instruments. The authors found that the Hologic DXA tended to give lower %BF values (a mean difference of 0.7 $\pm$ 0.2%) and higher FFM values compared to the Lunar DXA. Overall, this study revealed that the small differences in BMC measurement that can occur with different DXA instruments have only a minimal influence on %BF estimates when using a 4-C model (34). This study, however, did emphasize that when available, bone mineral density should be measured along with other FFM components to minimize error in predicting body fatness, especially for those individuals that lie outside the "norm" for BMD and/or BMC.

A recent study conducted at the University of Georgia does not support the theory that bone mineral density plays a substantial role in the density of the fat-free mass. Evans et al. (13) examined whether bone mineral density and bone mineral content were related to the mineral fraction of the fat-free mass (M_{FFM}) and the density of fat-free mass (D_{FFM}) in a group of 216 young men (n = 115) and women (n = 101), that included 155 whites and 61 blacks, and 132 University of Georgia collegiate athletes (varsity football, basketball, volleyball, gymnastics, swimming, and track and field), and 84 nonathletes (individuals who were recreationally active but did not participate in structured exercise more than 20 minutes/day, three times/week). Subjects underwent a single testing session in which body density was measured using underwater weighing, total body water was measured using deuterium oxide dilution, and total bone mineral mass and density were measured with a Hologic DXA whole-body scan. Percent body fat was then calculated using the following equation from Lohman:

$$\% BF = [(2.747/D_b)-(0.714w)+(1.146m)-2.0503] \times 100$$

where D_b is body density, w is total body water expressed relative to body mass, and m is total body mineral relative to body mass. Fat-free mass was then calculated from %BF and body mass, while the D_{FFM} was estimated from the water, mineral, and protein fractions of the FFM and their respective densities.

As expected, the results showed that men had significantly greater BMD and BMC than women, blacks had significantly greater BMD and BMC than whites, and athletes had significantly greater BMD and BMC than nonathletes. In regards to the total sample, there was no significant relationship between BMD and M_{FFM}. "However, when the effects of gender, race, athletic status, and their interactions were held constant with the use of multiple regression, BMD contributed significantly to the prediction of M_{FFM}, which explained 16.8% of the variance in M_{FFM}" (13). Overall, there was no significant relationship between BMD and M_{FFM} in Caucasians ($r = 0.06$) or African-Americans ($r = -0.19$), or for athletes ($r = 0.08$). Also, a significant relationship was not found between BMC and M_{FFM}, however BMC did contribute significantly to the prediction of M_{FFM} when all other variables were held constant. Bone mineral density was found to contribute significantly to the prediction of the D_{FFM} when the effects of gender, race, athletic status, and their interactions were held constant, but this contributed to only 1.6% of the variance in D_{FFM}.

In general, this study did not reveal any significant relationships between BMD and M_{FFM} or D_{FFM} within the entire sample. When the effects of given variables were held constant via multiple regression, BMD and BMC were found to only explain 10-17% of the variance in M_{FFM} and 0-2% of the variance in D_{FFM}, in addition to that explained by the demographic variables. Thus, the researchers concluded that BMC and BMD should not be used to infer differences in M_{FFM} and D_{FFM}. These results do not agree with past studies that have inferred a positive relationship of BMD and BMC to M_{FFM} and D_{FFM} (9, 12, 51).

Dual Energy X-Ray Absorptiometry (DXA)

A body composition assessment method that has increased in use over the past few years is dual-energy x-ray absorptiometry. "DXA is a scanning technique that measures the differential attenuation of the two x-rays as they pass through the body" (37). In addition to its primary use of measuring total bone mineral content (BMC) and total bone mineral density (BMD), DXA machines are also capable of estimating body composition (fat-free soft tissue and fat tissue). DXA whole-body scans are usually fairly short in duration (15 minutes or less), high in precision in estimating total BMD and total BMC, and emit minimal radiation exposure to the subject (equivalent to the amount of radiation received in two hours by the average U.S. resident from all background sources).

A number of studies have investigated the validity of DXA in evaluating body composition when compared to more traditional assessment methods (7, 38, 40). Salamone and associates (40) recently examined the validity of a Hologic DXA in estimating fat mass and body composition in 60 healthy, elderly adults. Thirty women and 30 men, aged 70-79 years old (mean age 73.7 ± 2.2 years), 53 Caucasians and 7 African-Americans, served as subjects. All 60 of the subjects lived independently and had a BMI ranging from 17.5 to 39.8 $kg \cdot m^{-2}$. All measurements were conducted on the same day following an overnight fast. Lohman's 4-C model served as the criterion method with which to validate the DXA. "Small but significant underestimations of total FM (<1.0 kg, $P < 0.0001$) by the DXA fan beam compared with the four-compartment model were found" (40). However, the proportion of variance in total fat mass from the DXA explained by the 4-C model was $\geq$94%, with the standard error of estimate ranging from 1.4 to 1.6 kg. Thus, overall the DXA estimates of percent body fat compared favorably to those of the 4-C model. A high, positive correlation ($R^2 = 0.98$, SEE = 1.6 kg) was also found between fat-free mass values of the DXA and 4-C model (40). This study's findings suggest that the Hologic DXA offers a substantial promise in estimating FFM, FM, and %BF in elderly men and women when compared to Lohman's 4-C model.

In another study, Pritchard and colleagues (38) evaluated the Lunar DXA as a method of body fat assessment with four traditional methods: UWW, skinfold thickness, tetrapolar/whole-body BIA, and deuterium oxide dilution. Fourteen healthy subjects, 6 men and 8 women, mean age of 36.9 $\pm$ 13.4 years, participated in this study. %BF values using DXA correlated highly ($r = 0.913$) with %BF values determined by UWW; no significant difference was found between the two techniques. The %BF DXA values also correlated highly with those of the skinfolds ($r = 0.824$), BIA ($r = 0.972$), and deuterium dilution ($r = 0.787$). Overall, the results showed the DXA scan overpredicted percent body fat by 1.3-4.8% when compared to UWW, however DXA was found to have a lower coefficient of variation (0.9-1.6%) compared to the CV of UWW (3.8-6.6%) when a small subject sample was repeatedly tested (38). Thus, the researchers concluded that DXA is a legitimate method for assessing body composition.

A study conducted by Bolanowski and associates (7) compared body fat measurements of DXA with those of bioelectrical impedance analysis in 100 subjects, 59 women and 41 men. Values for lean body mass (LBM), fat body mass (FBM), and percent body fat (%BF) were recorded for both the DXA and BIA. Data analysis showed highly statistically significant linear relationships ($p < 0.001$) between LBM, FBM, and %BF assessed by DXA and BIA in both males and females (7). Differences were found between DXA and BIA measurements of both fat and fat-free mass, which resulted in underestimation of LBM and overestimation of %BF by the DXA compared to BIA values. The authors concluded that these differences are most likely attributed to the different assumed constants of fat-free mass and fat mass densities between the two body composition assessment methods (7). However, since neither of these techniques is generally considered a criterion estimate, these results must be viewed with caution.

A number of other studies do not support the use of DXA as a primary measure of percent body fat (2, 19, 27). Instead, some researchers believe that DXA scans should only be used to measure bone mineral density, which could then be entered into a multi-compartment equation to estimate percent body fat (9, 40). Johansson et al. (27) compared %BF estimates via DXA with those of hydrostatic weighing, skinfold thicknesses, and BIA, and reported DXA measures for fat mass and %BF to be consistently lower than the other measures. Other studies have found %BF estimates from DXA to be much higher than measurements by total body potassium ion or from a multi-component model (2, 19). Thus, one can conclude that there are mixed results when it comes to the use of DXA in estimating percent body fat; it may underestimate, overestimate, or accurately estimate percent body fat depending on the subject population and the criterion measure being used.

A number of studies have actually used DXA as the criterion measure even though further research is needed regarding DXA's validity as a body composition assessment method (25, 37). In a study by Houtkooper et al. (25), the body composition profiles of elite American heptathletes were investigated. Nineteen female heptathletes, mean age 25.5 ± 3.5 years, mean height of 175.0 cm ± 6.6 cm, and mean weight of 67.3 ± 7.1 kg, took part in this study. Subjects' body composition was estimated through skinfolds, BIA, and a DXA scan. The DXA estimates of mean values for body composition variables were 57.2 ± 6.1 kg FFM, 10.1 ± 2.6 kg FM, 114 ± 7% BMD for age/racial reference group, and 15 ± 3%BF. The standard error of estimate for %BF estimates for skinfolds and BIA were 2.5% and 3.0%, respectively, while the total error in %BF estimate for skinfolds and BIA were 2.4-2.8% and 5.0-6.5%, respectively. Regression analysis revealed a significant difference in estimates between DXA and BIA, but not DXA and skinfolds. Thus, the researchers concluded that skinfolds provide more accurate estimates of %BF relative to DXA than BIA (25).

Panotopoulos et al. (37) also used DXA as the reference method in their study of body composition assessment in obese women. Fifty-three obese women, aged 15-75 years old, who were apparently in good health, served as subjects. Each subject's percent body fat was measured via a type IMP BO1 BIA device that utilizes two subcutaneously inserted electrodes and a micropressor to calculate impedance, near-infrared interactance (NII), and a Hologic DXA whole-body scan. Prior to the impedance measurement, gender, height, weight, wrist circumference, and physical activity level were entered into the BIA device. Compared with DXA, BIA gave significantly higher estimates of lean body mass and lower estimates of body fat, while NII gave lower estimates of LBM and higher body fat values, but these differences were not statistically different. Bland-Altman plots of the means from all 3 methods revealed a large lack of agreement, which could be due to the fact that all three of the methods studied are based on different assumptions, some of which may have been violated. For example, obese subjects have been shown to have a disturbance in body hydration which would clearly affect BIA's estimate of total body water and %BF. The authors also admitted that there may be some errors in DXA's measurement of body composition "because it is sensitive to differences in body thickness, and body fat may be overestimated in the subjects with the largest thickness" (37).

In summary, dual energy x-ray absorptiometry has been found to have varied results as a single body composition assessment tool, yet has high reproducibility and accurate results when measuring BMD and BMC. Further studies are needed that compare DXA estimates of body fatness with multi-compartment models in diverse populations.

Bioelectrical Impedance (BIA)

A method that utilizes electrical currents to estimate body composition is bioelectrical impedance analysis (BIA). Impedance can be defined as "the frequency-dependent opposition of a conductor to the flow of an alternating electric current," and is the product of resistance and reactance (4, 14). Traditionally, bioelectrical impedance has been measured via tetrapolar/whole-body methods that involve the placement of gel electrodes on the skin, or the insertion of needles into subcutaneous compartments of the distal upper and lower extremities. A number of studies have used the technique in which the subject lies in a supine position on a nonconducting surface with arms slightly abducted from the trunk, and legs separated so that they are not in contact with each other. Gel electrodes are then placed on the right side of the body at specific sites (usually the distal arm/wrist and leg/ipsilateral ankle) (25). Impedance is then measured with a small current that is undetectable to the subject. Tissues in the body will respond differently to the applied current based on their level of hydration. Tissues that contain a large amount of water and electrolytes, like blood and muscle, will allow the current to flow through, while those that contain low levels of water and electrolytes, like adipose tissue (fat) and bone, will be highly resistive to the current.

A number of studies have validated the use of tetrapolar/whole-body impedance as an accurate body composition assessment tool when compared to other methods (21, 42, 53). Lukaski et al. (31) compared body composition estimates of tetrapolar BIA (specifically using the prediction equation of $FFM = ht^2/R$, where R = resistance) with those of UWW in 47 men and 67 women aged 19-50 years old. No significant differences were found between the predicted FFM and %BF from the two assessment methods. The researchers concluded that tetrapolar BIA devices appear to be good predictors of %BF and FFM compared to UWW.

Regarding the use of BIA as a body composition assessment method, various segments of the population have been investigated to determine the effect that age, gender, and/or body size might have on BIA results. Roubenoff et al. (39) looked at tetrapolar BIA as a %BF-predictor in healthy, elderly adults. Specifically, the researchers compared a published BIA equation designed to predict FFM that had been derived in a young, healthy population (mean age 27 years) with equations developed for the elderly that had been derived from 455 participants in the Framingham Heart Study (mean age 78 years). Both BIA predictions were then compared to %BF estimates of a whole-body DXA scan. Two groups of subjects participated in this study: 455 older adults (mean age 78 years, mean BMI 27.3 $kg{\cdot}m^{-2}$) of the original Framingham study, and 284 elderly adults (mean age 76 years, mean BMI 25.5 $kg{\cdot}m^{-2}$) that had participated in the New Mexico Aging Process Study (NMAPS). When the young-population equation was applied to the Framingham participants, it caused an overestimation of FFM in the heavier subjects (thus also causing an underestimation in %BF), that was quickly eliminated when the age-specific equation was used. For the NMAPS group, the young-population equation actually gave %BF estimates that were closer to those of DXA, while the age-specific equations tended to cause an overestimation of lean mass. Roubenoff et al. (39) concluded that the difference in FFM and %BF estimates from the two different BIA equations did not appear to be age-specific. Thus, the researchers recommended that any population-based study that uses BIA to estimate %BF should include a validation study for the BIA equation being used in a subset of the population in order to minimize error.

Baumgartner et al. (5) looked at the effect of obesity and body geometry on tetrapolar BIA %BF estimates in 86 obese men (n=40) and women (n=46), mean age 38.5 $\pm$ 10.2 years. The study's results suggested that adipose tissue (when in large amounts) may directly affect impedance values, causing an overestimation in FFM and underestimation in %BF. This change in impedance value may be a result of altered hydration status and/or fluid distribution that is often seen in obese individuals, in addition to body geometry. Whole-body impedance measures have been found to be most representative of the arms and legs. If an individual has abdominal obesity, then BIA may underestimate their FFM due to the fact that the majority of the impedance value is coming from the extremities and not where their excess adipose tissue lies.

Finally, a study by Segal et al. (43) compared densitometrically-determined lean body mass (LBM) with that of tetrapolar BIA in 1069 men and 498 women, aged 17-62 years old, with body fat ranging from 3 to 56%. Equations for predicting LBM based on BIA's measurement of impedance in addition to height, weight, and age were created for the two genders. Fatness-specific equations to predict LBM were then derived from the data, which resulted in standard error of estimates of 1.97-3.03 kg. Segal and colleagues (43) concluded that the precision of predicting LBM can be enhanced with sex- and fatness-specific equations.

In another study, Baumgartner and colleagues (4) studied the relationship of impedance between the arm, trunk and leg during whole-body BIA analysis and found that impedance measures of a single extremity were highly correlated with traditional arm-to-leg impedance values. Other studies have found that the extremities actually account for the majority of the whole-body impedance value when using traditional tetrapolar BIA methods (25, 42). The results of this study suggest that single extremity impedance may reasonably predict arm-to-leg impedance values and body composition estimates. From this study, new BIA devices have been developed that do not require gel electrodes and are instead hand-held or foot-to-foot devices that are based on the single extremity theory.

The Tanita® TBF-305, developed by the Tanita Corporation (Tokyo, Japan), is a foot-to-foot BIA device that uses a single frequency to estimate percent body fat. At first glance, the Tanita® would appear to be an ordinary bathroom scale. However, this device contains two subdivided stainless steel electrodes that are mounted on a platform scale, which allows for the simultaneous measurement of impedance and body mass. A small current (500 μA) is sent through the anterior portion (the ball of the foot) of the foot pad electrodes as an individual stands barefoot on the Tanita®. The voltage drop is then detected in the posterior portion of the electrodes (the heel of the foot), and impedance is then measured in Ω, ranging between 150-900Ω. The following variables are then computed based on this impedance value and body weight: %BF, fat mass, lean body/fat-free mass, and total body water.

A study conducted in 1997 looked at the validity of the Tanita® vs. traditional arm-to-leg bioelectrical impedance using gel electrodes (35). Two-hundred and thirty-one healthy adults (97 men and 134 women), ranging in age from 18 to 79 years, average BMI 25.0 $kg \cdot m^{-2}$, took part in this study. A high correlation ($r = 0.99$) was found between the Tanita® and the traditional arm-to-leg method. This study also revealed similar within day and between day coefficients of variation for both the Tanita® and the gel electrode BIA technique. The Tanita's specific measures of TBW and FFM were also highly correlated with the conventional arm-to-leg technique's TBW and FFM values. Overall, Nuñez et al. (35) concluded that the Tanita® is extremely useful when studying large populations due to its portability and quick and easy use.

In another study, Jebb et al. (26) evaluated the effectiveness of the Tanita® in measuring body fat compared to a 4-C model in 205 healthy men (n=104, mean age 43.8 $\pm$ 16.0 years) and women (n=101, mean age 40.4 $\pm$ 14.6 years). The 4-C model used was developed by Fuller et al. (16) and incorporates the following components: body volume (via underwater weighing), total body water (via isotope dilution), and bone mineral/ash (via a Hologic total body DXA scan). Subjects' skinfold thicknesses were also measured at four sites (triceps, biceps, subscapula, and suprailiac crest). In addition to the Tanita® TBF-305, body composition was also estimated via tetrapolar BIA, specifically the Bodystat-1500 system. A high correlation ($r = 0.889$) was found between the 4-C model and the Tanita® for all subjects combined, and an $r = 0.810$ for males only and $r = 0.854$ for females only.

Correlation analysis between the 4-C model and the Bodystat BIA revealed an r of 0.901 for the entire sample, 0.818 for males only, and 0.881 for females only. Correlation analysis between all other body composition methods and the 4-C model gave r values greater than 0.85 for each comparison. In general, the body fat values measured by UWW, skinfolds, and the Tanita®, were higher than those determined by the 4-C model (0.2 $\pm$ 2.4%, 0.5 $\pm$ 4.6%, and 0.9 $\pm$ 5.1% respectively), while total body water, DXA, and the Bodystat (tetrapolar BIA) tended to give slightly lower %BF values (-1.2 $\pm$ 2.2%, -0.1 $\pm$ 3.1%, -1.5 $\pm$ 4.65%, respectively) (26). When a best-fit regression equation was applied to the Bodystat data, no significant differences were found between the Bodystat and the Tanita®. The mean residual bias in the test data set was –0.1% $\pm$ 4.3 % for males and 1.2 $\pm$ 3.1% for females. Thus, the researchers concluded that the Tanita® is a valid alternative method to other impedance-based prediction techniques for the measurement of body fat (26). This study did emphasize that further research is still needed to determine the absolute accuracy of the Tanita®, since it tended to overestimate %BF compared to a 4-C model. However, the authors did point out that the Tanita® does appear to be useful for evaluating large, diverse populations when both time and money are lacking, although results will not be as accurate as multi-compartment models (26).

Other studies have compared the Tanita® with 2-C based body composition assessment tools. Utter and colleagues (48) found the Tanita® body fat analyzer (model TBF-105) accurately assessed fat-free mass relative to underwater weighing in 98 obese and 27 nonobese women over a period of time in which only small to moderate changes in body mass were made during a weight loss/management program. Cable et al. (10) investigated the validity of the Tanita® versus underwater weighing in 192 heterogeneous males, mean age of 39.0 ± 16.8 years. Bland-Altman plots of the difference in FFM between UWW and the Tanita® versus the average FFM from the two methods showed no systematic difference, with a mean difference of 0.07 ± 3.5 kg between the two methods. A high correlation was found between the two body composition methods ($r = 0.92$, $p<0.001$) and the standard error of estimate for FFM was 3.5 kg (10). The researchers concluded that the Tanita® provided accurate assessments of body fat in a heterogeneous group of males when compared to underwater weighing (10).

In recent years, many studies have compared the Tanita® with body composition methods that are not considered to be criterion measures (15, 47, 49). Franckowiak et al. (15) examined the estimates of body mass, FFM, and percent body fat obtained from a Hologic DXA whole-body scan and the Tanita® body fat analyzer in 48 healthy men and women (mean age 33.3 ± 11.1 years, BMI of 24.3 ± 4.5 $kg \cdot m^{-2}$). The results showed that %BF via the Tanita® was significantly lower than that of the DXA, with the greatest differences present in obese and very lean individuals. Thus, the researchers cautioned that commercially available body composition devices have a tendency to inaccurately assess very lean and obese individuals (15). Another study conducted by Tyrrell et al. (47) found a high correlation between foot-to-foot BIA and DXA in estimating fat-free mass (FFM), fat mass, and %BF in 82 children, age 4-11.

A second study conducted by Utter et al. (49), examined the relationship between leg-to-leg BIA (specifically the Tanita® TBF-305) and skinfolds in assessing body fat in NCAA collegiate wrestlers. Five subject samples were analyzed during the 1998-1999 wrestling seasons. Samples ranged from 90-274 males, age 17-23. Lange skinfold calipers were used to measure subcutaneous adipose tissue at three sites: triceps, subscapula, and abdomen. Each site was measured 3 times to the nearest 0.5mm, with the median value recorded. These values were then entered into the prediction equation of Lohman et al. (30) to determine body density and percent body fat was then determined with the equation of Brozek et al. (8). Significant correlations ranging from 0.67-0.83 were found between the two body composition assessment methods and the standard error of estimates for body fat ranged from 2.1-3.5% throughout the five assessment periods (49). Thus, the researchers concluded that the Tanita® can accurately estimate percent body fat when compared to skinfolds in a diverse collegiate wrestling population. In addition, the researchers suggested that further studies be conducted that focus on the validation of the Tanita® against a reference method, using multi-compartment models to derive reference values of fat-free mass (49).

In a recent study (45), the effect of physical activity in young men on the Tanita® TBF 305's estimation of percent body fat was investigated. The men were divided into three groups based on the number of hours of aerobic exercise they participated in each week: less active (less than 2.5 hours per week), moderately active (between 2.5 and 10 hours per week), and highly active (10 or more hours per week). Each subject was measured anthropometrically (height, weight, waist and hip circumferences), in addition to being underwater weighed and tested with the Tanita® in both the athlete and adult modes. When compared to the body fat percentages via underwater weighing, the highly active and moderately active groups were best estimated with the Tanita® in the athlete mode, while the adult mode more accurately estimated the less active men (45). The researchers concluded that contrary to the manufacturer's guidelines, moderately active males should be measured with the "athlete" mode versus the "adult" mode, which was found to overestimate their %BF by 4.7% (45).

Swartz et al.'s (45) study focuses attention on the Tanita's definition of athleticism. According to the manufacturer's guidelines, an athlete is an individual who is involved in recreational or professional sports for at least 10 hours per week and has been doing so for at least the past six months, has a resting heart rate at or below 60 beats per minute, and/or has competed in national and regional sporting events. These guidelines were developed under the assumption that top-notch athletes tend to be much leaner than the average population, specifically have body fat percentages that fall outside the norm for the average "adult." These guidelines are very stringent and leave little room for exceptions. For example, according to these guidelines both a healthy, fit individual who exercises 5-7 hours per week and an overweight, sedentary individual would be classified as an "adult." The guidelines do not allow for any leeway between someone who is moderately active and someone who is inactive and, according to Swartz et al. (45), the result will be a significant overestimation of the %BF in recreationally active males.

In summary, the foot-to-foot BIA system appears to provide generally good estimates of %BF; however, in specific groups inaccuracies have been found. To this point, data examining the impact of varying levels of physical activity on foot-to-foot estimates of %BF in women have not been published.

CHAPTER 3

MANUSCRIPT

Abstract

Purpose: To determine which activity mode (athlete vs. adult) of a foot-to-foot bioelectrical impedance analysis (BIA) device best estimates body composition in young women of varying activity levels when compared to Lohman's 3-compartment (3-C) model.

Methods: Body fat percentage (%BF) was estimated in 60 young women (mean age 23.3 $\pm$ 4.8 y) using both the athlete and the adult mode of the Tanita® TBF-305. Body density (D_b) via underwater weighing and bone mineral via a whole-body DXA (Lunar DPX-NT) scan were used to compute the 3-C estimate of %BF. Based on reported physical activity, each subject was categorized into an aerobic activity group (less active (LA): 2 hours or less of aerobic exercise/week, moderately active (MA): >2 hours but <10 hours of aerobic exercise/week, and highly active (HA): $\geq$10 hours of aerobic exercise/week).

Results: For the LA women, there was no significant difference between the 3-C estimate of %BF and that from the BIA adult mode (28.8 $\pm$ 1.1% vs. 30.7 $\pm$ 1.1%, respectively). For the MA women, the BIA athlete mode and the 3-C model yielded similar results (21.1 $\pm$ 0.9% vs. 20.7 $\pm$ 1.1%, respectively), while the BIA adult mode provided significantly higher estimates (29.3 $\pm$ 1.0%). For the HA women, both the BIA athlete (20.9 $\pm$ 0.9%) and BIA adult (31.2 $\pm$ 1.1%) estimates were significantly higher than the 3-C criterion value (17.3 $\pm$ 1.1%).

Conclusions: The BIA adult mode appears to be an acceptable alternative for body composition assessment in less active young women, while the athlete mode can be used to estimate %BF in young women who are recreationally active. However, in extremely active women, both the athlete and adult mode overestimate %BF.

Key Words: BIOELECTRICAL IMPEDANCE, EXERCISE, AEROBIC ACTIVITY, BODY COMPOSITION, BODY FAT.

Introduction

Body composition is often assessed in a number of populations due to its importance in both health and fitness. Not only can body composition be used as an indicator of health risk and obesity, it is often used in combination with skill-related components of fitness when training athletes. A number of body composition assessment methods have been developed over the years that are quick and easy to administer, yet their reliability and validity is often questioned when compared to criterion measures. Although not practical in non-research settings, multi-compartment modeling provides the standard against which newer technologies can be evaluated.

The use of bioelectrical impedance analysis (BIA) to assess body composition is not new. Previous studies have investigated the validity of traditional BIA devices (tetrapolar, whole-body methods) compared to "gold standard" methods, including underwater weighing and multi-compartment models. Unfortunately, traditional BIA methods rely heavily on electrode placement and tester expertise, and can be expensive and time-consuming. In the past decade, the demand for quick, easy, and relatively inexpensive body composition assessment techniques has been answered with the invention of a number of new assessment methods, including the Tanita® TBF-305 foot-to-foot BIA device. This device is extremely easy to use, requires very little effort by the subject, is relatively inexpensive, and estimates body fat in approximately 10-15 seconds. Validation studies have been conducted between the Tanita® and tetrapolar BIA methods, which found the Tanita® to be an acceptable alternative to the traditional methods (26, 35).

The Tanita® TBF-305 contains two different modes for body composition assessment, "athlete" and "adult." Each mode uses a regression equation that incorporates impedance, gender, body mass, and height to estimate body fat percentage (%BF), fat-free mass (FFM), and total body water (TBW). The "athlete" mode is specified for individuals who participate in 10 or more hours of aerobic exercise per week and have been doing so for the last 6 months, have a resting heart rate of 60 bpm or less, and/or compete in local and national sporting events. This mode was developed specifically for athletes and highly active individuals, since they tend to be much leaner than the normal adult population. The "adult" mode however is recommended for estimating %BF in both inactive and moderately active individuals and does not distinguish between people that are sedentary and those that exercise on a regular basis.

Very little research has been done regarding the effect of physical activity on %BF estimates of the two BIA modes. Swartz et al. (45) found that the Tanita overestimated %BF in recreationally active young men. The goal of this study was to investigate a group of young women highly diversified in aerobic activity levels and compare their %BF via the "athlete" and "adult" modes to a criterion measure. Lohman's 3-compartment model was chosen as the criterion to account for individual differences in bone mineral that may be attributed to differences in activity level. Thus, the purpose of this study was to determine which activity mode (athlete vs. adult) of the Tanita® TBF-305 best estimates body composition in young women of varying activity levels when compared to Lohman's 3-compartment model.

Methods

Subjects and General Protocol

Sixty, healthy females between the ages of 18 and 38 (23.3 $\pm$ 4.8 years) volunteered for this study. Prior to participation, each subject was informed of potential risks and benefits, and signed an informed consent form (see Appendix A) approved by the University of Tennessee Institutional Review Board. Subjects were qualified to participate if their body mass index (BMI) was $\leq$ 27.5 $kg \cdot m^{-2}$ and they were not pregnant. Individuals using medications and/or supplements known to alter total body water (steroids, diuretics, creatine, etc.), or who had a pacemaker or implanted defibrillator device were excluded from the study. All of the subjects were categorized into the following groups based on reported physical activity (see Appendix B): 1) less active (LA: 2 hours or less of aerobic exercise per week), 2) moderately active (MA: greater than 2 but less than 10 hours of aerobic exercise per week), and 3) highly active (HA: 10 or more hours of aerobic exercise per week).

Each subject came to the lab for a single testing session. Subjects were instructed to avoid participating in any type of exercise for 12 hours and refrain from alcohol consumption for 48 hours prior to testing. Subjects reported to the laboratory having fasted overnight, but were allowed to drink water in their typical patterns on the morning of testing. All tests were conducted with the subject wearing a lycra, form-fitting swimsuit.

Following the removal of their shoes, subjects' height was measured to the nearest 0.01 m with a wall-mounted stadiometer (Seca Corp., Columbia, MD). Body mass was measured to the nearest 0.1 kg with a Bod Pod® scale (Life Measurement Instruments, Concord, CA). Body mass index (BMI) was then calculated as the ratio of weight to squared height ($kg \cdot m^{-2}$).

Bioelectrical Impedance Analysis (BIA)

Bioelectrical impedance analysis estimates were performed according to the manufacturer's specified procedures. Subjects were asked to remove all jewelry and other accessories and were clothed only in their swimsuit. Gender, height, and activity level were manually entered into the Tanita® keypad. Body mass was measured automatically to the nearest 0.2 kg during the impedance measurement. Each subject's body fat was predicted in both the "athlete" and "adult" modes of the BIA device.

The Tanita® TBF-305 (Tanita Corporation, Tokyo, Japan) is a foot-to-foot, pressure contact electrode BIA device that at first glance resembles a bathroom scale. The Tanita® actually contains two stainless-steel foot pad electrodes that are mounted on a platform scale. The electrodes for each foot are subdivided into anterior (the ball of the foot) and posterior (the heel of the foot) portions. The analyzer measures impedance by sending a small current (500 μA) through the anterior portion of the foot pad electrodes to the posterior portion where the voltage drop (impedance) is determined. Once impedance is measured, the Tanita® then uses a regression equation to estimate body composition.

Dual-Energy X-ray Absorptiometry (DXA)

Total bone mineral density (BMD) and bone mineral content (BMC) were determined from whole-body scans using a Lunar DPX-NT whole-body X-ray densitometer (GE Medical, Milwaukee, WI), with software version 4.0.

Underwater Weighing (UWW)

Immediately prior to the UWW assessment, residual volume (RV) was measured "on-land" using the modified oxygen dilution procedure described by Wilmore (55). Continuous gas analysis was performed with a nitralyzer (KaeTech Instruments, Green Bay, WI) equipped with a digital display, while subjects breathed into a spirometer filled with 100% oxygen. At least two trials were performed to measure the RV in order to achieve two values within 100 ml of each other. The average of these two trials was then recorded as the measured RV and was later used in the calculation of body density.

Body density (D_b) was estimated from hydrostatic (underwater) weighing in a submersion tank containing an electronic scale placed on four force cell transducers coupled to an integrated amplifier (Precision Biomedical Systems, Inc., University

Park, PA). The subject was asked to expel as much air as possible from her lungs during complete submersion in the tank of warm water (temperature between 33°C and 36°C). This procedure was repeated 6 to 10 times. The three highest documented mass measurements within 0.1 kg were averaged and recorded as the underwater mass. Body density was determined from underwater mass using the equation of Goldman and Buskirk (18), with gastrointestinal gases assumed to be 100 ml.

Lohman's 3-compartment Model

Body fat percentage was estimated from D_b and total body mineral using the three-compartment model of Lohman (29):

$$\% \text{ BF} = (6.386/D_b + 3.961\text{m} - 6.09) \times 100$$

where D_b = body density via UWW, and m = total body mineral (osseous and non-osseous) as a fraction of body weight. Total body mineral (osseous and non-osseous) as a fraction of body weight was calculated from the method of Salamone et al. (40). Bone mineral content in kg is multiplied by a factor of 1.25 to provide an estimate of total body mineral. Subsequently, this value is divided by the subject's body weight in kg and entered into the above equation as "m."

Statistical Analyses

Statistical analyses were performed using SPSS for Windows version 9.0 (SPSS, Inc., Chicago, IL). Descriptive statistics were calculated for all physical characteristics (i.e., age, height, weight) in addition to body composition estimates. A one-way analysis of variance (ANOVA) was used to compare overall mean subject characteristics between the 3 activity groups. Post-hoc testing with Bonferroni adjustments were conducted to determine between group differences. Pearson product moment correlation analyses were conducted to identify the relationship between %BF via Lohman's 3-compartment model and the two BIA modes. A 3 x 3 repeated measures ANOVA was used to compare %BF results from each of the 3 body composition techniques. Post-hoc testing with Bonferroni adjustments were conducted to determine between group differences. Agreement between methods for estimating %BF was evaluated using Bland-Altman plots. The level of significance was set *a priori* at α=0.05 for all statistical tests.

Results

Physical Characteristics

Physical characteristics of subjects are listed in Table 1. The difference in activity levels is apparent with the statistically significant difference between the three groups in the number of hours of aerobic exercise performed per week (LA: 1.4 $\pm$ 0.7 h, MA: 6.0 $\pm$ 1.8 h, and HA: 14.0 $\pm$ 3.2 h.) Height and body mass were statistically higher for the HA group compared to the LA and MA groups, while an additional statistical difference was found in BMC between the HA (2.78 $\pm$ 0.5 kg) and MA (2.38 $\pm$ 0.3 kg) groups.

%BF Comparisons

In Table 2, %BF values obtained by Lohman's 3-compartment model and the two BIA modes are presented. A significant mode by activity group interaction was observed ($p<0.001$). %BF estimation for the LA women via the athlete mode was significantly different ($p<0.0001$) than that of the adult mode and Lohman's 3-C. The

Table 1: Physical Characteristics of Participants (mean ± SD)

Measure	Less Active Women (n=19)	Moderately Active Women (n=21)	Highly Active Women (n=20)
Age (y)	24.5 ± 5.35	23.2 ± 4.5	22.2 ± 4.3
Height (m)	1.65 ± 0.05†	1.65 ± 0.07	1.69 ± 0.10
Body mass (kg)	57.1 ± 6.1†	56.1 ± 5.2†	64.5 ± 9.7
BMI ($kg \cdot m^{-2}$)	21.1 ± 1.8	20.6 ± 1.9	22.1 ± 2.3
Bone Mineral Density ($g \cdot cm^{-2}$)	1.155 ± 0.082	1.147 ± 0.069	1.198 ± 0.091
Bone Mineral Content (kg)	2.478 + 0.329	2.381 + 0.30†	2.776 + 0.493
Exercise ($h \cdot wk^{-1}$)	1.4 ± 0.7*	6.0 ± 1.8*	14.0 ± 3.2*

(BMI = body mass index)
*=Significant difference between all three groups ($p<0.05$)
†=Significant difference compared to the highly active group ($p<0.05$)

Table 2: Comparison of %BF estimates obtained with Lohman's 3-compartment Model and the BIA "Athlete" & "Adult" Modes (mean ± SE)

Body Composition Method	Less Active Women (n=19)	Moderately Active Women (n=21)	Highly Active Women (n=20)
Lohman's 3-C Model (%BF)	28.8 ± 1.1	20.7 ± 1.1	17.3 ± 1.1
BIA "Athlete" Mode (%BF)	22.8 ± 1.0†	21.1 ± 0.9	20.9 ± 0.9†
BIA "Adult" Mode (%BF)	30.7 ± 1.1*	29.3 ± 1.0†*	31.2 ± 1.1†*

† = Significantly different from 3-C ($p<0.0001$)
* = Significantly different from "Athlete" mode ($p<0.0001$)

adult mode for the MA group significantly overestimated ($p<0.0001$) body fat compared to both the athlete mode and 3-C, while both the athlete and adult modes for the HA significantly ($p<0.0001$) overestimated %BF compared to the 3-C. Figures 1 and 2 show the impact of hours of aerobic exercise on the %BF estimates between the two BIA modes and 3-C.

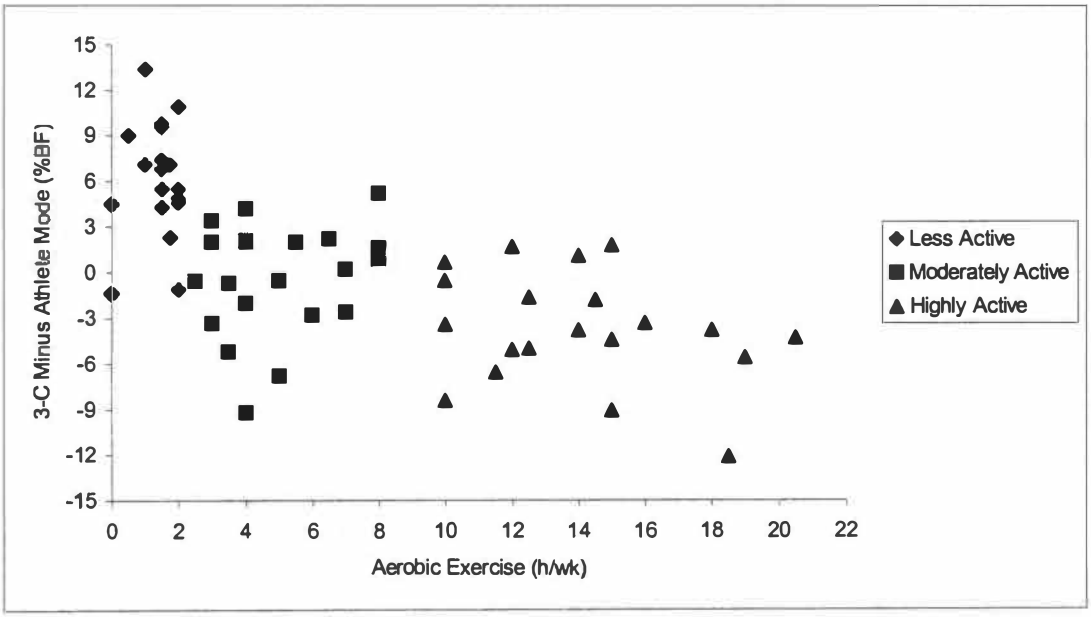


Figure 1. Relationship between aerobic exercise volume and %BF prediction in the BIA "athlete" mode.

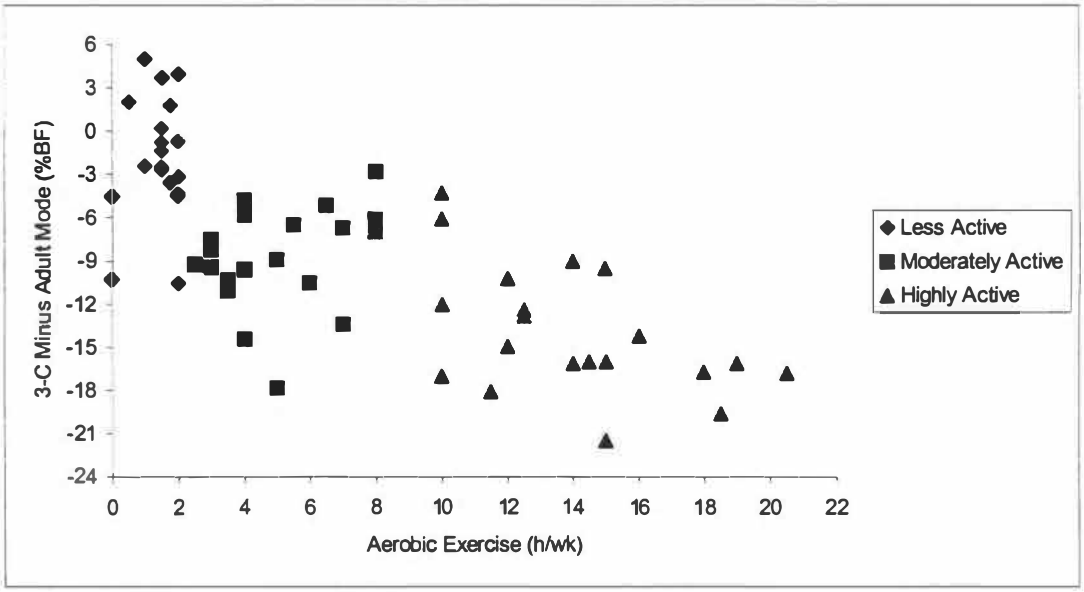


Figure 2. Relationship between aerobic exercise volume and %BF prediction in the BIA "adult" mode.

Influence of Body Fat on BIA Estimates

Figures 3 and 4 show the impact of body fat percentage on %BF estimates of the BIA modes. Figure 3 illustrates a significant relationship (r = 0.782) between %BF and prediction in the "athlete" mode. The athlete mode tended to overestimate %BF in the leanest individuals, while the moderately fat individuals were estimated accurately. In addition, the athlete mode underestimated %BF to the greatest extent in the most fat individuals. Figure 4 illustrates a significant relationship (r = 0.738) between %BF and prediction in the "adult" mode. The adult mode tended to overestimate %BF to the greatest extent in individuals who had the lowest %BF.

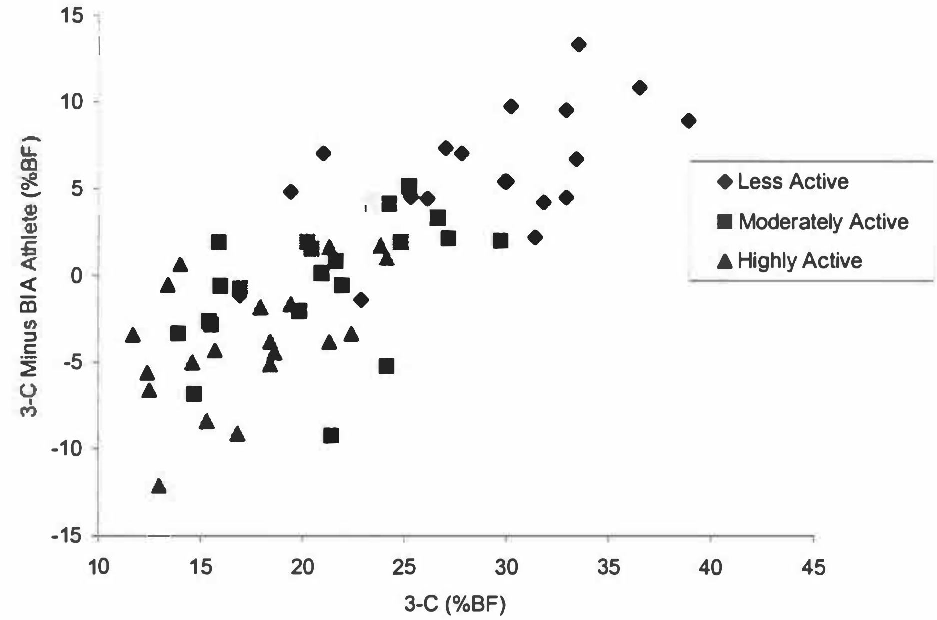


Figure 3. Relationship between 3-C %BF and body fat prediction in the BIA "athlete" mode.

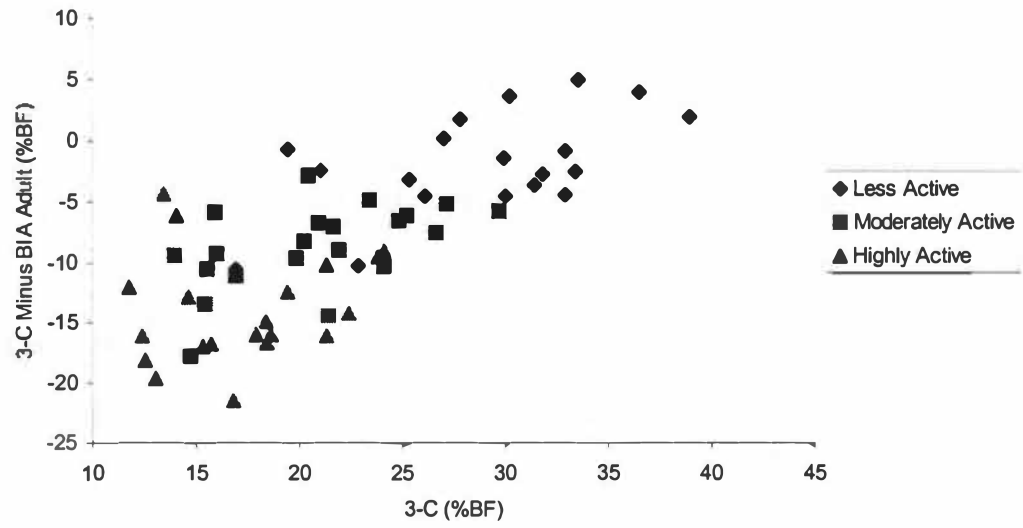


Figure 4. Relationship between 3-C %BF and body fat prediction in the BIA "adult" mode.

%BF Limits of Agreement

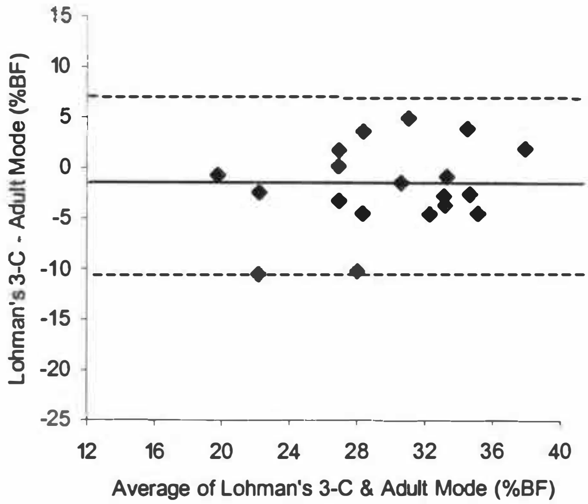
Figures 5, 6, and 7 reflect the agreement between the 3-C estimates of %BF and those from the 2 BIA modes for the LA, MA, and HA groups, respectively. The solid lines represent the mean difference between the body composition methods, while the dashed lines represent the limits of agreement ($\pm$ 2 SD). The mean difference and limits of agreement between the athlete mode and Lohman's 3-C model for the LA, MA, and HA were 6.04 $\pm$ 7.44, -0.37 $\pm$ 7.30, and -3.56 $\pm$ 6.88%, respectively. When the adult mode and Lohman's 3-C model were compared, the mean difference and limits of agreement for the LA, MA, and HA were -1.83 $\pm$ 8.42, -8.61 $\pm$ 7.07, -13.85 $\pm$ 8.58%, respectively.

Correlation Analysis

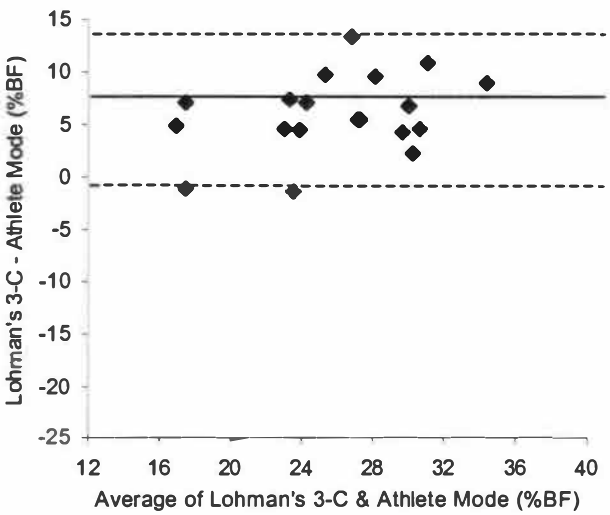
Pearson product-moment correlation between the athlete mode and 3-C yielded correlations of 0.77, 0.66, and 0.59 for the LA, MA, and HA, respectively. Correlation analysis between the adult mode and 3-C yielded correlations of 0.70, 0.67, and 0.61 for the LA, MA, and HA, respectively.

Discussion

The Tanita® TBF-305 is a convenient, quick, and easy method to estimate body composition, which claims to accurately assess %BF regardless of individual characteristics. Because high volumes of exercise typically lead to alterations in body composition, the foot-to-foot impedance analysis system uses a separate regression formula for "athletes" who participate in 10 hours or more of exercise per week. However, few studies have examined the utility of this device for estimation of body

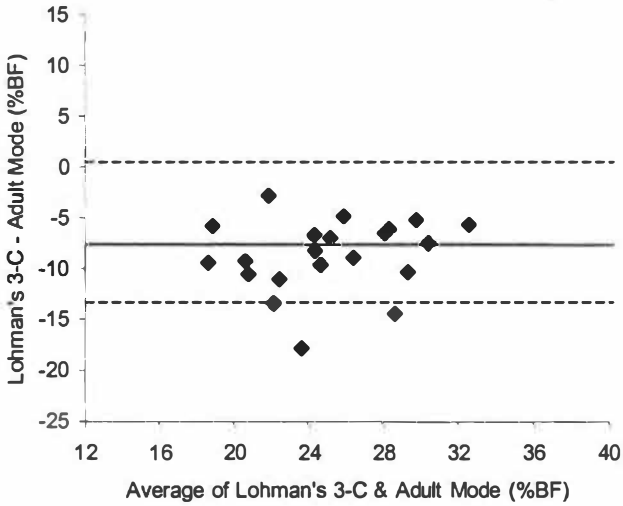


(A)

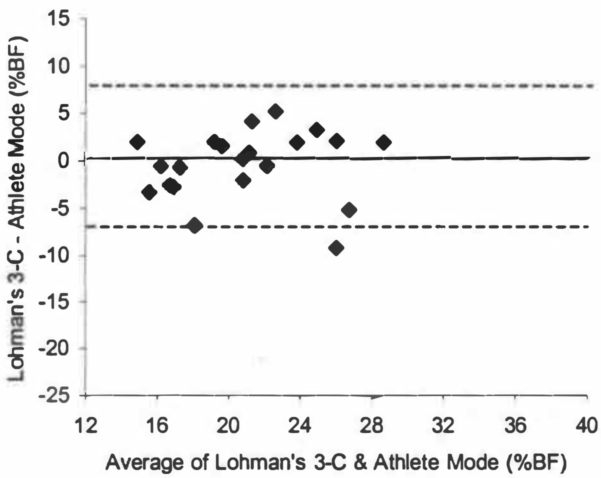


(B)

Figure 5. Comparison of percent body fat (%BF) scores from Lohman's 3-compartment model and (A) BIA adult mode in less active young women, (B) BIA athlete mode in less active young women.

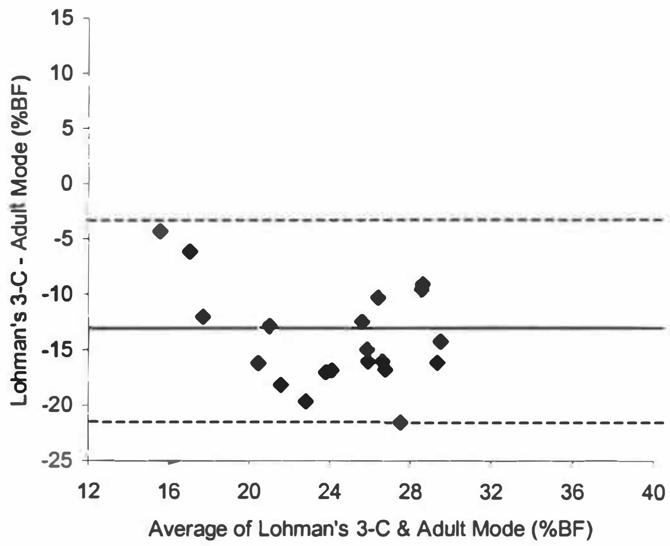


(A)

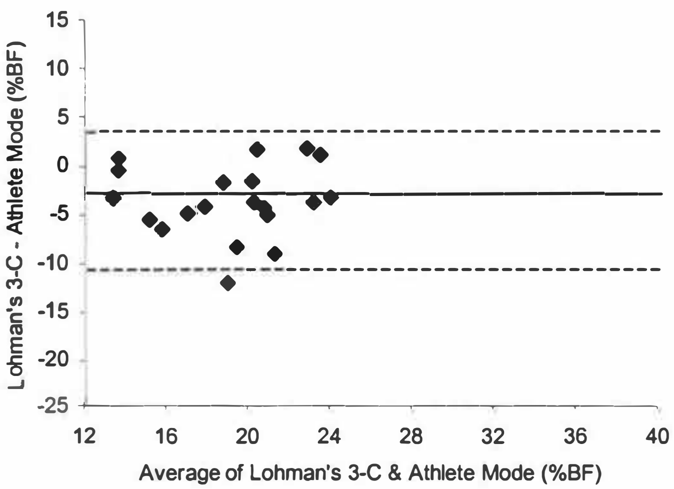


(B)

Figure 6. Comparison of percent body fat scores (%BF) from Lohman's 3-compartment model and (A) BIA adult mode in moderately active young women, (B) BIA athlete mode in moderately active young women



(A)



(B)

Figure 7. Comparison of percent body fat scores (%BF) from Lohman's 3-compartment model and (A) BIA adult mode in highly active young women, (B) BIA athlete mode in highly active young women.

composition in individuals varying greatly in the amount of exercise participation. The purpose of this study was to compare body composition estimates in young adult females who varied in aerobic activity levels. The two modes of the BIA (athlete and adult) were compared to values from Lohman's 3-C.

Percent body fat determined by the BIA "adult" mode was not significantly different from that of Lohman's 3-C model for the less active women (women who engaged in 2 hours or less of aerobic exercise per week). The correlation between these estimates was r = 0.70. However, an examination of Figure 5A reveals that even though the group mean difference was near zero, there was a wide discrepancy between the estimates for some individuals. Percent body fat determined by the BIA "athlete" mode was not significantly different from that of Lohman's 3-C model for the moderately active women (women who participated in more than 2 but less than 10 hours of aerobic exercise per week). Pearson's product-moment correlation between these two estimates was r = 0.66. A closer examination of Figure 6B, however, reveals a wide range between the estimates for some individuals even though the group mean difference was almost zero (-0.37). Both BIA modes were found to significantly overestimate percent body fat from that of Lohman's 3-C model for the highly active women (women who participated in 10 or more hours of aerobic per week). Figures 7A and B reveal group mean differences of –3.56 and –13.85 for the athlete and adult modes, respectively. Closer examination of the two figures also reveals a large degree of variability in the two estimates for some individuals. Regardless of activity level, our data suggest that a sizable difference can occur between %BF estimates of Lohman's 3-C and either of the BIA modes for a given individual.

In a similar study, Swartz et al. (45) investigated the prediction of body fat in less active, moderately active, and highly active young men with the Tanita® TBF-305. BIA estimates in the adult mode agreed with estimates from hydrostatic weighing in less active men. For moderately and highly active men, BIA estimates in the athlete mode were similar to %BF from hydrostatic weighing. The results of that study support the manufacturer's guidelines for the less active and highly active groups, however the moderately active group was best estimated with the "athlete" mode.

Results similar to Swartz and colleagues (45) were found in the present study. The less active women were best estimated with the "adult" mode (mean difference of 1.83%, $p = 0.163$), which corresponds to the manufacturer's guidelines. The "adult" mode overestimated the moderately active women by an average of 8.61%, similar to that found by Swartz et al. (45) where moderately active men were overestimated by an average of 4.7% in the "adult" mode. In contrast with the manufacturer's recommendations, the "athlete" mode was found to accurately estimate %BF in our moderately active women (mean difference of 0.37%) and Swartz et al's (45) moderately active men. Unlike the study by Swartz et al. (45), the "athlete" mode did not accurately estimate %BF of the highly active participants in this study. The mean difference in estimation was lower with the athlete mode (3.68%) compared to the adult mode (13.97%), yet both BIA modes significantly overestimated body fatness compared to Lohman's 3-C. The reason for the difference between Swartz et al.'s results (45) and these data may be found in the subject characteristics. The MA and HA men in Swartz et al. (45) had similar body composition (12.1 ± 1.2% and 12.5 ± 1.2%, respectively), while in the present study, the HA women (17.3 ± 1.1%) were leaner than the MA women (20.7 ± 1.1%), thus creating a more distinctive HA group. This finding suggests that the foot-to-foot BIA provides an unacceptable estimate of %BF in women who train aerobically 10 or more hours per week and are extremely lean.

Only a few studies have compared %BF estimates from foot-to-foot analyzers to body composition reference methods (e.g., UWW and multi-compartment models), or with other body composition assessment methods (e.g., DXA and skinfolds), and the results of these studies are mixed. Jebb et al. (26) compared the Tanita® TBF-305's adult mode %BF estimate (regardless of participants' exercise habits) with those of a four-compartment model in a large diverse group. The correlation between the 4-C model and the BIA was high (r = 0.901), however the foot-to-foot analyzer tended to give higher %BF values compared to the 4-C model. This could be due to the fact that the "athlete" mode was not used to assess any of the subjects, even though some of them may have qualified as "athletes" under the manufacturer's guidelines. As seen in the present study, when individuals are more active, the foot-to-foot analyzer, particularly in the adult mode, will overestimate %BF.

Cable et al. (10) also found agreement between %BF and FFM estimates of the Tanita® (model TBF 105) and UWW in 192 heterogeneous males (39.0 ± 16.8

years, average body mass equal to 81.9 ± 14.3 kg). The mean difference in FFM between the two methods was only 0.07 kg and Bland-Altman plots of the data showed no systemic differences. The limits of agreement between the two methods' estimation of FFM was only ± 3.5 kg, which corresponded to a value of ± 4.3% BF. In the present study, the limits of agreement between the two BIA modes and Lohman's 3-compartment model were slightly higher and ranged between ± 6.88% and ± 8.58% BF. The higher limits of agreement in the present study might be a result of the diversity in activity levels of the female subjects and their higher %BF (22.1 ± 6.7%) compared to the males (18.1 ± 8.9%) in Cable et al. (10).

When compared to other body composition techniques, the Tanita® correlates highly with %BF estimates via DXA in children aged 5-11 (47), and also with 3-site skinfolds in collegiate wrestlers (49). Although research is limited regarding the accuracy of the foot-to-foot analyzer in estimating %BF, the published studies tend to conclude that it is a suitable alternative to traditional methods that are more time and labor intensive.

A potential limitation of the current study is the use of Lohman's 3-C model as the criterion measure of body composition. Multi-compartment models decrease error in body fat estimation and account for individual variations in the FFM (56). However, the model used in this study does not account for individual variation in body water. One can argue that the use of a 4-compartment model as the criterion would have provided even more accurate results since both body water and body mineral would have been used in calculating %BF. However, a primary suspected difference in fat-free mass density (D_{FFM}) for this given population was BMD (and BMC) as a direct result of the subjects' wide variation in activity levels. In addition, Withers et al. (56) did not find a significant difference in %BF estimates via Lohman's 3-C and 4-C models in a group of 436 men and women aged 20-97 years old.

Conclusion

In moderately active (more than 2 but less than 10 hours of aerobic exercise per week), young adult females, the "athlete" mode of the Tanita® TBF-305 best estimates %BF when compared to Lohman's 3-compartment model. Although the manufacturer's guidelines suggest that moderately active individuals should not be classified any differently than sedentary individuals (both should be classified under the "adult" mode), our results demonstrated otherwise. Surprisingly, our study revealed that highly active young women (10 hours or more of aerobic exercise per week) tended to be overestimated by the BIA "athlete" mode when compared to Lohman's 3-compartment model. Therefore, neither mode accurately estimated %BF for intensely training women. The less active females were best estimated with BIA "adult" mode when compared to the criterion. As a result of this study, the Tanita's "adult" mode seems to be an acceptable alternative to Lohman's 3-C model when estimating %BF in less active women, while the "athlete" mode is a good alternative for estimating moderately active women when resources such as time and money are limited. Further investigation is needed regarding why the "athlete" mode did not accurately assess %BF in highly active women since this mode was developed primarily for these higher exercise status individuals. In addition, other studies are needed to investigate why such wide variation in %BF estimation occurred between the BIA modes and Lohman's 3-C model for some of the subjects in our study.

Additional studies are needed that incorporate children, older adults, and various ethnic groups to determine how foot-to-foot BIA devices estimate %BF in these individuals. From our study's results and the results of Swartz et al. (45), it is highly possible that the guidelines surrounding the two modes of the Tanita® TBF-305 may need to be modified, including the possibility of adding a third mode, such as "fitness" for individuals who train regularly, in addition to the "adult" and "athlete" modes.

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APPENDICES

APPENDIX A

INFORMED CONSENT

INFORMED CONSENT

Title of the Study: The effect of physical activity levels on body composition assessment in young women.

Investigators: Allison Kellie Wallis and Dixie L. Thompson, Ph.D.

Address: Dept. of Exercise Science and Sport Management
HPER Building, Room 144
University of Tennessee (Knoxville Campus)
1914 Andy Holt Ave.
Knoxville, TN 37996

Phone: (865) 974-8768

Purpose:
You are invited to participate in a research study. The purpose of this study is to examine different ways of estimating body fat percentage (body composition). This form explains the testing procedures in addition to the risks and benefits of participation. If you have any questions regarding the information contained in this form, please ask A. Kellie Wallis or Dr. Thompson before signing.

Procedures:
You will attend one testing session in the Applied Physiology Laboratory in the Health, Physical Education and Recreation (HPER) Building on the University of Tennessee campus. The testing session will last approximately 2 hours and we ask that you refrain from eating or drinking anything other than water at least 6 hours prior to your appointment. We also ask that you avoid participating in any type of exercise 12 hours prior to your testing session and refrain from alcohol consumption for 48 hours prior to your visit. The testing session itself will be composed of 4 body composition assessments in addition to anthropometric measurements (weight, height, and waist and hip circumferences) and some survey information. Upon arrival to the laboratory you will first be asked to fill out a physical activity and supplement questionnaire. Upon completion of these forms we will measure your height, weight, and waist and hip circumferences. The 4 body composition assessments described below will then be performed. For each assessment you will need to wear a form-fitting swimsuit. If you do not have a swimsuit, you may borrow a freshly laundered one from the lab.

Tanita

You will be asked to stand on a "scale" with bare feet, dressed in your swimsuit for approximately one minute. This device estimates your body fatness through the movement of electrical currents in your body. You will not be able to feel the current and this test is harmless.

Bod Pod

We will measure your body fat percentage using the Bod Pod, a sealed chamber where you will sit for approximately one minute. During this time you will be able to breathe normally and view your surroundings. The Bod Pod will then estimate your body fat percentage by measuring your body weight and size (volume).

DXA

Dual energy x-ray absorptiometry (DXA) is a technique frequently used to measure bone density. This procedure can also be used to estimate body fatness. For this procedure, you will lie on an x-ray table for approximately 15 minutes. This is a painless, non-invasive procedure much like other x-rays, except there is much less radiation exposure.

Underwater Weighing

We will first measure your lung size as you breathe into a device called a spirometer which measures volumes of air. Following this procedure you will be weighed underwater. In order to measure your underwater weight, you will sit on a platform in a tank of warm water, exhale as much air as you can and submerge yourself under water for a few seconds.

Benefits of Participation:
From the results of the single testing session, you will be told your body fat percentage from each assessment method used. In addition, you will be told your bone mineral density, which can be useful in assessing your risk for osteoporosis.

Risks of Participation:
Most body composition assessment methods do not pose any known physical risks to subjects. When undergoing a DXA scan, you will be exposed to low levels of radiation. The amount of radiation exposure during a DXA scan is equivalent to the amount of radiation received in two hours by the average U.S. resident from all background sources. If, however, you are pregnant or think you may be pregnant you should not undergo this procedure. In addition, if you have a pacemaker or an implanted defibrillator, you should not participate in this project due to the potential risk of the Tanita interfering with the proper functioning of these devices.

Right to Ask Questions and/or Withdraw From This Study:
If you have any questions or concerns at any time throughout the course of this study (testing sessions, etc.), or after completion of all procedures, you can contact Miss Wallis at (865) 974-8768 or Dr. Thompson at (865) 974-8883. If you should have any questions regarding your rights as a subject you may contact the University of Tennessee Institutional Review Board at (865) 974-3466. As a volunteer in this study you have the right to withdraw at any time without prejudice.

Confidentiality:
Only A. Kellie Wallis, Dr. Thompson, and you will have access to any of your personal information that is collected during this research study. All information collected will be kept in a locked desk drawer in the office of Kellie Wallis, HPER Room 144. Following completion of the study, the information will then be transported to a locked file cabinet located in Dr. Thompson's office, HPER Room 340. If the results of this study are published, your name will be absent from all of the published material.

Authorization

By signing this informed consent form, I am indicating that I have read and understood this document, in addition to having received a copy of the form for my personal records. I also understand that there is a small amount of radiation exposure during the DXA testing. The investigators have given me the opportunity to ask any questions I may have. By signing this form, I am indicating that I agree to participate in this research study.

__________________________ ____________
Participant Signature Date

__________________________ ____________
Investigator Signature Date

APPENDIX B

QUESTIONNAIRE

PHYSICAL ACTIVITY AND SUPPLEMENT QUESTIONNAIRE

Subject Number: ______

Please answer all questions as correctly and completely as possible. None of this information will be made known to any other individuals. If you have any questions regarding this form, please ask one of the researchers for clarification.

Date of Birth (dd/mm/yy): ___________

Do you currently exercise on a regular basis? Y N

If yes, what type of exercise do you engage in? (Please be as specific and detailed as possible.)

How long have you been participating in all of the activities you listed above?

I would like you to provide an outline of a typical week in your life regarding your exercise and physical activity habits. Try to be as specific as possible (i.e. name of activity, duration of activity, etc.)

Monday:

Tuesday:

Wednesday:

Thursday:

Friday:

___

Saturday:

___

Sunday:

___

Please list any dietary supplements you currently use on a regular basis, or have used in the last 3 months:

___
___
___

APPENDIX C

SUPPLEMENTAL STUDY #1

SUPPLEMENTAL STUDY #1:
%BF-BOD POD COMPARED TO %BF-LOHMAN'S 3-COMPARTMENT MODEL IN YOUNG ADULT FEMALES

Introduction

Recent advancements in technology have led to the development of air displacement plethysmography, a body composition assessment method that is frequently being used in a number of clinical, research, and fitness settings. The Bod Pod® utilizes this technique to estimate percent body fat. This system, based on Boyle's Law, recognizes that an inverse relationship exists between pressure (P) and volume (V) (i.e., $P_1V_1 = P_2V_2$).

The Bod Pod® is a single sealed structure that is divided into two chambers by a fiberglass seat. The front chamber is used for testing and is where the subject sits, while the rear chamber is the reference chamber. Located between the two chambers is a volume-perturbing diaphragm. When this diaphragm oscillates via computer control, complementary volume perturbations occur in the two chambers (11). As volume changes within the chamber, pressure fluctuations occur and are used to determine the air volume of the chamber. "Chamber air volume is determined both with and without the subject seated in the test chamber. Thus, body volume is the difference between the two measures" (11). Body volume, body mass, thoracic gas volume, and an estimate of body surface area allow for the calculation of body density. The three primary advantages of the Bod Pod® are easy operation, a comfortable testing environment for the subject, and fast results. Unfortunately, the Bod Pod® may not be able to accommodate the morbidly obese due to its chamber size and some subjects may feel uncomfortable with its rigid clothing requirements (a form-fitting swimsuit and swimcap) (11). Another possible drawback is the possibility of claustrophobia in the Bod Pod®. Any individual that panics when in small, confined spaces could find it uncomfortable to undergo this procedure.

Past Research

A number of populations have been tested in the Bod Pod®, including athletes, the obese, children, and the elderly. Many of these studies have compared the Bod Pod® to hydrostatic weighing, where as others have compared it to multi-compartment models and/or additional body composition assessment tools (i.e., DXA, BIA). In a study conducted by Vescovi et al. (50), 68 women (mean age 22.1 ± 5.4 years) and 27 men (mean age 24.1 ± 7.1 years), were assessed with both the Bod Pod® and hydrostatic weighing. The results did not reveal any significant differences in mean body density and %BF by the Bod Pod® and UWW for men, women or both genders combined (50). However, upon closer examination Vescovi et al. (50) found that the Bod Pod® significantly underestimated body density in lean individuals, thus overestimating %BF compared to UWW for this group of subjects. The researchers concluded that the Bod Pod® is an accurate tool for estimating body composition compared to UWW for all individuals, except for those that are very lean, possibly due to the fact that these individuals fall outside the average percent body fat range (50).

Another study examined the validity of the Bod Pod® with hydrostatic weighing in 68 adults (42 men and 26 women), of varying ethnicity (47 Caucasians, 10 Hispanics, 7 African-Americans, and 4 Asian-Americans), age, and body size (33). A subset of 16 individuals (7 males and 9 females) from the original subject population were tested on two different days in both the Bod Pod® and UWW in order to examine test-retest validity. It should be noted that all 16 of these individuals did have previous experience in being underwater weighed. Overall, there were no significant differences between the percent body fat values of the Bod Pod® and UWW for the two genders combined or when they were analyzed separately as males and females. The mean difference between the Bod Pod® and UWW for both genders was only –0.3 ± 0.2%. In regards to the test-retest analysis, no significant differences were found between the first and second trials for either the Bod Pod® or UWW. The between-trial standard deviations were 0.4% and 0.5% for the Bod Pod® and UWW respectively, while the coefficient of variation (CV) for the Bod Pod® was 1.7 ± 1.1% and the CV for UWW was 2.3 ± 1.9%. Finally, the standard error of estimate (SEE) between the two body composition assessment techniques was only 1.81, which according to Lohman is highly acceptable (30). McCrory et al. (33) concluded that the Bod Pod® is a highly reliable and valid measurement tool for body composition in apparently healthy subjects.

A number of other studies agree with the previous findings and support the use of the Bod Pod® for body composition analysis in all types of populations. Yee et al. (57) found no significant differences in body fat percentage via the Bod Pod® versus UWW in 30 elderly men and 28 elderly women (age 70-79), while Wells and Fuller (54) concluded that the Bod Pod® showed good precision for both body volume and body density measurements during repeated measures of individuals varying in age and body size (16 men, aged 22-48 years; 12 women, aged 24-42 years; 13 boys, aged 5-14 years; and 17 girls, aged 5-16 years).

Purpose

The purpose of this study was to compare %BF estimates of the Bod Pod® with those of Lohman's 3-compartment model in young adult females.

Methods

Subjects and General Protocol

Sixty young adult females (23.27 $\pm$ 4.78 years old) were recruited for this study. All subjects signed an Informed Consent document approved by the University of Tennessee Institutional Review Board. Anthropometric measures and %BF assessment using the 3-C model of Lohman are explained in the "Manuscript" (Chapter III) section of this document.

Bod Pod®

The Bod Pod® (Life Measurement Instruments, Concord, CA) was first calibrated using a two-point calibration method with volumes of 0 and 49.774 L (the manufacturer's calibration cylinder). Subjects were tested wearing minimal clothing (a lycra swimsuit) and a swimcap in order to minimize the effect of hair and clothing on body volume measurement. Each subject was weighed on the manufacturer's scale to the nearest 0.1 kg. The subject was then seated within the Bod Pod® chamber to permit two measurements of body volume to be made, each lasting approximately 45 seconds. If these two volumes agreed within 150 ml of each other, the subject's body volume was assumed to be the average of the 2 values. If the first 2 body volume measurements did not correspond, a third measurement was made. If 2 of the 3 values did not agree within 150 ml, the chamber was recalibrated and the procedure repeated. Thoracic gas volume was predicted based on subject's age, gender, and body size. Body density was then calculated using the Bod Pod® determined body volume and mass. Body density was used to determine %BF using the equation of Siri (44) and the modified equation of Heyward and Stolarczyk (24). The Siri (44) model assumes a fat-free mass density (D_{FFM}) of 1.1 kg/L, while that of Heyward and Stolarczyk (24), specific to women, assumes a D_{FFM} equal to 1.097 kg/L.

Statistical Analyses

Statistical analyses were performed using SPSS for Windows version 9.0 (SPSS, Inc., Chicago, IL). Repeated measures analysis of variance (ANOVA) was used to compare %BF results from the two Bod Pod® equations and Lohman's 3-C. Post-hoc testing with Bonferroni adjustments were conducted to determine between method differences. Agreement between methods for estimating %BF was determined using Bland-Altman plots. The level of significance was set *a priori* at $\alpha=0.05$ for all statistical tests.

Results and Discussion

%BF estimates of the 60 young women via the Bod Pod® and Lohman's 3-C model are compared in Table A.1. The Lohman 3-C estimate of %BF was not statistically different from either Bod Pod® estimate. The Bod Pod® estimate using the Siri equation was higher ($p<0.0001$) than that obtained with the Heyward and

Table A.1: Comparison of %BF estimates obtained with the Bod Pod and Lohman's 3-compartment model (mean ± SD)

Body Composition Model	All Women (n=60)
Bod Pod - Siri Equation (%BF)	23.06 ± 5.92
Bod Pod - Modified Equation (%BF)	21.80 ± 5.99*
Lohman's 3-C (%BF)	22.14 ± 6.75

*= Significant difference in %BF estimate compared to %BF-Bod Pod® using the Siri Equation ($p<0.0001$)

Stolarczyk equation. The Siri equation's %BF estimate on average differed by only +0.92% from the 3-C model, while the equation of Heyward and Stolarczyk was even closer in value to the 3-C model, with a difference of only -0.34%. The D_{FFM} of the subjects in this study was 1.0985 kg/l, lower than assumed by Siri (44) and higher than assumed by Heyward and Stolarczyk (24). Figure A.1 illustrates the relationship between the Bod Pod® using the equation of Siri and Lohman's 3-C %BF estimates. Correlation coefficient analysis between these two %BF estimates revealed an "r" value equal to 0.840.

Figure A.2 illustrates the relationship between the Bod Pod using the equation of Heyward and Stolarczyk and Lohman's 3-C %BF estimates. Correlation coefficient analysis between these two %BF estimates also revealed a high "r" value, specifically an "r" equal to 0.838. The two "r" values reveal that there is a strong

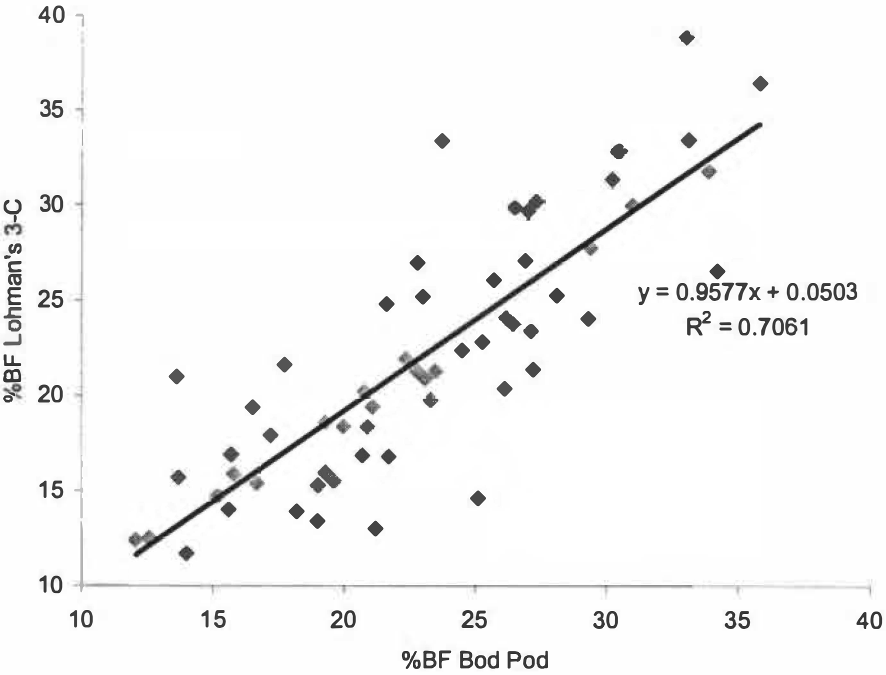

Figure A.1. Comparison of %BF Estimates from Lohman's 3-C Model and the Bod Pod® using the equation of Siri.

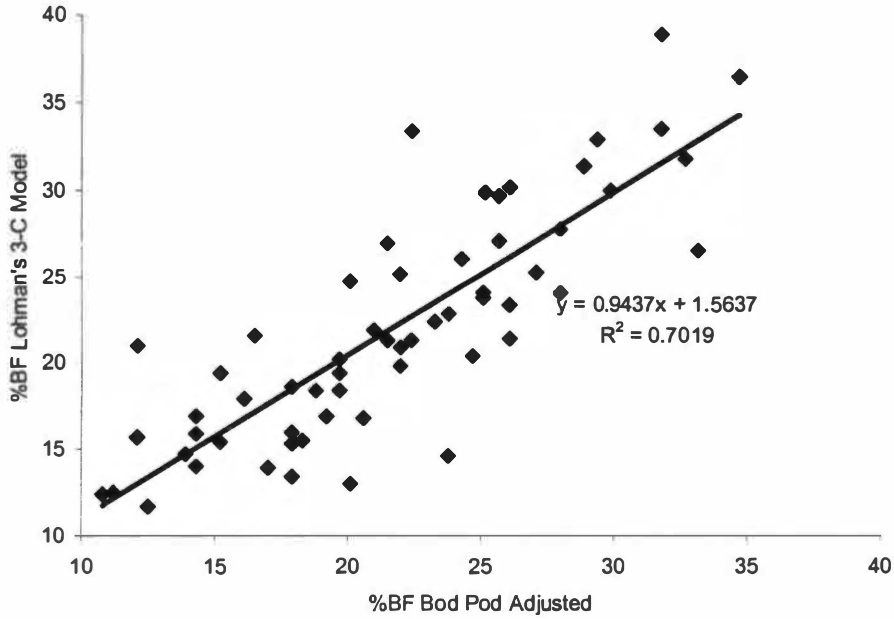

Figure A.2. Comparison of %BF Estimates from Lohman's 3-C Model and the Bod Pod® using the modified equation of Heyward and Stolarczyk.

relationship between the two equations of the Bod Pod® and Lohman's 3-C model, each giving similar results to the 3-C model.

Figures A.3 and A.4 compare the prediction of %BF with the 3-C model and the Siri and Heyward and Stolarczyk equations, respectively. The solid line represents the mean difference between the body composition methods, while the dashed lines represent the limits of agreement ($\pm$ 2 SD). The mean difference and limits of agreement between the Bod Pod's Siri equation and Lohman's 3-C model were –0.93 $\pm$ 7.4%, while the mean difference and limits of agreement between the Bod Pod's modified equation and Lohman's 3-C were 0.335 $\pm$ 7.4%. Although neither Bod Pod® equation's group mean was found to be significantly different from the 3-C model, large individual errors are visible in Figures A.3 and A.4. This suggests that a sizable difference could occur between %BF estimates of Lohman's 3-C and one of the Bod Pod® equations for a given individual.

In summary, the Bod Pod® estimations of body fat using the equations of Siri and Heyward and Stolarczyk were similar to %BF estimates from Lohman's 3-C model. Although the equation of Heyward and Stolarczyk gave slightly closer estimates of %BF compared to Lohman's 3-C model, we conclude that either Bod Pod® equation is a suitable alternative for estimating percent body fat in young women. Because of the large limits of agreement between the 3-C and Bod Pod® estimates of %BF, additional research is needed to identify the source of this error.

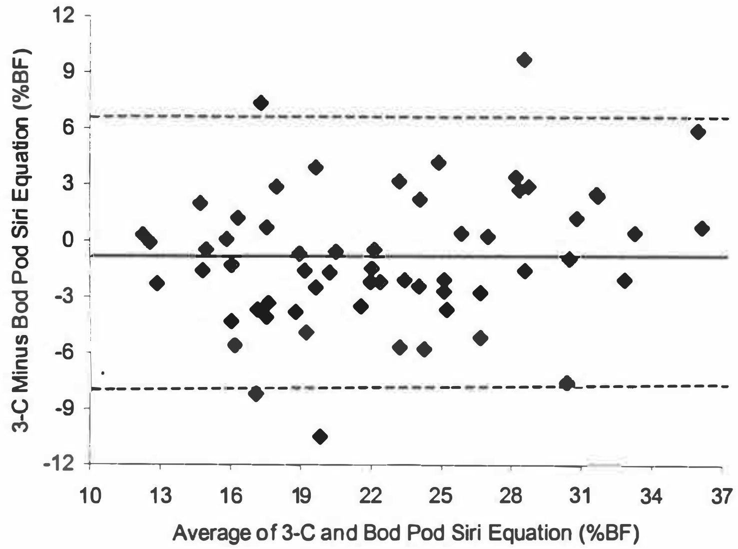

Figure A.3 Comparison of percent body fat scores from Lohman's 3-compartment model and the Bod Pod using the Siri equation in Young Women (n=60, %BF = percent body fat).

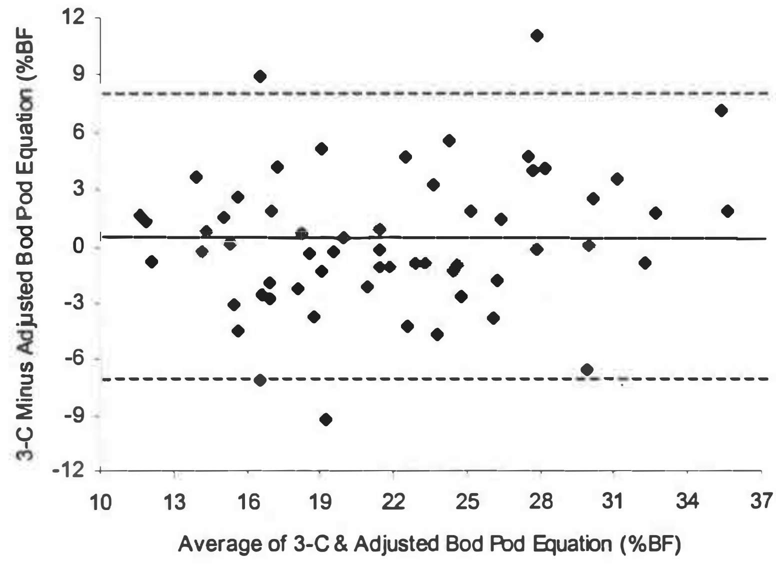

Figure A.4 Comparison of percent body fat scores from Lohman's 3-compartment model and the Bod Pod® using the modified equation of Heyward and Stolarczyk in Young Women (n=60, %BF = percent body fat).

APPENDIX D

SUPPLEMENTAL STUDY #2

SUPPLEMENTAL STUDY #2:
%BF-DXA COMPARED TO %BF-LOHMAN'S 3-C MODEL IN YOUNG WOMEN

Introduction

As described in Chapter 2, whole-body DXA scans are not only capable of estimating bone mineral density and bone mineral content, but also %BF, FFM and FM. A number of studies have investigated the validity of various DXA devices in predicting body composition compared to both criterion methods (e.g. multi-compartment models) and predictive methods (e.g. BIA, the Bod Pod®). The results from these studies have varied immensely; some have found a large degree of agreement with the DXA and other methods, while others show significant differences. Some studies have even used DXA as the criterion method for %BF estimate in their investigations. It is evident that more research needs to be conducted surrounding the DXA's use as a body composition assessment method.

Purpose

The purpose of this study was to compare %BF estimates of a Lunar whole-body DXA scan with those of Lohman's 3-compartment model in young adult females.

Methods

57 young women underwent body fat testing with Lohman's 3-C model and a whole-body Lunar DXA scan. (Please note that only 57 subjects out of the original 60 were used for statistical analysis due to improper DXA readings). Protocol specifics are listed previously in chapter 3 of this document, entitled "Manuscript."

Results and Discussion

Table A.2 contains %BF estimates for 57 young women from both the DXA and Lohman's 3-compartment model. In general, the DXA overestimated %BF compared to the 3-C model. Figure A.5 compares the %BF estimates from the two techniques for the entire sample.

Table A.2: Comparison of %BF estimates obtained with DXA and Lohman's 3-compartment Model (mean ± SD)

Body Composition Model	All Women (n=57)
DXA (%BF)	27.20 ± 6.74*
Lohman's 3-C (%BF)	22.14 ± 6.91

* = Significantly different compared to Lohman's 3-C (p<0.01)

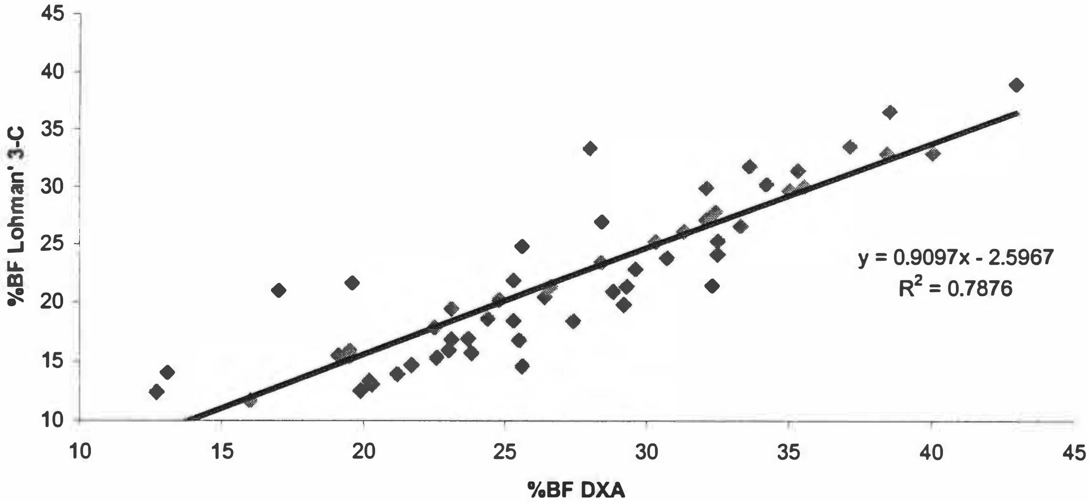

Figure A.5. Relationship between %BF Estimates from Lohman's 3-C Model and DXA.

A paired t-test between the two methods revealed t(56) = 11.766, where α was set equal to 0.05. The large t-value indicates that there is a significant difference between the two body composition methods. On average, the two methods differed by 5.06% in estimating percent body fat of the young women. Pearson product moment correlation analysis revealed an "r" value of 0.887 for the entire sample, thus indicating a strong relationship between the two methods even though the methods produced significantly different results (Figure A.5).

Figure A.6 compares the prediction of %BF from DXA with the 3-C model. The solid line represents the mean difference between the body composition methods, while the dashed lines represent the limits of agreement (± 2 SD). The mean difference and limits of agreement between DXA and Lohman's 3-C model were

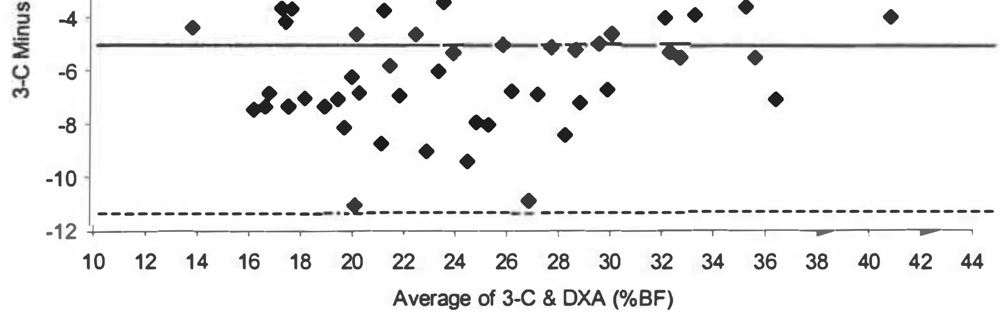

Figure A.6 Comparison of percent body fat scores from Lohman's 3-compartment model and the DXA in 57 Young Women (%BF = percent body fat).

-5.05 $\pm$ 6.48%. The Bland-Altman plot illustrates that a wide discrepancy in %BF estimates occurred between the two body composition methods for some individuals. Thus, in addition to being significantly different in value, a sizable difference could also occur between %BF estimates of Lohman's 3-C and the DXA for any given individual.

Overall, we conclude that the DXA is not a suitable alternative to use when estimating %BF in young adult females when compared to a 3-C model. Our study found that the DXA tended to overestimate %BF by approximately 5% compared to Lohman's 3-C. We recommend the use of a 3-C model to estimate body fatness in young women if time and resources are available. Future research is still needed to evaluate the validity of the DXA as a body composition assessment tool in a number of populations including males, elderly adults, children, and the obese.

APPENDIX E

ANTHROPOMETRIC MEASUREMENTS

ANTHROPOMETRIC MEASUREMENTS

Standardized circumference measurements of the waist, hip, and umbilicus were made with the subject standing in an erect position with feet together while wearing her swimsuit. Circumference measurements were made to the nearest 0.1 cm using a tape-measure fitted with a tension spring. Waist measurements were taken at the narrowest part of the torso, above the umbilicus and below the xiphoid process. Hip circumferences were measured at the widest portion of the hips above the gluteal fold. Umbilical measurements were taken at the level of the umbilicus. Each circumference was measured twice and then averaged for a final value. All of the circumference measurements were taken by a single technician. The values from the waist and hip circumference measures were used to calculate a waist-to-hip ratio (WHR), while the values from the umbilicus and hip circumference measures were used to calculate an umbilicus-to-hip ratio (UHR) that was then compared to the WHR. WHR is often used to indirectly determine an individual's risk of obesity as well as quantify the distribution of body fatness. For young women, a WHR > 0.85 places an individual at a "very high risk" for obesity and associated health conditions, including cardiovascular disease and diabetes (1). Table A.3 contains anthropometric measures of 60 young women.

Table A.3 Anthropometric Measurements (mean ± SD)

Measure	Less Active Women (n = 19)	Moderately Active Women (n = 21)	Highly Active Women (n = 20)
Waist (cm)	67.1 ± 5.1	65.4 ± 4.1	69.9 ± 5.6
Hips (cm)	93.8 ± 5.3	92.3 ± 3.5	95.3 ± 5.5
Umbilicus (cm)	72.1 ± 5.3	68.6 ± 4.5	73.2 ± 6.7
WHR	0.72 ± 0.05	0.71 ± 0.04	0.74 ± 0.03
UHR	0.77 ± 0.05	0.74 ± 0.04	0.77 ± 0.04

VITA

Allison Kellie Wallis was born in Rochester, NY on February 3rd, 1978. From a young age, Kellie had a love for sports and exercise, including soccer which she began playing at the age of 6. Kellie graduated with honors from Greece Arcadia High School in Rochester, NY in June 1996. She then attended the University of Dayton and received her Bachelors of Science in Education and Allied Health Professions with a major in Pre-Physical Therapy in May 2000. At the University of Dayton, Kellie assisted in a number of research studies, including strength training in prepubescent children and the role of maximum heart rate in predicted VO_2 max in collegiate football players. Over the years Kellie has also participated in a number of charity events, including Avon's 3-Day Walk for Breast Cancer. She has also volunteered for numerous organizations including Habitat for Humanity and the American Cancer Association. Kellie entered the University of Tennessee in August 2000 in pursuit of a masters degree in Exercise Physiology. Kellie served as a Graduate Teaching Assistant in the Physical Education Activities Program at UT during the 2000-2001 and 2001-2002 schoolyears. Kellie was recently awarded the Albert W. Hobt Memorial Scholarship for Excellence in Teaching (Spring 2002). Kellie will graduate suma cum laude receiving a Masters of Science degree with an emphasis in Exercise Physiology in August 2002.