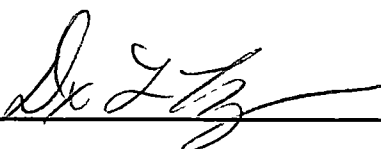


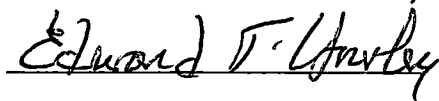
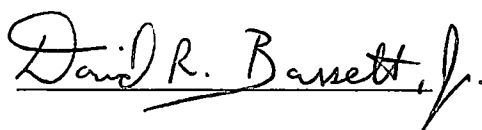
To the Graduate Council

I am submitting herewith a thesis written by Colleen Grace McMahon entitled "Comparison of body fat measurement techniques in females" I have examined the final 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 Sports Studies

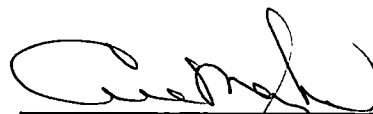


Dixie Lee Thompson, Major Professor

We have read this thesis and
recommend its acceptance:



Accepted for the Council:


Associate Vice Chancellor and
Dean of The Graduate School

**Comparison of Body Fat Measurement
Techniques in Females**

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Colleen Grace McMahon

August, 2000

DEDICATION

This thesis is dedicated to my Grandparents, Robert and Anne Byrne, and to my mother, JoAnne Finn. Thank you all for your support and encouragement throughout this entire process. I could not have come this far without the help and inspiration you all have offered. Your optimism and faith have shown me that anything is possible when you believe in yourself and have faith in God. Thank you all for your wonderful influences and for your dedication to me

ACKNOWLEDGMENTS

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

My major Professor, Dr. Dixie Lee Thompson: Thank you for taking me under your wing and motivating me to have the courage to write a thesis. Thank you for helping me realize my potential, and for the many hours spent editing this document. I could not have made it through without your devotion to me as a student. You are a wonderful instructor and advisor whom I admire. Your guidance was invaluable to the completion of this thesis.

Dr. Edward T. Howley: Thank you for seeing the Exercise Scientist in me! You welcomed me into the laboratory as an undergraduate and showed me the possibilities of this field. Thank you for giving me the opportunity to explore the field of Exercise Science. You are an incredible teacher, advisor, and friend. Thank you for having a passion for teaching and a care for the quality of your student's knowledge. I admire your abilities as a professor and as an individual.

Dr. David R Bassett, Jr: Thank you for letting me explore the field of Exercise Science with the Kenz accelerometer! You gave me a wonderful opportunity as an undergraduate to participate in research and develop an interest in this area. Thank you for trusting me and for pushing my potential to succeed. I have enjoyed learning from you, as you are an excellent instructor. Thank you for all of your hard work and dedication.

Cary Springer, MS: Thank you for all of your guidance in the statistical analysis used in this study. You are invaluable to our department.

Ann M Swartz, MS: Thank you for taking time to edit my papers, to teach me in the lab, and to give me advice and guidance. I appreciate your friendship and respect your abilities as a potential professor.

Brittney Massey, MS: Without you I would not have had the patience to complete this project. You are my greatest friend and confidant and I thank you for everything you do!

Jason Langely, MS: Thank you for motivating me to write, for making me exercise, and for listening to my many "traumatic" writing experiences. Your friendship was invaluable to the completion of this thesis.

Todd Robert Prescott: Thank you for having patience throughout this entire process and allowing me space to finish my thesis. Your friendship and love mean everything to me, and I appreciate your support and encouragement.

Special thanks are extended to the many subjects who participated in this study.

ABSTRACT

The main objective of this study was to assess the accuracy of the Tanita-TBF 305 foot-to-foot bioelectrical impedance analyzer for the estimation of body composition as compared to hydrostatic weighing. The secondary objective of this investigation was to assess the impact of waist-to-hip ratio (WHR) on the estimation of body composition by the Tanita foot-to-foot analyzer. Participants were 40 pre-menopausal, obese females (39.7 ± 7.8 yrs; $46.5 \pm 1.0\%$ BF). In addition, the subjects were sub-divided based on WHR: 1) ≤ 0.75 lower body obesity (LBO); 2) ≥ 0.85 upper body obesity (UBO); 3) between 0.75 and 0.85 overall obese group. The results showed no significant differences in anthropometric characteristics between the sub-groups except for WHR ($p < 0.0001$). Estimation of body composition variables such as fat-free mass (FFM), fat mass (FM), and % body fat (BF) were obtained with the Tanita TBF-305 and hydrostatic weighing (HW). There were no significant differences for the total sample ($n=40$) in FFM, FM, or %BF between methods. Further, there was a significant correlation between HW and foot-to-foot BIA for FFM ($r = 0.70$), FM ($r = 0.93$), and %BF ($r = 0.55$) ($p < 0.001$). The standard error of the estimate for %BF was 5.6%. A repeated measures ANOVA showed no significant influence of body shape (i.e., WHR) on the prediction of %BF ($p = 0.77$). Correlation analysis revealed no relationship between WHR and the difference in %BF between methods ($r = 0.03$, $p = 0.85$) for the entire sample. In conclusion, the Tanita TBF-305 has the ability to accurately predict body composition in obese, pre-menopausal females. Furthermore, deviations in body shape (i.e., WHR) have

no significant influence on the ability of the Tanita TBF-305 to estimate body composition.

TABLE OF CONTENTS

CHAPTER	PAGE
1. Introduction.....	1
Purpose.....	6
Hypotheses.....	6
2. Review of Literature	8
Obesity: Prevalence and Current Trends	8
Quantification of Obesity.....	9
Hydrostatic Weighing.....	11
Residual and Gastro-Intestinal Volume.....	12
Percent Body Fat From Hydrostatic Weighing.....	13
Bioelectrical Impedance Analysis.....	14
Effect of Obesity on BIA	16
Impedance.....	19
Frequency.....	21
Volume.....	22
Body Geometry... ..	22
Body Water Distribution.....	25
Population Specific Equations	26
Methods of BIA	27
Distribution of Body Fat	32
Summary.....	33

3. Methods.....	34
Subject Screening and Selection... ..	34
Anthropometric Measurements	35
Bioelectrical Impedance Analysis.....	36
Hydrostatic Weighing	36
Residual Lung Volume	37
Statistics	39
4. Results.....	40
5. Discussion.....	49
BIA and HW for total sample	49
Effect of WHR on Estimation of Body Composition	52
References.....	55
Appendices.....	60
Appendix A: Informed Consent Form	61
Appendix B: Questionnaire.....	64
Vita.....	66

LIST OF TABLES

TABLE	PAGE
1. Anthropometric Characteristics of Subjects	41
2. Body Composition from Hydrostatic Weighing	41
3. Comparison of Body Composition Variables	41
4. Impact of Body Shape on the Prediction of %BF	42

LIST OF FIGURES

FIGURE	PAGE
1. Comparison of Percent Body Fat Scores From Hydrostatic Weighing and Bioelectrical Impedance Analysis	43
2. Comparison of Percent Body Fat Scores From Hydrostatic Weighing and Bioelectrical Impedance Analysis for Subjects with Upper Body Obesity.....	44
3. Comparison of Percent Body Fat Scores From Hydrostatic Weighing and Bioelectrical Impedance Analysis for Subjects with Lower Body Obesity	45
4. The Relationship of Waist-to-Hip Ratio and the Difference Between Hydrostatic Weighing and Bioelectrical Impedance Analysis Estimation of Percent Body Fat	47
5. The Relationship of Waist-to-Hip Ratio and the Difference Between Hydrostatic Weighing and Bioelectrical Impedance Analysis Estimation of Percent Body Fat in Subjects with Upper and Lower Body Obesity.....	48

CHAPTER 1

INTRODUCTION

With the prevalence of obesity increasing at an alarming rate, research in the area of body composition has become a major concern of public health care professionals. It is estimated that nearly 30% of adults and 18-25% of adolescents are obese (Kuczmarski, 1994; Keller et al., 1996). Although there is documented increase in prevalence for both genders, women of all races have a particularly high occurrence of obesity (Solomon, et al, 1997). Studies have shown that excess body fat is linked with several negative health conditions such as non-insulin dependent diabetes (NIDDM), cardiovascular and coronary artery disease (CAD), hyperlipidemia, and hypertension (AMA, 1988). The incidence of hypertension, hyperlipidemia, and NIDDM is two to three times greater in obese individuals (National Institutes of Health (NIH), 1985). The risk for developing such comorbidities is not only related to total adiposity, but also to the distribution of adipose tissue. Visceral fat or intra-abdominal fat has a stronger relationship to cardiovascular disease than total adipose tissue mass (Bjorntorp, 1990). Therefore, when attempting to quantify the prevalence of obesity and the impact it has on society, measurement techniques must be accurate for total body fat as well as for body fat distribution assessment. The waist-hip ratio is the most common method for assessing body fat distribution, and hence, one's risk for such comorbidities associated with central adiposity (Bjorntorp, 1990; Solomon et al., 1997). Furthermore, many researchers are interested in the etiology and prevention of obesity, however, measurement and definition

of obesity must first be standardized. It is clinically important to accurately assess body composition in central obesity given the associated adverse metabolic conditions.

In the standard approach to evaluate body composition, the body is subdivided into two or more compartments, one of which is fat. The conventional two-compartment (2-C) model sub-divides the body into fat and fat-free tissues, assuming a constant density of (0.9 kg/L) and (1.1 kg/L), respectively (Siri, 1961). An additional assumption of the 2-C model is a constant hydration state of the fat-free mass (FFM) of 73.8% (Siri, 1961). Given these assumptions, body fat percentage (%BF) can be estimated if total body density (D_b) is known:

$$\%BF = (495/D_b) - 450$$

% BF = body fat percentage
 D_b = total body density

The 2-C model generally provides accurate estimates of body composition as long as the basic assumptions are met. However, there are inter-individual (Heyward, 1996) and inter-racial (Schuette, 1984) differences in the composition of the FFM. Nonetheless, the 2-C model remains a valuable criterion against which other methodologies can be compared.

A common technique that applies the 2-C model is hydrostatic weighing (HW). In HW body volume, which is directly proportional to the loss in mass, is calculated from the amount of water displaced while the subject's body is submerged in water (Goldman and Buskirk, 1969). Body volume is used to calculate body density given that density is defined as mass per unit volume (Goldman and Buskirk, 1969):

$$D_b = \frac{M}{V} = \frac{M_a}{\frac{(M_a - M_w)}{D_w}}$$

M = mass

M_a = body mass in air

D_w = density of water

V = volume

M_w = body mass in water

Because the density of water changes with temperature, a correction must be made for water density to accurately obtain body volume (V) and, consequently, density of the body. Additionally, adjustments must be made for residual lung volume and gastrointestinal volume (see Chapter 2). Body density is then applied to the 2-C model to estimate FFM and %BF based on the previous assumptions. Hydrostatic weighing is generally considered the “gold standard” for estimating %BF and a technique to which other methodologies are compared. This methodology is not, however, without its drawbacks. This method tends to be cumbersome, time consuming, and difficult for the subject. Also, the elaborate equipment and technical expertise required by HW renders this method impractical for large population studies. For these reasons, other methodologies have been introduced.

Recently, easier, less expensive techniques have been introduced to estimate body fatness. One such method is bioelectrical impedance analysis (BIA). BIA has gained recent attention due to the abundance and low cost of commercially available BIA analyzers. BIA is an easy, non-invasive, and quick method to estimate body composition and is available for research and clinical usage. BIA involves applying a small, alternating current to the body as impedance or resistance to flow of the current is measured. Impedance is then used to predict total body water (TBW), FFM, FM, and

%BF (Duerenberg, 1996; Foster et al., 1996). Because the FFM is predominately made up of water (73%), electrical current is conducted readily via electrolytes, thus creating little resistance to the current. Due to the physiologically low water content of adipose tissue, fat creates a greater resistance to the electrical current. Therefore, FFM and %BF are predicted assuming the resistance to the current is inversely proportional to fat free mass (Bell et al., 1998).

The older, conventional BIA analyzers used a tetrapolar arrangement of four electrodes, one each on the ankle, foot, wrist, and hand. A recent model marketed by Tanita (Tanita Inc, Tokyo, Japan, Model # TBF-305) uses foot-to-foot BIA to assess body composition. The foot-to-foot method uses metallic foot plates to measure the impedance of the electrical current and predicts body fatness by using this value in a regression equation developed by the manufacturer. There are limited studies involving the foot-to-foot method, and accuracy in the obese population is unclear. A recent study by Utter et al. (1999) found significant correlations between FFM estimated by foot-to-foot BIA as compared to HW in obese females ($r = 0.78$, $p < 0.001$, SEE 3.7 kg). In contrast, Frainkowiak et al. (2000) demonstrated an overestimation of FFM by foot-to-foot BIA and hence, an underestimation of %BF in obese females as compared to dual energy x-ray absorptiometry (DEXA) ($p < 0.001$). Data on the accuracy of the foot-to-foot analyzers among obese individuals appears to be conflicting. Furthermore, the mode of reference selected for comparison varies from study to study, thus compromising general conclusions on accuracy.

BIA in general provides a quick, relatively inexpensive, and non-invasive procedure to estimate adiposity (Houtkooper, et al., 1996) and can be used in large epidemiological studies to assess the prevalence of obesity (Roubenoff, 1996). However, when applied to obese subjects, BIA tends to underestimate percent body fat while overestimating FFM when generalized equations are applied (Segal et al., 1988). A study by Carella et al. (1997) found an overestimation of the FFM by approximately 4.0 kg in obese subjects as determined by BIA as compared to hydrostatic weighing. Baumgartner et al. (1998) found similar results when equations developed for lean individuals were used to estimate percent body fat of obese subjects. This overestimation of the FFM may be due to violations of the assumptions required of BIA seen in the obese state (Duerenberg, 1996). Duerenberg (1996) suggests that those who are obese impose additional error in predicting body fatness due to the differences in body geometry, increased relative TBW, and increased extracellular water (ECW). Since BIA uses impedance to estimate TBW and/or FFM, the high water content of the lean tissues and the expansion of ECW, as seen in obesity, would lead to an overestimation of TBW and consequently, an overestimation of FFM.

Another factor that influences BIA is body geometry. To date, there are limited data regarding the impact of body geometry on the estimation of body composition. One assumption made in BIA is that the body is a perfect cylinder with uniform cross-sectional area (Foster and Lukaski, 1996). However, the human body is better represented as several cylindrical parts in a series, including the trunk and extremities (Kushner, 1992). In obesity, the excess accumulation of fat in the central or peripheral

region creates a further violation of this assumption. The effect of additional adipose tissue in the central or peripheral region is unclear. Foster and Lukaski (1996) reported that changes in geometry of the trunk had little impact on impedance values measured by BIA, whereas changes in the geometry of the extremities had a large impact on impedance measures. In addition, other studies have suggested that adipose tissue in the abdominal region does not contribute to much of the resistance measured via BIA (Duerenberg, 1996). It is feasible that body fat distribution patterns may affect the impedance values of BIA, thus, compromising the estimation of body composition. Given the increased risk for such conditions as NIDDM and CVD associated with central adiposity, measurement techniques should be sensitive to differences in fat distribution. There is also little evidence concerning the impact of body fat distribution on the estimation of body composition via the foot-to-foot BIA system. Since the foot-to-foot method of BIA has just recently been introduced, the effects of body shape, or fat distribution, on Tanita's body composition assessment is unknown.

Purpose

The purpose of this study was to compare the Tanita body fat predictions of obese females to the criterion method, hydrostatic weighing. In addition, the effect of body geometry was assessed by comparing Tanita's prediction of body fat in those with central obesity versus those with peripheral obesity as defined by waist-hip ratio (WHR).

Hypotheses

1. Body fat percentage determined by the Tanita TBF-305 will be different as compared to hydrostatic weighing in obese females.

2. The results of the Tanita TBF-305 for %BF will be influenced by body geometry, i.e., waist-hip ratio. This will result in a significant correlation between WHR and the difference in %BF between HW and BIA.

CHAPTER 2

REVIEW OF LITERATURE

Obesity: Prevalence and Current Trends

Obesity has become one of the most pervasive public health problems in our country. Obesity is most accurately defined as an excess accumulation of adipose tissue ($\geq 20\%$ of male weight and $\geq 30\%$ of female weight) (Benke and Wilmore, 1974). Based on information from the National Health and Nutrition Exam Surveys, it was estimated that one-third of the adult population was overweight or obese between the years of 1988-1991 (Kuczmarski et al., 1994). Similar results have been documented in children. It is estimated that 25-30% of pre-pubertal children and 18-25% of adolescents are obese (Keller, 1996). Studies have shown that childhood and adolescent obesity can lead to adult obesity, thus increasing the risk for cardiovascular and coronary artery disease, hyperlipidemia, diabetes, and hypertension (Becque et al., 1998, Kuczmarski et al., 1994, Solomon et al., 1997). Because obesity is strongly linked to such adverse health conditions, the American Heart Association (AHA) has recently reclassified obesity as a major, modifiable risk factor for coronary heart disease (Eckel et al., 1998).

The prevalence of overweight and obesity is increasing for both men and women (Eckel et al., 1998), with women, especially non-white women, having the greatest increase in prevalence (Solomon et al., 1997). The etiology of obesity is multifactorial, influenced by both genetics and lifestyle (Kuczmarski, 1994). Because of the complex nature of obesity, research is focused on the etiology, prevention, and treatment of such a condition. However, in order to accurately quantify the prevalence of obesity in our

society, and to further understand the impact obesity has on the individual, accurate measurement techniques of body composition must be obtained.

Quantification of Obesity

There are several types of measurements that provide information regarding body size and shape such as body mass index (BMI), waist-hip ratio (WHR), and circumference measurements. The AHA has adopted a classification criteria for obesity using BMI. A BMI between 25-30 kg/m² is classified as overweight and a BMI > 30 kg/m² is classified as obese (Eckel et al., 1998). BMI is calculated by dividing one's weight in kilograms by height in meters squared (kg/m²). Because of the ease of measurement, BMI is commonly used in epidemiological studies. Additionally, the association between BMI and negative health outcomes makes it a clinically important variable. One limitation when using BMI to define obesity is the fact that lean body mass is not distinguished from fat mass. Revicki et al. (1986) report moderate correlations ($r = 0.71$) between BMI and %BF from hydrostatic weighing, a direct method of estimating adiposity, with a standard error of estimation (SEE) of 5.4%. Data from this study indicate the potential error associated with predicting body fat from BMI. Although BMI may be a useful research tool for assessing the risk of adverse conditions associated with excess fat, it is not the most accurate method for estimating body composition.

Another widely used indirect measurement of obesity is the waist-hip ratio (WHR). This measurement helps to quantify the distribution of body fatness of an individual. Central obesity, when a greater proportion of fat is located in the abdomen, is referred to as android obesity. Conversely, when a disproportionate amount of fat is

located on the hips and thighs it is referred to as peripheral or gynoid obesity. Research has shown that the pattern of body fat distribution is an important predictor of health risks associated with obesity (Van Itallie, 1988; Solomon et al., 1997). Android obesity is associated with a higher risk of developing cardiovascular disease and diabetes (Solomon et al., 1997), and can be assessed by the WHR. A WHR of ≥ 0.85 for females and ≥ 0.95 for males is classified as high risk (Van Itallie, 1988). Solomon et al. (1997) report data indicating that the WHR may be a stronger predictor for mortality and morbidity than BMI. Using WHR as the independent variable, women in the highest quintile (indicating central adiposity) had a relative risk of death of 2.6 as compared to those in the lowest WHR quintile (Solomon et al., 1997). In addition, lower body obesity can also be assessed by the WHR. In obese women, a value of ≤ 0.75 typically represents accumulation of body fat on the hips and thighs. Fat distribution on the lower extremities does not appear to be as strongly related to the adverse effects of obesity as does central accumulation of fat (Van Itallie, 1988). However, Solomon et al. (1997) point to a recent study from the Manitoba Heart Health Survey, in which BMI was more strongly related to metabolic abnormalities than WHR, therefore implying that non-central obesity is not necessarily a harmless condition.

The BMI and WHR provide simple, non-invasive methods of defining obesity and assessing the risk of co-morbidities associated with obesity. However, these measurements are indirect and do not give an indication of body composition. When attempting to quantify obesity for an individual, it is critical to obtain accurate, more direct estimates of body fatness.

The more common reference methods for determining percent body fat use a 2-compartment (2-C) model. Siri (1961) suggested that the body be represented by fat mass (FM) and fat-free mass (FFM). The fat component is assumed to have a density of 0.9 kg/L and appears fairly consistent across individuals. The FFM is composed of all tissues except lipids and is assumed to have a density of 1.1 kg/L and a water content of 73%. In order to meet the assumption that the FFM density is 1.1 kg/L, the various component parts of the FFM must exist in similar proportions among individuals (i.e., similar bone density). When these assumptions are met, the 2-compartment reference model generally provides an accurate assessment of body fat (Heyward, 1996).

Hydrostatic Weighing

Hydrostatic weighing (HW) is a common technique for determining body density which can subsequently be applied to the 2-compartment model. HW is based on Archimedes' principle, which states that when an object is submerged in water, it is bouyed up by a counterforce equal to the weight of the water displaced and proportional to the volume of the object (Goldman and Buskirk, 1961). The assumed density of the FFM (1.1 kg/L) is greater than the density of water at temperatures commonly used in HW (35-36°C) (Goldman and Buskirk, 1961). In contrast, the assumed density of the FM (0.90 kg/L) is less than that of the water. Therefore, those with greater amount of fat-free mass (FFM) will weigh more in water than those with a higher amount of body fat for the same total body mass. The mass of the person underwater is recorded and used to calculate body volume and subsequently body density given that density is defined as mass per unit volume (Goldman and Buskirk, 1961):

$$D_b = \frac{M}{V} = \frac{M_a}{\frac{M_a - M_w}{D_w}}$$

To accurately estimate body volume, two other volumes must be taken into consideration; 1) Residual lung volume and 2) Gastro-intestinal volume. These two variables will be discussed in the following section.

Residual and Gastro-Intestinal Volume

Residual volume (RV) is defined as the amount of air left in the lungs after maximal expiration. (Wilmore, 1969). RV can be measured by several different methods including nitrogen wash-out, oxygen dilution, and hydrogen dilution (Buskirk, 1961). Buskirk (1961) reports that each of these methods generally yield similar values for RV. However, Wilmore's (1969) modified oxygen dilution technique offers many advantages for both the investigator and the subject. This procedure substantially reduces the time needed for a single RV measurement (i.e., 8-10 min vs. 15-30 min), thus allowing duplicate measurements to be made without tremendous time allotment. In addition, the modified oxygen dilution apparatus reduces the dead space of the total system to allow for a faster clearance of nitrogen (Wilmore, 1969). Wilmore (1969) has shown the reliability of this method by test-retest correlations in females with $r = 0.987$ and $SEE = \pm 30$ ml. Several other authors agree that measurement of RV is crucial to accurately determine body volume, however, the measurement technique is not without error (Hayward, 1996; Craig, 1998). It has been reported that a 600 ml difference in RV may

cause fluctuation in total body fat by approximately 8% (Hayward, 1996). Therefore, care must be taken when estimating RV.

The second volume that must be accounted for when determining body volume is gastro-intestinal volume (VGI). VGI is defined as the total volume of gas bubbles in the gastro-intestinal tract (Buskirk, 1961). The usual body volume determination of Goldman and Buskirk (1961) does not account for VGI due to the high variability and difficulty of measurement. However, Buskirk (1961) reports studies that suggest an average VGI of 115 ml with a range of 0-500 ml. In order to provide a more valid estimate of body volume, and consequently body density, a value of 100 ml has been proposed to represent VGI (Buskirk, 1961).

Percent Body Fat From Hydrostatic Weighing

After calculation of body density (D_b), an equation must be selected to estimate percent body fat (%BF). Typically, the equations of Siri (1961) and Brozek et al. (1963) are used to convert D_b into %BF. Generally, the precision of hydrostatic weighing is approximately 1-1.5% body fat when the densities of FFM and FM meet the criterion assumptions, as previously mentioned (Heyward et al., 1992). However, any condition in which these assumptions are not met can lead to inaccurate assessment of body composition. Because these equations are invalid in some sub-populations in which the density of FFM is not equal to 1.1 kg/L, body fat predictions of such populations are inaccurate. For example, the bone density in African American adults is typically higher than their Caucasian counterparts, potentially invalidating the Siri (1961) or Brozek et al. (1963) equations for this race (Schutte, 1984). Regardless, for many research

applications HW remains a viable criterion measure of body density, to which other methodologies are compared.

Body composition assessment by HW, however, is not without its limitations. The technique itself requires elaborate equipment, skilled technicians, and the cooperation of the subject. Nonetheless, HW has been used for many years and in many different settings to estimate body composition and remains an invaluable criterion measure. Due to the complex nature and time required of HW, other methods of determining body composition have been introduced, and will further be discussed in the following sections of this review.

Bioelectrical Impedance Analysis

Bioelectrical impedance analysis (BIA) is an alternative, easily administered technique that has been introduced to estimate body fatness. BIA applies a low-level current to the subject's body as the impedance of the current is measured (Duerenberg, 1996; Foster et al., 1996). The underlying principle of BIA is that electrolyte containing water is predominate in the fat-free tissues, and is an excellent conductor of electrical current. In contrast, fat mass offers resistance to the current due to the physiologically low water content of adipose tissue (Segal et al., 1987). Thus, total body water (TBW) is predicted from the measured impedance values from BIA. FFM can also be predicted from the impedance values of BIA given that the FFM is comprised of approximately 73% water (Segal et al., 1987). Since TBW is assumed to represent a fixed percentage of the FFM, FFM can be predicted assuming the resistance to the current (impedance) is indirectly proportional to FFM (Foster and Lukaski, 1996) Kushner and Schoeller

(1986) have demonstrated that TBW can accurately be estimated from impedance values measured by BIA. In this study, the impedance values were represented by the resistive index (Ht^2/R), where R is the resistance measured from BIA and Ht^2 is height squared. Kushner and Schoeller (1986) compared TBW estimated from BIA to that estimated by deuterium-isotope dilution (D_2O -TBW) in men and women of varying %BF. There was a high correlation coefficient between Ht^2/R and D_2O -TBW in females ($r = 0.85$, $SEE = 2.00$, $p < 0.01$). Also, the results from a stepwise multiple regression analysis showed that Ht^2/R was the most significant independent predictor of D_2O -TBW, accounting for 94% of the total variability from the regression analysis (Kushner and Schoeller, 1986). This study provides evidence that BIA can accurately assess TBW as compared to the D_2O method, an accepted criterion for TBW estimation (Kushner and Schoeller, 1986).

Another study by Kushner et al. (1990) assessed the ability of BIA to estimate changes in body composition in obese females as compared to the D_2O dilution method. The results for the entire sample ($n = 12$) showed a highly significant correlation between TBW and FFM estimates of BIA and D_2O dilution ($r = 0.971$, $SEE = 1.47$ L and $r = 0.971$, $SEE = 2.03$ kg, respectively). BIA was shown to slightly underestimate water loss throughout the study, however, this was not statistically different from D_2O dilution. The BIA predicted TBW and FFM with an accuracy of 0.23 and 0.34 kg and a precision of ± 1.43 and ± 2.0 kg (Kushner et al., 1990). The results of this study are in agreement with that of Kushner and Schoeller (1986), suggesting that BIA can accurately assess TBW and FFM in the obese population.

When using BIA to assess body composition, an equation must be chosen to calculate FFM from the measured impedance values. BIA equations often incorporate such values as resistive index (H^2/R), weight, and height to estimate FFM. Segal et al. (1985) have shown the predictive accuracy of such equations to vary between 2.7 and 6.1% BF. In an attempt to account for the wide variability among population sub-groups, different generalized equations have been developed which include other variables such as age, gender, or physical activity level (Gray et al., 1989; Kushner and Schoeller, 1986). In addition, fatness-specific equations have been developed to perhaps account for the large variability seen when generalized equations are used for the obese population (Segal et al., 1988). The specifics of such equations will be discussed in a later section of this review.

Effect of Obesity on BIA

Many studies have suggested that BIA in general tends to overestimate FFM in obese individuals as compared to hydrostatic weighing (Carella et al, 1997; Heyward et al, 1992; Gray et al., 1989). In a study by Carella et al. (1997), body composition of obese subjects was tested during a very-low-energy-diet (VLED), comparing arm-to-leg BIA to hydrostatic weighing. They found that FFM, as predicted by BIA, was highly correlated with FFM predicted by hydrostatic weighing during each week of dieting ($r = 0.92-0.98$; $p < 0.0001$). However, there were large, although not statistically significant ($p > 0.2$), differences in the mean FFM from BIA with BIA overestimating FFM by 4.0 (± 5.4) kg (Carella et al., 1997). The discrepancy between the two methods was consistent throughout the study and was more pronounced in men with central adiposity.

Additionally, Baumgartner et al. (1989) showed the abdominal (trunk) portion of the body contributes very little to total body impedance, thus providing some explanation for the increased discrepancy seen with central adiposity. Consequently, when a greater amount of adipose tissue is located centrally, the impedance value may be lower than expected and may lead to an overestimation of the FFM. Because of the directional bias between the methods, the authors did not render these two methodologies interchangeable to assess changes in body composition of obese patients. The differences seen in this study may have been statistically significant if a larger sample size had been used (N=17).

A study conducted by Heyward et al. (1992) assessed the predictive accuracy of BIA for estimating body composition in obese and non-obese women as compared to hydrostatic weighing (HW). Results for the total (n= 148) sample show significant differences ($p < 0.001$) between %BF from HW (29.9%) and BIA (26.3%) with a SEE of 5.4% body fat. For the obese group alone, %BF from HW (36.9%) was significantly different from %BF of BIA (29.9%) ($p < 0.05$). The total error (E) was much larger for the obese group as compared to the non-obese group, reflecting a substantial underestimation of % BF by as much as 7% when the manufacturer's (Valhalla Scientific, Model 1990B) BIA equations were used. The authors suggest that the discrepancy seen in the obese group may be due to an overestimation of the FFM by BIA. This hypothesis will be discussed in a later portion of this review

A study by Gray et al (1989) assessed the ability of BIA to estimate body composition over a wide range of adiposity, 8.8- 59% BF. For the entire sample of 87

adults, the correlation between FFM from HW and H^2/R from BIA was very high, ($r = 0.94$, $SEE = 4.10$). The investigators also compared the FFM predictions of HW to that of BIA, as determined by the generalized equations developed by Segal et al. (1988). This equation included such variables as gender, resistance, height squared, weight, and age to estimate FFM from BIA. The greatest improvement over the correlation of FFM-HW with FFM as predicted by the general BIA equations was seen in the most obese quartile ($r = 0.82$ to $r = 0.95$, $p < 0.05$). These data suggest that anthropometric variables such as height squared, weight, age, and gender are important predictors of FFM in addition to the resistance value. Another important finding of Gray et al. (1989) was that in the two most obese groups ($> 42\%$ BF and $> 48\%$ BF), the impedance method overestimated FFM as compared to FFM-HW. Of these groups, the greatest overestimation was seen in those $> 48\%$ BF, where FFM was overestimated by approximately 5 kg. The investigators point to the findings of Segal et al. (1987), suggesting that possible changes in body composition of obese subjects, such as expanded fluid volume, may lead to such predictive errors when using BIA (Gray et al., 1989). However, they did not directly measure TBW and were not able to directly attribute this finding to an increase in hydration status as Segal et al. (1987) found. Data from Gray et al (1989) suggest caution be used when applying general BIA equations to very obese subjects for the estimation of body composition.

Several investigators have offered different theories for the discrepancy in estimates of FFM seen between BIA and hydrostatic weighing in obese individuals. Deurenberg (1996) attributes the large variability associated with BIA and obesity to

violations of the basic assumptions of this method. There are several factors that affect the estimation of body fat via BIA such as increased TBW, differences in body geometry, and increased extracellular water (ECW) (Segal et al., 1987, Deurenberg, 1996; Baumgartner et al., 1998). The physiological basis and assumptions of BIA will be discussed in the following sections, including how each of these violations, as seen in the obese state, affect the prediction of body fatness.

Impedance

Impedance is a measure of opposition to the flow of electrical current through the body. Impedance can be determined by introducing an alternating electrical current into the body and measuring the potential difference that occurs. Current is conducted through body fluids and electrolytes, thus the resistance of different parts of the body is indirectly proportional to the amount of electrolytes it contains. Therefore, resistance of muscle, blood, and urine is low, whereas resistance for bone and adipose tissue is high (Baumgartner et al., 1998). In contrast, cellular membranes act as capacitors to electrical current, resulting in a brief storage of voltage known as reactance (Foster and Lukaski, 1996). Hence, impedance (Z) is a function of both resistive (R) and reactive (X_c) components and is best represented by the following equation:

$$Z = \sqrt{R^2 + X_c^2}$$

Foster and Lukaski (1996) report that at frequencies used by BIA (i.e., 50kHz), the impedance of the body is primarily resistive, with little contribution of reactance (capacitance). Baumgartner et al., (1998) agree, stating that greater than 90% of the

measured impedance is composed of resistance (R). Therefore, many researchers have suggested that R be used as a predictor of FFM and TBW instead of the impedance term (Z) (Lukaski, 1996; Foster and Lukaski, 1996).

When measuring bioelectrical impedance, many basic assumptions are made about the body and its electrical properties and shape. Bioelectrical impedance is related theoretically to the volume and length squared of a conductor. It is best represented by the following equation:

$$V = \rho \left(\frac{H^2}{R} \right)$$

where ρ is the specific resistivity of an object, H is the height of an object, R is the resistance or impedance of the conductor, and V is assumed to represent volume of TBW or FFM (Houtkooper et al., 1996; Lukaski, 1996). This relation is based on the assumption that the body represents a simple geometric conductor with variable length, uniform cross-sectional area, and homogenous composition (Houtkooper et al., 1996; Lukaski, 1996). When applied to the human body these assumptions are not completely met. The cross-sectional area of the body is not constant and ρ varies between individuals depending on hydration status and fluid distribution (Houtkooper et al., 1996). However, despite these violations, H^2/R and TBW or FFM have been highly correlated in subjects of varying body composition in many studies (Kushner et al., 1992; Kushner et al., 1990; Bell, 1998; Kushner and Schoeller, 1986).

Frequency

Frequency is defined as the number of waves of current passing a given point in one second. Electrical properties of bodily tissues are largely frequency dependent. Foster and Lukaski (1996) attribute this frequency dependence to the notion that cell membranes are poor conductors but good capacitors. Therefore, at low frequencies (i.e., ~1 kHz), cell membranes are basically non-conductive allowing current to flow primarily through the extracellular space. In contrast, at higher frequencies sometimes used by BIA (i.e., 500-800 kHz), cell membranes become very good conductors, thus facilitating flow of current into both intra- and extracellular space. In terms of body composition, a low frequency is assumed to measure ECW only, whereas high frequencies are thought to measure TBW (Oldham, 1996; Lukaski, 1996; Foster and Lukaski, 1996). Typically, BIA utilizes electrical current at a frequency ≥ 10 kHz (Foster and Lukaski, 1996; Lukaski, 1996). The most common, single frequency analyzers use a frequency of 50 kHz measured at the wrist and ankle of the same side (Chumela et al., 1996, Oldham, 1996). Total body impedance is difficult to assess at a single frequency due to intra-individual differences in conductive properties of tissues (Baumgartner et al., 1989). Several investigators have suggested using multifrequency impedance to improve body composition assessment as compared to single 50 kHz impedance due to the differentiation of intra and extracellular water (Lukaski, 1996; Chumlea et al., 1996; Duerenburg and Schouten, 1992).

Volume

One of the most important assumptions of BIA is that of the relationship of impedance and volume. Theoretically, a relationship exists between the volume of a conductor and the square of the height divided by its impedance. It is difficult, however, to measure the precise volume of the human body because the relationship is based on the assumption that the body is a perfect cylinder with uniform resistivity. This assumption is not entirely true because the body varies in length, cross-sectional area, and in resistivity of body segments (Baumgartner et al., 1989). Rather, the volume of the FFM of the body is indirectly estimated based on the indirect correlation found to exist between volume and impedance, as previously stated. In addition, Kushner (1992) states that the body is not a perfect cylinder, and instead, is best represented as several cylindrical parts in a series, including the trunk and extremities.

Body Geometry

Body volume cannot be accurately assessed without the inclusion of body geometry. Several studies have been conducted looking at segmental impedance values and their effect on total-body impedance. It has been reported that impedance values of the trunk contribute to only 10-20% of the total-body impedance, although it contains approximately one-half of the conductive mass (Duerenberg, 1996). The limbs or extremities account for most of the whole-body impedance measurements even though they make up only a small portion of body volume. Foster and Lukaski (1996) report that the forearm contributes approximately 28% and the lower leg about 33% of the whole-body resistance, whereas the trunk contributes approximately 9%. Baumgartner et al.

(1989) tested the hypothesis that the arm and leg determine most of the whole-body resistance by obtaining body-segment measurements of length and resistance in men and women of varying adiposity. They found that the resistance of the whole body was primarily determined by the resistance of the arm and leg. In addition, Baumgartner et al. (1989) also found that the whole body resistance was less than the sum of the resistance for body segments by an amount equal to the resistance of the trunk. This finding suggests that in conventional arm-to-leg BIA, the trunk contributes little or none of the impedance measured. The conclusion drawn from these segmental and whole-body impedance studies is that whole-body impedance is primarily composed of resistance at the distal limbs even though they account for a small portion of total body volume. To test this theory, Foster and Lukaski (1996) developed a digitized 2-dimensional model of the body in which electrodes were placed at the wrist and contralateral ankle. By using this mathematical representation of the body, they found that small changes in geometry of the leg and arm lead to large changes in impedance, but small changes in body volume. In contrast, changes in trunk geometry had little impact on impedance measures but large effects on body volume measurements (Foster and Lukaski, 1996).

There are several hypothesized mechanisms for the discrepancy seen between whole body impedance and body segment resistance measures (Baumgartner et al., 1989; Foster and Lukaski, 1996). It has been reported by Baumgartner et al. (1989) that the primary conductor in BIA is appendicular skeletal muscle. It has been suggested that in the wrist and ankle the measurement current flows in a direction perpendicular, or transverse to, the direction of skeletal muscle fibers, results in a greater impedance

measurement (Foster and Lukaski, 1996). Therefore, it has been suggested that the arm and leg contribute most to the whole-body impedance measurements.

Other factors may influence the discrepancy seen between whole-body and segmental impedance measurements. Baumgartner et al. (1998) evaluated the effects of increased adipose tissue on impedance measured by BIA by using whole body magnetic resonance imaging (MRI) scans along with segmental and whole body impedance measurements. Data for women show a larger volume of subcutaneous adipose tissue (SAT) than of muscular tissue on the arm (57%) and leg (54%). In the abdominal region, 29% of the trunk volume was SAT and 10% was intra-abdominal adipose tissue (IAT). Thus, the volume of adipose tissue in the arm and leg region was substantially greater than that of muscular volume, allowing the effect of adipose tissue on impedance to be assessed. The results for women show that leg SAT and total SAT were associated significantly ($p < 0.05$) with whole body impedance. The leg SAT approached statistical significance ($p < 0.06$) in women when associated with segmental leg impedance. These data suggest that SAT can affect measured resistance when the volume of adipose tissue is greater than the volume of muscular tissue, as is often the case for many obese women (Baumgartner et al., 1998). To evaluate the magnitude of the effect of SAT on impedance, a regression equation was developed from whole body and segmental impedance data. The resulting impedance was approximately 5% underestimated, which resulted in an overestimation of FFM by about 10%. Again, this study demonstrates the potential effect adipose tissue has on impedance, and consequently, on the overestimation of FFM.

In obesity, the increased mass and distribution of body fat disrupts the assumed body geometry. Researchers have suggested that altered body geometry may be one of the potential reasons why BIA overestimates FFM when equations developed from lean individuals are used. Duerenberg (1996) attributes the finding of disproportionate impedance values of the trunk and limbs, to the short, large diametrical nature of the trunk. Since impedance is directly proportional to length and inversely proportional to diameter, the larger the trunk, the lower the impedance (Duerenberg, 1996). However, when Baumgartner et al., (1998) assessed the effect of volume of adipose and muscle tissue of the trunk on whole-body resistance, they found no significant influence. Why body geometry of an obese individual contributes to an overestimation of FFM measured by BIA is not clear. The literature is conflicting in this area and further studies are needed to test the theoretical reasoning for this relationship.

Body Water Distribution

A possible explanation for the overestimation of FFM seen in obese individuals was suggested by Segal et al. (1987). They found the hydration status of the FFM in obese individuals to be greater (77.5%) than their lean counterparts (72.6%). An increased hydration of the FFM would ultimately lead to an overestimation of FFM, and hence, an underestimation of %BF. Because BIA estimates TBW, the percent fat predictions of BIA may be inaccurate when this assumption is violated. In the formulas used to predict percent fat from FFM and impedance, the water fraction is assumed to represent 73.2% of the FFM (Deurenberg, 1996; Carella et al., 1997). However, it has been shown that the hydration status or fluid distribution status of obese individuals is

altered as defined by the TBW/LBM ratio (Segal et al., 1987). The literature also indicates that the increase of TBW may not be evenly distributed between the intra and extracellular fluid compartments. One study noted that the ECW volume was larger in obese women as compared to normal weight subjects (Waki et al., 1991). This expansion was magnified at higher BMI values suggesting that volume of body fat had an increasing effect. It is theorized that the increase in fluid volume leads to an overestimation of FFM and hence, an underestimation of body fat, because BIA is based on the relationship of TBW and FFM.

Population Specific Equations

The various BIA equations available may contribute to the discrepancies in the literature about the accuracy of BIA. There are many prediction equations available that convert impedance or resistance to percent body fat based on its relationship to TBW and FFM. These equations often include, but are not limited to, weight, height, gender, age, race, physical activity level, and resistive index (H^2/R). The inclusion or exclusion of certain variables depends on the specific population tested and the reference population of which the equation is based. Kushner et al. (1998) have suggested that the resistive index (H^2/R) be included to accurately predict %BF via BIA. Because of the multitude of equations published in the literature, many researchers have attempted to validate and cross-validate these equations in different populations. Segal et al. (1988) have developed fatness-specific equations to account for varying levels of adiposity and have cross-validated them in similar subject samples. They found improvements in the correlation of FFM and impedance when the fatness specific equations were applied as

compared to the manufacturer's equation (RJL Systems, Detroit, MI) ($r = 0.889$ to 0.930) (Segal et al, 1988).

Gray et al. (1989) attempted to re-assess the findings of Segal et al (1988) and to test the validity of their prediction equations across a wide range of body fatness. They tested 78 adults ranging in body fatness from 8.8-59%. The estimate of FFM from BIA, using Segal et al. (1988) fatness-specific equations, for the entire sample was highly correlated to that of HW ($r = 0.97$). However, this improvement was not substantial over the predictions of the non-specific equations ($r = 0.96$ for the entire sample). When the most obese individuals were compared to hydrostatic weighing, FFM was overestimated using the fatness-specific equations. This study suggests that the fatness-specific equations of Segal et al. (1988) inaccurately predict FFM as compared to hydrostatic weighing in subjects with high levels of adiposity ($>48\%$).

Methods of BIA

In all methods of BIA there must be a "source" and a "sink" for the electrical current. One of the most common models of BIA uses four gel electrodes to measure impedance and is termed the tetrapolar method. This arm-to-leg BIA requires placement of gel electrodes at specific anatomical locations on the ipsilateral wrist, hand, ankle, and foot (Nunez et al., 1997). The distal skin electrodes induce a small current as the proximal electrodes measure the voltage drop that occurs (Bell et al., 1998). This measure of impedance is then used to predict FFM and percent body fat as previously explained.

Recently, a derivation of the arm-to-leg BIA system has been introduced. This newer system uses a 50 kHz single-frequency foot-to-foot or leg-to-leg impedance model (Tanita Corp., Tokyo, Japan) (Utter et al., 1999; Nunez et al., 1997; Bell et al., 1998). The Tanita BIA uses four metallic foot electrodes mounted on a scale device to measure impedance of the body. The device simultaneously measures weight and impedance as the subject stands barefoot on the scale. The subject's feet make pressure-contact with the electrodes and take the place of the gel electrodes of the tetrapolar method (Nunez et al., 1997). In addition, the Tanita BIA systems use an equation to assess FFM in those of varying size, age, and training status (Utter et al., 1999). Because the conventional arm-to-leg BIA systems have reportedly overestimated FFM of obese individuals (Baumgartner et al., 1998; Gray et al., 1989; Carella et al., 1997), the incorporation of variables such as age, weight, height, gender, or physical activity level into BIA equations may have the potential to minimize such measurement error.

The foot-to-foot BIA system has many operational advantages over the more conventional BIA models. It provides rapid, non-invasive feedback regarding body composition and requires minimal cooperation or time from the subject. In addition, the need for proper gel electrode placement is eliminated. Another advantage of the leg-to-leg BIA is that it does not require special technical skill of the operator, thus allowing use in many different professions (Nunez et al., 1997; Utter et al., 1999). However, there are limited data on the validity of the leg-to-leg BIA systems due to the recent introduction into the field of body composition.

Nunez et al (1997) attempted to validate the foot-to-foot pressure contact BIA system's ability to estimate body composition versus HW. They tested male and female subjects across a wide range of body fatness (N=97, BMI=25.5 $\pm$ 4.5 kg/m² for men; N=134; BMI= 25.1 $\pm$ 0.9 kg/m² for women). The investigators found high correlations between impedance (H^2/Z) from leg-to-leg BIA and FFM from hydrostatic weighing ($r=0.89$, SEE= 5.82 kg, $p < 0.001$). This suggests that the foot-to-foot method can be effective for estimating body composition. In addition, multiple regression analyses carried out with H^2/Z and FFM from HW, revealed age, gender, and WHR as significant covariates to the model, increasing R^2 from 0.79 to 0.86 (Nunez et al., 1997). The authors suggest that age and gender-mediated effects on TBW distribution may have contributed to the improvement of the regression analyses. The increased regression model variance that occurred with the addition of WHR was small, but significant. Further research is needed to clarify the impact of body fat distribution on BIA estimates of FFM and %BF. However, this study recruited men and women of fairly average body fat levels (17.9 $\pm$ 8.7% for men and 28.6 $\pm$ 9.8% for women), which may have limited the effect of WHR. It can be concluded from this study that the leg-to-leg BIA system is comparable to hydrostatic weighing for the assessment of body composition in healthy men and women with an average BMI of approximately 25 kg/m².

Another study by Bell et al. (1998) assessed the validity of foot-to-foot BIA (Tanita MBF 305, Tanita Inc., Tokyo, Japan) for the prediction of TBW as compared to deuterium oxide dilution. Their results show an underestimation of TBW by 0.8 L when measured by the foot-to-foot method. When the mean value of the two methods was

plotted against the difference in TBW, there was a significant negative correlation ($r = -0.22$; $p < 0.01$), suggesting that at higher volumes the underestimation of TBW is increased. The data from this study can be extrapolated to the assessment of FFM and percent body fat. Because of the correlation between FFM and TBW, a progressive underestimation of TBW with increasing volume would lead to an underestimation of FFM and hence, an overestimation of percent body fat. These results are not typical of the studies conducted with the more conventional arm-to-leg BIA systems. As TBW may be increased in obesity (Segal et al., 1987; Houtkooper et al., 1996), this data suggests that a progressive underestimate of FFM would occur. Most researchers, however, have reported an overestimation of FFM in obese subjects. The conflicting data suggest the need for comparison studies of this newer foot-to-foot approach.

A recent study by Utter et al. (1999) attempted to assess the leg-to-leg BIA method for the prediction of body composition in obese ($43.2 \pm 0.6\%$ BF) and non-obese ($24.0 \pm 1.5\%$ BF) women. For the entire sample they found significant correlations between BIA and underwater weighing (UWW) for the prediction of FFM ($r = 0.78$, $p < 0.001$, SEE 3.7 kg). When the resistive index (H^2/Z) was related to FFM from UWW the correlation coefficient was lower than that found by Nunez et al. (1997) ($r = 0.54$, $p < 0.001$ vs. $r = 0.89$, $p < 0.001$) (Utter et al., 1999). Although they did not directly report TBW measurements, the FFM data do not suggest a progressive underestimation at higher volumes as did Bell et al. (1998). Utter et al. (1999) included both obese and non-obese women in which they found no significant differences in FFM by BIA as compared to UWW. This study suggests that the leg-to-leg BIA system accurately estimates FFM as

compared to UWW in both obese and non-obese women. This study also suggests that the leg-to-leg system does not overestimate FFM in obese subjects as many studies utilizing the tetrapolar BIA method have concluded (Buamgartner et al., 1998; Carella et al., 1997; Gray et al., 1989).

A more recent study attempted to measure the accuracy of another foot-to-foot BIA system (Tanita TBF 612, Tanita Inc., Arlington, IL) in men and women of varying body composition (Franckowiak et al., 2000). The Tanita estimates of FFM and FM were compared to measures obtained by dual energy x-ray absorptiometry (DEXA). The results showed that the Tanita significantly ($p < 0.001$) underestimated %BF ($25.5 \pm 9.2\%$) as compared to DEXA ($28.0 \pm 11.9\%$) for the entire sample ($N = 48$). The Tanita had the greatest difference in estimates of body fat in those classified as obese ($BMI > 30 \text{ kg/m}^2$) as compared to DEXA ($42.8 \pm 2.1\%$ vs. $49.5 \pm 2.8\%$, respectively). The results of this study do not agree with the findings of Utter et al. (1999). This may be due, in part, to the different reference models used in each study (i.e., UWW vs. DEXA). The manufacturers of the Tanita BIA systems recommend using DEXA as a criterion measure because results from their laboratories demonstrate strong correlations of body composition measures from BIA to DEXA (personal correspondence with Tanita representative). However, the results of Franckowiak et al. (2000) do not demonstrate significant agreement between BIA (Tanita TBF 612) and DEXA.

The foot-to-foot BIA system has the potential to give rapid, non-invasive measures of body composition in a wide range of clinical settings. It also has the potential to eliminate some of the technical error associated with gel electrode placement,

subject positioning, and technician skill (Nunez et al., 1997). While the foot-to-foot system has many operational advantages, the current data on validity are limited and conflicting. Data from Nunez et al (1997) have shown the between day CV's for impedance from 1.0-3.6% and within day CV's from 0.4-1.5%. However, these subjects were of normal weight with an average BMI of 25 kg/m^2 . Because of the discrepancy when using obese subjects, further studies are needed to assess the validity of this newer foot-to-foot method.

Distribution of Body Fat

Perhaps some of the discrepancy seen in the literature between foot-to-foot BIA and HW is due to body fat distribution patterns. There are currently no studies looking at the effect of central or peripheral obesity on the foot-to-foot assessment of BIA. Nunez et al. (1997) saw a small, but statistically significant increase in the regression model variance upon addition of the WHR of normal weight subjects. This study provides evidence that body fat distribution may be a factor when assessing body composition via foot-to-foot BIA. Because the electrical current is induced and measured across the extremities, body fat located in the abdominal (trunk) region may potentially be underestimated. In contrast, body fat located in the hips and thighs may be accounted for due to the nature of the foot-to-foot measurement. Whether the pattern of body fat contributes to the overestimation of FFM and consequently, to the underestimation of %BF, is still undetermined. More research is needed in this area to help rule out possible mechanisms for the underestimation of %BF via BIA of obese subjects.

Summary

Obesity continues to increase in America, contributing to significant health problems such as CVD and NIDDM (Kuczmarski et al., 1994). Several methodologies exist to assess body composition, but evidence is conflicting on the best mode for obese individuals. The studies cited in this review of literature have suggested an underestimation of %BF by the arm-to-leg BIA method in obese subjects. The newer, foot-to-foot analyzers have been introduced to alleviate technician error, degree of subject cooperation, and time for the subject. However, research is limited on the accuracy of the foot-to-foot models and data on obese subjects is not very clear. Several hypotheses have been introduced to explain such discrepancies including increased ECW, altered body geometry, and increased bone density of the obese (Duerenburg, 1996). The degree to which each of these theories affects body composition analysis via BIA is not completely understood. Therefore, more research is needed to understand the impact of body fat distribution on the assessment of body composition via BIA. If fat distribution does affect measurement error, then different methodologies or equations can be developed to obtain more accurate results. Obesity continues to be a problem in America, and measurement techniques need to be refined in order to accurately quantify the prevalence of obesity in our society.

CHAPTER 3

METHODS

Subject Screening and Selection

Forty obese, pre-menopausal women between the ages of 18 and 50 (39.67 ± 7.83 yrs), volunteered to participate in this study. Subjects were recruited through posted flyers on the University of Tennessee campus and at local health clubs, and through articles in the local newspaper. Subjects were qualified to participate if their body mass index (BMI) was $\geq 30 \text{ kg/m}^2$. Waist-hip ratio (WHR) was used to determine fat distribution patterns and to distinguish peripheral obesity (accumulation of adipose tissue on the hips and thighs with a $\text{WHR} \leq 0.75$) and central obesity (accumulation of adipose tissue on the trunk and abdomen with a $\text{WHR} \geq 0.85$). Twelve subjects exhibited peripheral obesity, while 13 subjects had central obesity. All participants read and signed an informed consent form (Appendix A) approved by the Institutional Review Board at the University of Tennessee. All subjects completed a questionnaire concerning their use of vitamins, supplements and medications (Appendix B) to screen for possible interactions with body composition measurements. Individuals using medications known to alter total body water (diuretics, corticosteroids, etc.) or who had a pacemaker device were excluded from the study. Those with diagnosed diabetes or osteoporosis were also excluded. All testing took place at the Applied Physiology Laboratory at the University of Tennessee. Each subject made one visit to the laboratory, and the testing was completed in approximately 1.5 hours. Prior to testing, subjects were asked to abstain

from food or beverages for at least 4 hours, from strenuous exercise or caffeine consumption for at least 12 hours, and from alcohol for at least 48 hours. Subjects were measured in a lycra swimsuit following emptying of their bladders.

Anthropometric Measurements

Standard anthropometric measurements (Lohman et al., 1988) were taken including body mass; standing height, and waist, hip, and umbilical circumferences. Subjects removed their shoes and standing height was measured to the nearest 0.1 cm with a wall-mounted stadiometer. After changing into a lycra swimsuit, weight was measured and reported to the nearest 0.1 kg using the Tanita digital scale (Tanita Inc., Tokyo, Japan, Model TBF 305) and a calibrated physician's scale (Health-O-Meter Inc., Bridgeview, IL). Body mass index (BMI) was then calculated as weight/height^2 (kg/m^2). Standardized circumference measures were made with the subject standing in an erect position with feet together while wearing undergarments. Circumference measurements were made with a tape measure fitted with a tension-gauge to standardize the compression of the skin. Waist measurements were taken at the narrowest part of the torso, above the umbilicus and below the xiphoid process. Hip circumference was measured at the widest portion of the hips above the gluteal fold. Umbilical circumference was measured at the level of the umbilicus. Each circumference was measured in duplicate and averaged for a final value. The values from the waist and hip circumference measures were used to calculate WHR. Subject groups were then determined by the following WHR values; ≤ 0.75 peripheral obesity and ≥ 0.85 central obesity.

Bioelectrical Impedance Analysis

BIA was performed using the Tanita TBF 305 apparatus (Tanita Inc., Tokyo, Japan). The subjects were asked to remove all accessories such as jewelry or eyeglasses. Subjects were then required to wear a lycra swimsuit and stand barefoot on the foot-to-foot impedance apparatus. The foot-to-foot BIA system utilizes two subdivided stainless steel foot pad electrodes mounted on a scale. The anterior portion of the foot pad applies the single-frequency, 50kHz current while the posterior (heel) portion measures the voltage drop or impedance. Subjects were asked to remain as still as possible while the measurements were made. The Tanita records body weight and predicts total body water, fat free mass, and fat mass based on a regression equation incorporating impedance, gender, height, weight, and activity pattern. The equation incorporated into the apparatus by the manufacturer yielded the variables of interest (i.e., fat mass, fat-free mass, and percent body fat).

Hydrostatic Weighing

Measurement of body density (D_b) was made by standard hydrostatic weighing technique utilizing a submersion tank containing a submerged electronic scale placed upon force cell transducers coupled to an integrated amplifier (Precision Biomedical Systems, Inc., University Park, PA) (Akers and Buskirk, 1969). A chart recorder continuously measured the subject's underwater mass from the electronic output of the scale system. The hydrostatic weighing scale was tared with the weight belt as the subject was submerged in the tank. The scale was checked prior to each test with a

known calibration weight of 1.98 kg. Each subject performed between 5-7 trials of maximal exhalation while submerged in the tank. Mass in water was calculated from the average of the 3 heaviest measurements within 0.1 kg. Temperature of the water was measured prior to each test and the corresponding water density value was recorded.

Body density was determined by the equation of Buskirk (1961):

$$D_b = \frac{M_a}{\frac{(M_a - M_w)}{D_w} - V_r - V_{gi}}$$

RV = Residual Volume

VGI = Gastrointestinal Volume

(constant = .1 L) (Buskirk, 1961)

Fat-free mass and percent body fat were calculated using the equation of Siri (1961):

$$\% \text{ FAT} = \left(\frac{495}{D_b} \right) - 450$$

Residual Lung Volume

Residual lung volume (RV) is defined as the volume of air left in the lungs after a maximal exhalation (Buskirk, 1961). Measurement of RV was completed prior to underwater weighing using the modified oxygen dilution procedure (Wilmore, 1969). This procedure utilized a Collins' 9-liter respirometer (Warren E. Collins, Inc., Boston, Mass) to measure RV. Continuous gas analysis was made with a Nitralyzer (KaeTech Instruments, Greenbay, WI) equipped with a digital display for visual analysis of the

output The nitrogen analyzer (KaeTech Instruments, Greenbay, WI) was calibrated according to manufacturer's instruction before each test, and the span was checked between each breathing trial (79.6%). The two-way breathing valve, tubing, and spirometer were assembled then flushed with oxygen to remove the nitrogen, as monitored by the Nitralyzer. The respirometer was filled with 7 liters of oxygen, which typically represents the upper limits of vital capacity (Wilmore, 1969).

The procedure was explained to the subject as the mouthpiece and nose clip were put comfortably into place. The subject was instructed to exhale to maximal capacity while the breathing valve was open to room air. At this point the subject turned the breathing valve to connect herself with the respirometer, and the investigator recorded the initial nitrogen value. The subject then inhaled deeply and then took several rapid deep breaths. Visual observation of nitrogen percentage allowed an equilibrium nitrogen value to be recorded by the investigator. After achieving equilibrium, the subject was instructed to maximally exhale once again. The percentage of nitrogen at this point was recorded as the final nitrogen concentration. This procedure was repeated 2-3 times to achieve two values within 100 ml as determined by the following equation:

$$RV = \left[VO_2 \left(\frac{E_{N_2} - I_{N_2}}{Ai_{N_2} - Af_{N_2}} \right) - DS \right] \times BTPS \text{ factor}$$

RV = residual volume

VO₂ = initial volume of oxygen in spirometer

E_{N₂} = nitrogen equilibrium (as percentage)

I_{N₂} = initial nitrogen in VO₂ (as percentage)

Ai_{N₂} = initial alveolar nitrogen (as percentage)

Af_{N_2} = final alveolar nitrogen (as percentage)

DS = dead space of unit

BTPS factor = from standard tables using ambient pressure and spirometer temperature

The predicted RV values were used in the equation of Buskirk (1961) to estimate D_b as previously reported.

Statistics

The data were analyzed by SPSS version 10.0 statistical software (Chicago, IL). Descriptive statistics were calculated for estimates of %BF, FFM, and FM from BIA and hydrostatic weighing. The significance level for all tests was established *a priori* at $p < 0.05$. Paired t-tests were used to compare the mean %BF, FFM, and FM predictions of BIA and UWW regardless of body shape. The correlation between the BIA and UWW results were also calculated.

In order to determine if body shape influenced the BIA results, the total sample was split into 2 distinct sub-groups based on WHR: those $\leq .75$ and those $\geq .85$. A group-by-method ANOVA was used to look at the difference between the mean of BIA and UWW predictions. Additionally, correlational analysis was performed to assess the relationship between fat distribution pattern, (i.e., WHR) and the difference in %BF predictions from both methods.

CHAPTER 4

RESULTS

The subject characteristics of 40 obese women are reported in Tables 1 and 2, respectively. The average age of the subjects was 39.7 ± 1.2 years. An average BMI of $35.3 \pm 1.1 \text{ kg/m}^2$ and %BF-HW of $46.4 \pm 1.0\%$ illustrate the obese nature of this group (Table 1, 2). The total sample was sub-divided based on WHR: lower body obesity (LBO) = ≤ 0.75 and upper body obesity (UBO) = ≥ 0.85 . The LBO group consisted of 12 subjects, and the UBO group had 13 subjects included in the analysis. The UBO and LBO groups had similar anthropometric and body composition characteristics (Table 1, 2). However, an independent t-test showed a significant difference between the UBO and LBO groups for WHR ($p < 0.0001$).

The comparison of body composition variables from HW and BIA are reported in Table 3. There was no significant difference in the %BF, FM, or FFM predictions between methods ($p > 0.05$). The mean values from HW and BIA (Tanita) for %BF, FM, and FFM were all significantly correlated ($p < 0.01$; $r = 0.55$, $r = 0.93$, and $r = 0.70$, respectively). The standard error of the estimate (SEE) for %BF was 5.6%

A 2 X 3 repeated measures ANOVA showed no influence of body shape, as defined by WHR, on the ability of BIA to estimate body composition ($p = 0.77$) (Table 4). Figures 1, 2, and 3 represent Bland-Altman plots of the difference between %BF estimated by HW and BIA versus the average %BF of each method for the total group, those with UBO, and those with LBO, respectively. The solid line represents the mean

TABLE 1 Anthropometric Characteristics of Subjects (mean $\pm$ SE)

	Number	Height (cm)	Weight (kg)	WHR	BMI (kg/m ²)
All Subjects	40	164 $\pm$ 1.0	94.8 $\pm$ 3.2	0.81 $\pm$ 0.008	35.3 $\pm$ 1.1
LBO	12	162 $\pm$ 1.6	89.1 $\pm$ 3.8	0.74 $\pm$ 0.005*	34.5 $\pm$ 1.8
UBO	13	166.4 $\pm$ 2.2	103.2 $\pm$ 6.9	0.86 $\pm$ 0.004	37.1 $\pm$ 2.2

UBO = upper body obesity (WHR $\geq$ 0.85)

LBO = lower body obesity (WHR $\leq$ 0.75)

WHR = waist-to-hip ratio

BMI = body mass index

* significantly different from UBO ($p < 0.0001$)

TABLE 2. Body Composition from Hydrostatic Weighing (mean $\pm$ SE)

	Number	%BF	FM (kg)	FFM (kg)
All Subjects	40	46.5 $\pm$ 1.0	44.9 $\pm$ 2.4	49.9 $\pm$ 1.2
LBO	12	45.6 $\pm$ 1.9	41.2 $\pm$ 3.1	47.9 $\pm$ 1.5
UBO	13	48.1 $\pm$ 2.1	50.8 $\pm$ 5.6	52.3 $\pm$ 2.3

FM = fat mass

FFM = fat free mass

%BF = percent body fat

UBO = upper body obesity (WHR $\geq$ 0.85)

LBO = lower body obesity (WHR $\leq$ 0.75)

TABLE 3 Comparison of Body Composition Variables (mean $\pm$ SE)

	% BF	FM (kg)	FFM (kg)
HW	46.5 $\pm$ 1.0	44.9 $\pm$ 2.4	49.9 $\pm$ 1.2
BIA	45.2 $\pm$ 0.65	43.5 $\pm$ 2.0	51.3 $\pm$ 1.3

HW = hydrostatic weighing

BIA = bioelectrical impedance analysis

FM = fat mass

FFM = fat free mass

%BF = percent body fat

TABLE 4. Impact of Body Shape on the Prediction of %BF (mean $\pm$ SE)

	% BF	
	HW	BIA
UBO (n= 13)	48.1 $\pm$ 2.1	46.9 $\pm$ 0.9
LBO (n = 12)	45.6 $\pm$ 1.9	45.3 $\pm$ 1.0
Others (n = 15)	45.7 $\pm$ 1.6	43.8 $\pm$ 1.3

HW = hydrostatic weighing

BIA = bioelectrical impedance analysis

%BF = percent body fat

UBO = upper body obesity (WHR $\geq$ 0.85)

LBO = lower body obesity (WHR $\leq$ 0.75)

Others = WHR between 0.75 and 0.85

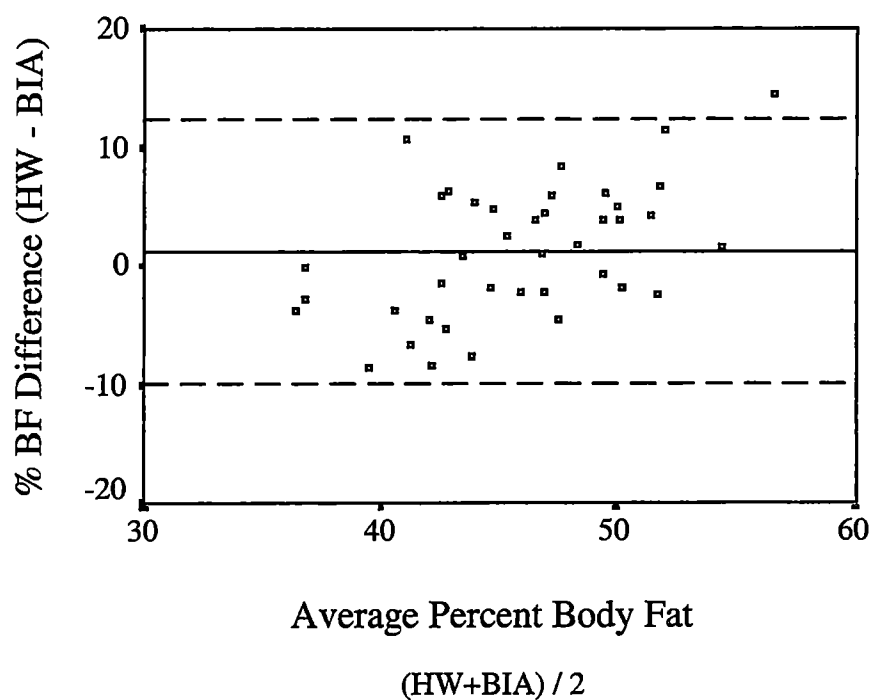


Figure 1. Comparison of percent body fat scores from hydrostatic weighing and bioelectrical impedance analysis (Data for entire sample, $n = 40$). (%BF = percent body fat, HW = hydrostatic weighing, BIA = bioelectrical impedance analysis).

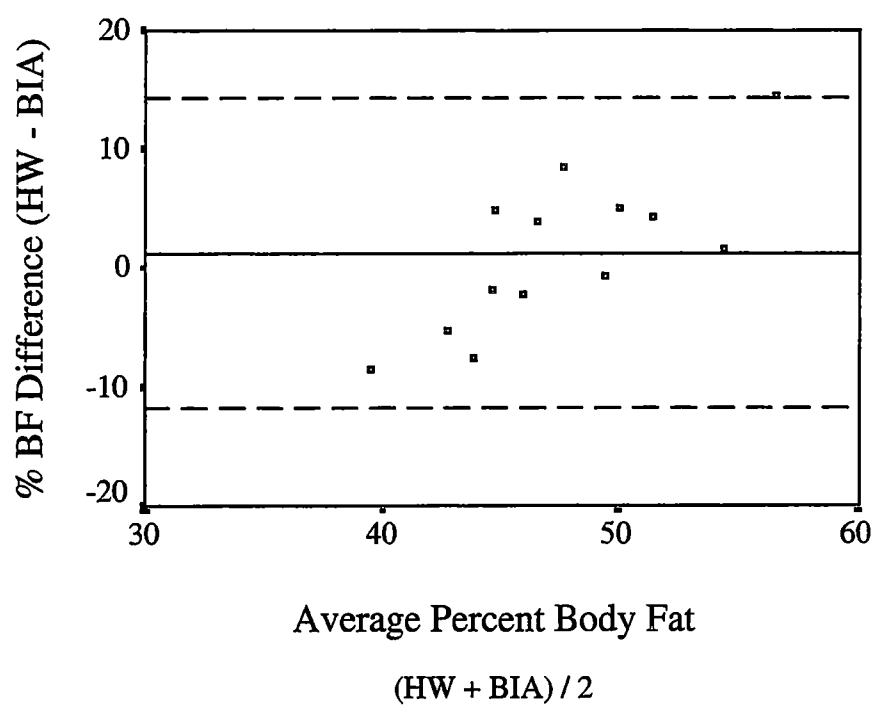


Figure 2. Comparison of percent body fat scores from hydrostatic weighing and bioelectrical impedance analysis for subjects with upper body obesity ($n = 13$) (%BF = percent body fat, HW = hydrostatic weighing, BIA = bioelectrical impedance analysis).

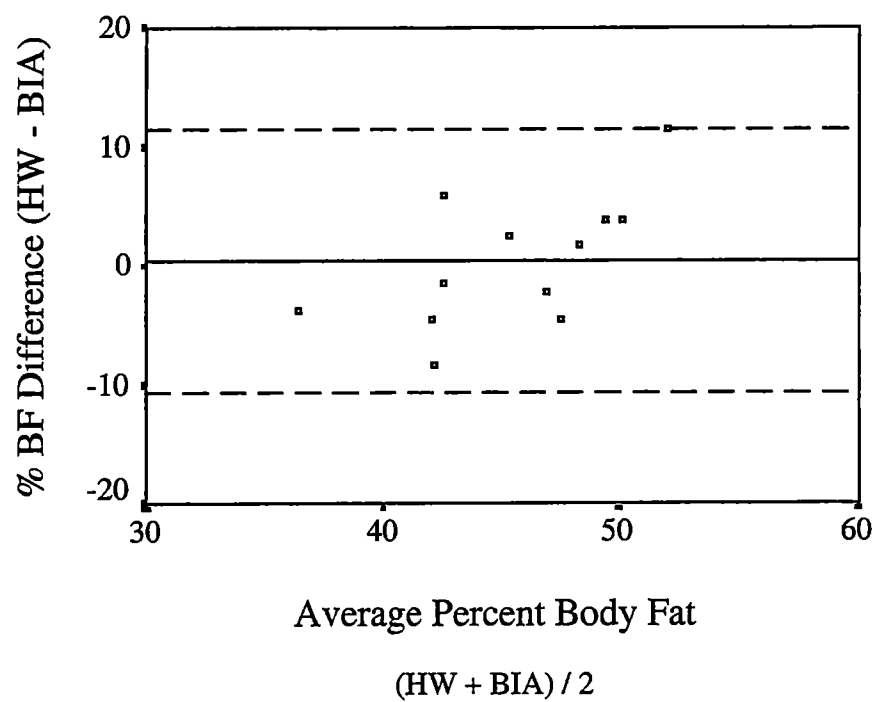


Figure 3. Comparison of percent body fat scores from hydrostatic weighing and bioelectrical impedance for subjects with lower body obesity ($n = 12$) (%BF = percent body fat, HW = hydrostatic weighing, BIA = bioelectrical impedance analysis).

difference between methods, whereas the dotted lines represent the limits of agreement (i.e., ± 2 SD). The mean difference and limits of agreement for the entire sample, the UBO group, and the LBO group were 1.22 ± 11.12 , 1.21 ± 13.08 , and $0.34 \pm 11.0\%$, respectively.

In order to further examine the influence of body fat distribution on the agreement between BIA and HW estimates of %BF, a correlational analysis was performed. The independent variable was WHR and the dependent variable was the difference between %BF from HW and BIA. This analysis revealed no significant correlation between the variables ($r = 0.031$, $p = 0.851$) (Figure 4). In an attempt to increase the chances of finding a significant correlation, an additional analysis was performed after removing those subjects with a WHR between 0.75 and 0.85. There was still no significant relationship ($r = 0.006$, $p = 0.977$) (Figure 5).

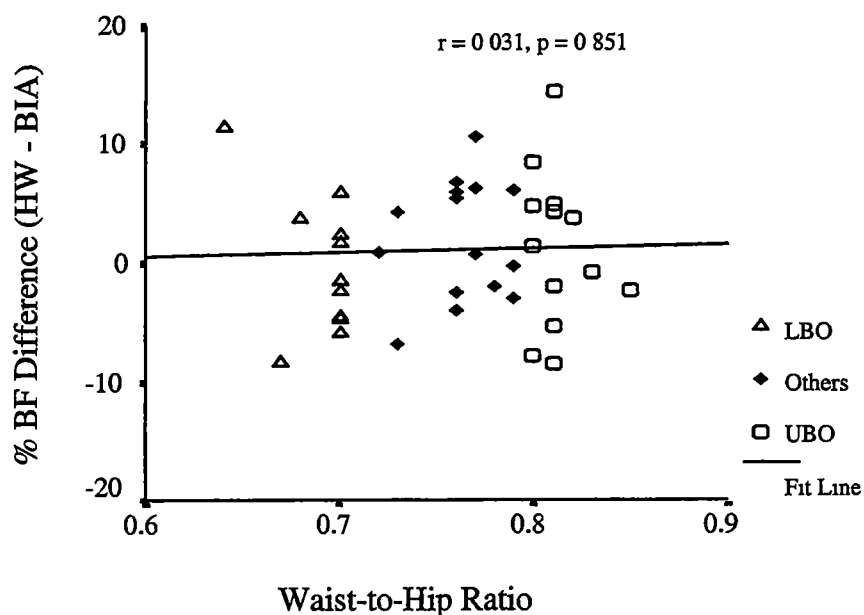


Figure 4. The relationship of waist-to-hip ratio and the difference between hydrostatic weighing and bioelectrical impedance analysis estimation of percent body fat (Data for entire sample, $n = 40$) (UBO = upper body obesity, LBO = lower body obesity, Others = waist-to-hip ratio between 0.75 and 0.85, HW = hydrostatic weighing, BIA = bioelectrical impedance analysis).

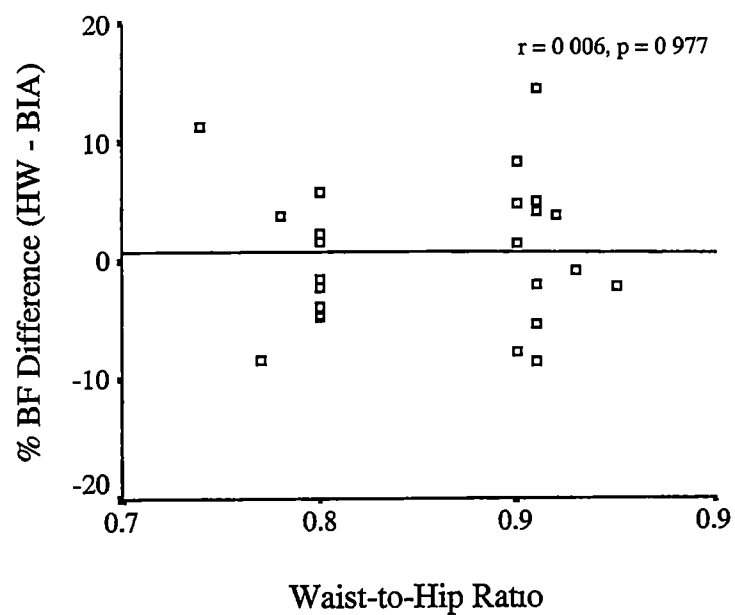


Figure 5. The relationship of waist-to-hip ratio and the difference between hydrostatic weighing and bioelectrical impedance analysis estimation of percent body fat in subjects with upper and lower body obesity ($n = 25$) (%BF = percent body fat, HW = hydrostatic weighing, BIA = bioelectrical impedance analysis).

CHAPTER 5

DISCUSSION

Obesity has become a major health concern in the United States due the increase in prevalence over the last decades (Mokdad et al., 1999; Solomon et al. 1996). This issue has gained the attention of public health officials, clinicians, and researchers in an attempt to quantify and treat this epidemic. Women of all races reportedly have a higher prevalence of obesity as compared to men (Mokdad et al, 1999; Solomon et al, 1996). It is well documented that an excess accumulation of body fatness is associated with adverse health conditions such as NIDDM, hypertension, hyperlipidemia, and CVD (AMA, 1988; NIH, 1985). Additionally, visceral fat or intra-abdominal fat is more closely linked to CVD than total adiposity (Bjorntorp, 1990). Therefore, when estimating body composition in clinical or research settings, it is important for measurement techniques to distinguish body fat distribution patterns as well as total %BF. It was the purpose of this study to assess total body fat percentage in obese females as estimated by two different techniques, the foot-to-foot Tanita BIA and the criterion method of HW. In an attempt to assess the impact of body fat distribution pattern on measurement technique, the group was sub-divided based on WHR. It was the secondary purpose of this study to assess the impact of WHR on BIA and HW estimates of body composition.

BIA and HW for the Total Sample

The primary purpose of this study was to assess the potential of the new foot-to-foot BIA for estimation of body composition in obese females. The results of this study

suggest that foot-to-foot BIA can accurately assess body composition in obese females as compared to HW. The correlation for measurement of % BF between methods was significant ($r = 0.55$, $p < 0.0001$). In addition, there were no significant differences between the %BF of the methods ($46.0 \pm 1.0\%$ HW vs. $45.2 \pm 0.7\%$ BIA; $p = 0.173$). Therefore, the primary hypothesis of this investigation was rejected; body fat percentage as estimated by BIA was not different from that of HW. The high correlation of FM and FFM of the two methods further demonstrates the ability of the foot-to-foot BIA to accurately estimate body composition ($p < 0.0001$). The results of the current study are similar to that found by Utter et al. (1999). When Utter et al. (1999) tested the foot-to-foot BIA (Tanita TBF-105) for the prediction of body composition, they found a high correlation of FFM from BIA and HW similar to that found in the current study ($r = 0.78$ and $r = 0.70$, respectively). In terms of body fatness, the subjects of Utter et al. (1997) were similar to the subjects tested in the current study ($43.2 \pm 0.6\%$ and $46.5 \pm 1.0\%$, respectively). Nunez et al. (1997) tested male and female subjects across a wide range of body fatness. They found a strong correlation between impedance from foot-to-foot BIA and FFM estimated from HW ($r = 0.89$). This suggests that the foot-to-foot method can be effective for estimating body composition. Because the introduction of the foot-to-foot method has been fairly recent, there are limited studies that examine its validity.

In contrast to the current findings, Franckowiak et al. (2000) showed a significant underestimation of %BF by foot-to-foot BIA as compared to DEXA ($25.5 \pm 9.2\%$ vs. $28.0 \pm 11.9\%$, $p < 0.001$). There were even greater differences between the two estimates of %BF in the more obese subjects (42.8 ± 2.1 vs. 49.5 ± 2.8). These data suggest that at

a higher %BF, the measurement error of the foot-to-foot BIA is increased as compared to DEXA. The results of Franckowiak et al. (2000) do not agree with the findings of the current study or of Utter et al. (1999). The %BF of the most obese group in the study by Franckowiak et al. (2000) was similar to the %BF of the subjects from Utter et al. (1999) and in the current study; thus, eliminating percent body fat as a possible source of error when comparing studies. Perhaps the discrepancy between the studies using foot-to-foot BIA can be attributed to the different reference models chosen for comparison. The use of DEXA as a criterion model has been suggested by the Tanita Corporation (personal correspondence with Tanita representative). However, the data supporting the use of DEXA as a criterion method for body composition analysis are inconclusive (Kohrt, 1995). It is important to point out that the model of the Tanita BIA analyzer varied between studies. In the current study the Tanita TBF 305 was used, whereas Utter et al. (1997) used the TBF 105 and Franckowiak et al. (2000) took measurements with the TBF 612 model. Although each model uses the same foot-to-foot approach, there may be variation in estimation of %BF between systems.

Studies from the tetrapolar method of BIA must also be considered. The more conventional arm-to-leg BIA analyzers have reportedly overestimated FFM, and consequently underestimated %BF in obese individuals when generalized equations were applied (Heyward et al., 1992; Gray et al., 1989). Several researchers attribute these findings to the particular equation selected for use in BIA (Heyward et al., 1992; Stolarczyk et al., 1997). Heyward et al. (1992) report that arm-to-leg BIA significantly ($p < 0.001$) underestimates %BF as compared to HW when the equations provided by the

manufacturer (Valhalla Scientific, Model 1990B) are applied to obese women. Other researchers report similar underestimation of %BF by the arm-to-leg BIA systems (Gray et al., 1989; Carella et al., 1997). Due to the variability in body composition estimates, fatness-specific equations have been developed in an attempt to more accurately assess body composition in the obese (Segal et al., 1988; Gray et al., 1989). While the research from arm-to-leg BIA studies clearly indicate the systematic overestimation of FFM in obese individuals, the results from the current foot-to-foot study and that from Utter et al. (1997) contradict these results. In fact, the data on FFM from BIA and HW are highly correlated ($r = 0.70$, $p < 0.0001$) in the present study of obese females. The reason for this difference between BIA methods is not clear.

Effect of WHR on Estimation of Body Composition

The secondary purpose of this study was to assess the influence of body geometry (i.e., WHR) on the ability of the Tanita TBF-305 to estimate body composition. The results of the current study show that WHR did not significantly influence the prediction of body composition measures as determined by foot-to-foot BIA. Correlational analysis revealed no significant association of WHR on the agreement between BIA and HW estimates of %BF for the total sample (Figure 4). These data ($n = 40$) show that regardless of body geometry, the Tanita foot-to-foot BIA estimates %BF similar to HW. Figure 5 demonstrates the results for the UBO and LBO groups separately. The relationship remained non-significant upon removal of the middle group ($r = 0.006$, $p = 0.977$).

The findings of this study are important to the field of body composition. Because of the relative ease with which foot-to-foot BIA can be administered, it can be used in many different settings. As a clinical tool, BIA can be used to determine obesity and hence, one's risk of developing comorbidities associated with obesity. The current findings are important because they support the use of this device regardless of body fat distribution pattern. It may also be beneficial for weight loss studies or clinical assessment of weight loss due to the ease of administration and low-cost of the system. Utter et al. (1999) also showed the foot-to-foot BIA has the ability to accurately track moderate changes in %BF in obese females. Further research is needed to determine the accuracy of foot-to-foot BIA during significant weight loss.

Although the current study did not find a significant influence of WHR on the estimation of %BF (Table 3), Nunez et al. (1997) reported an improvement in the ability to predict FFM from foot-to-foot BIA when WHR was included in the regression model ($R^2 = 0.79$ to 0.86). The results of their regression analysis point to the possible association of body fat distribution and impedance. It is plausible that the distribution of adipose mass has an influence on the impedance measured by BIA. Baumgartner et al. (1998) demonstrated that SAT on the leg and arm of obese females can affect the measured resistance when the volume of SAT exceeds that of muscular volume. Baumgartner et al. (1998) also demonstrated that the majority of resistance measured in BIA is due to impedance of the extremities, whereas the trunk contributes very little. Therefore, one would expect that in UBO, when a greater proportion of adipose mass is located in the trunk, the impedance value would be lower than expected because the trunk

contribution is minimal. In contrast, in LBO it is plausible that the adipose mass of the extremities would greatly affect impedance, as suggested by the findings of Baumgartner et al. (1998). However, Baumgartner et al. (1998) used arm-to-leg impedance analysis and it is unknown if similar results are seen from the foot-to-foot BIA system. The current data suggest a discrepancy between methods. Nevertheless, there is evidence that a relationship may exist (Nunez et al., 1997) and additional studies examining this issue are needed.

In conclusion, although some researchers have found BIA techniques to be inaccurate for obese individuals, the Tanita TBF-305 appears to accurately estimate %BF in obese females. Although the equation used by this device is protected, it appears that the use of gender, height, weight, and training status in combination with the measured impedance leads to accurate body composition estimates. Additionally, deviations in body geometry (i.e., upper body and lower body obesity) have no significant influence on the ability of the Tanita TBF-305 to estimate %BF. The results of this study suggest that this device is an accurate tool for assessing body composition in obese women, regardless of fat distribution pattern.

REFERENCES

REFERENCES

- ACSM. *ACSM's Guidelines for Exercise Testing and Prescription*, 5th ed. Baltimore, MD: Williams & Wilkins, 1995; 49-63.
- Akers R, Buskirk ER. An underwater weighing system utilizing "force cube" transducers. *J Appl Physiol*. 1969; 26 (5): 649-52.
- Baumgartner RN, Chumlea WC, Roche AF. Estimation of body composition from bioelectric impedance of body segments. *Am J Clin Nutr*. 1989; 50: 221-6
- Baumgartner RN, Ross R, Heymsfield SB. Does adipose tissue influence bioelectrical impedance in obese men and women? *J Appl Physiol*. 1998; 84 (1). 257-62.
- Becque D, Katch V, Rocchini A, Marks C, Moorehead C. Coronary risk incidence of obese adolescents: Reduction by exercise plus diet intervention. *Pediatrics*. 1998; 81: 605-12.
- Bell NA, McClure PD, Hill RJ, Davies PSW. Assessment of foot-to-foot bioelectrical impedance analysis for the prediction of total body water. *Eur J Clin Nutr*. 1998; 52: 856-59.
- Benke AR, Wilmore JH. *Evaluation and Regulation of Body Build and Composition* Englewood Cliffs, NJ: Prentice Hall, 1974; 21-7.
- Bjorntorp P. "Portal" adipose tissue as a generator of risk factors for cardiovascular disease and diabetes. *Atherosclerosis*. 1990; 81. 493-6.
- Brozek, J, Grande F, Anderson JT, Keys A. Densitometry analysis of body composition: revision of some quantitative assumptions. *Ann N Y Acad Sci*. 1963, 110: 113-40.
- Carella MJ, Rodger CD, Anderson D, Gossain VV. Serial measurements of body composition in obese subjects during a very-low-energy diet comparing bioelectrical impedance with hydrodensitometry. *Obes Res*. 1997; 5: 250-6.
- Chumlea WC, Guo SS, Cockram DB, Siervogel M. Mechanical and physiologic modifiers and bioelectrical impedance spectrum determinants of body composition. *Am J Clin Nutr*. 1996; 64 (suppl): 413-22.
- Duerenberg, P. Limitations of the bioelectrical impedance method for the assessment of body fat in severe obesity. *Am J Clin Nutr*. 1996; 64 (suppl). 449S-52S.

Deurenberg P, Weststrate JA, Paymans I, Van der Kooy K. Factors affecting bioelectrical impedance measurements in humans. *Eur J Clin Nutr.* 1988; 42: 1017-22.

Deurenberg P, Van der Kooy K, Hautvast JG. In obese subjects the body fat percentage calculated with Siri's formula is an overestimation. *Eur J Clin Nutr.* 1989; 43: 569-75.

Deurenberg P, Schouten FJM. Loss of total body water and extracellular water assessed by multifrequency impedance. *Eur J Clin Nutr.* 1992; 46: 247-55.

Eckel RH, Krauss RM. American Heart Association call to action: Obesity as a major risk factor for coronary heart disease. *Circulation.* 1998; 97: 2099-2100.

Foster KR, Lukaski HC. Whole-body impedance- What does it measure? *Am J Clin Nutr.* 1996; 64 (suppl): 388S-96S.

Franckowiak SC, Cotton RT, Ritter M, Walston JD, Beamer BA, Fritsch LL, Anderson RE. Accuracy of a low-cost, commercially available Tanita™ bioelectrical impedance analyzer to estimate body composition. *Med Sci Sports Exerc.* 2000; 32 (5-suppl): 113S.

Goldman D, Buskirk ER. A method for underwater weighing and the determination of body density. In: Brozek J, Henschel A, eds. *Techniques for Measuring Body Composition.* Washington, DC: National Academy of Sciences, 1961: 78-106.

Gray DS, Bray GA, Gemayel N, Kaplan K. Effect of obesity on bioelectrical impedance. *Am J Clin Nutr.* 1989; 50: 255-60.

Grubbs, L. The critical role of exercise in weight control. *Nurse Practitioner.* 1993; 18 (4): 20-9.

Heyward, V. Evaluation of body composition. *Sports Med.* 1996; 22(3): 146-55.

Houtkooper LB, Lohman TG, Going SB, Howell WH. Why bioelectrical impedance analysis should be used for estimating adiposity. *Am J Clin Nutr.* 1996; 64 (suppl): 436S-48S.

Keller C, Stephens K. Assessment, etiology, and intervention of obesity in children. *Nurse Practitioner* 1996, 21: 31-42.

Kohrt, WM. Body composition by DXA: Tried and true? *Med Sci Sports Exerc.* 1995; 27: 1349-53.

Kuczmarski RJ, Flegal KM, Campbell SM, Johnson CL. Increasing prevalence of overweight among US adults: the National Health and Nutrition Examination Surveys, 1960-1991, *JAMA* 1994; 272: 205-11.

Kushner RF. Bioelectrical impedance analysis: A review of principles and applications. *J Am Coll Nutr.* 1992; 11: 199-209.

Kushner RF, Kunigk A, Alspaugh M, Andronis PT, Leitch CA, Schoeller DA. Validation of bioelectrical-impedance analysis as a measurement of change in body composition in obesity. *Am J Clin Nutr.* 1990; 52: 219-23.

Kushner RF, Schoeller DA, Fjeld CR, Danford L. Is the impedance index (ht^2/R) significant in predicting total body water? *Am J Clin Nutr.* 1992; 56: 835-9.

Kushner RF, Schoeller DA. Estimation of total body water by bioelectrical impedance analysis. *Am J Clin Nutr.* 1986; 44: 417-24.

Lohman T, Roche A, Martorell R. *Anthropometric Standardization Reference Manual.* Champaign, IL: Human Kinetics, 1988; 39-54.

Mokdad AH, Serdula MK, Dietz WH, Bowman BA, Marks JS, Koplan JP. The spread of the obesity epidemic in the United States, 1991-1998. *JAMA.* 1999; 282: 1519-22.

National Institutes of Health. Health implications of obesity: National Institutes of Health consensus development statement. *Ann Intern Med.* 1985;103;1073-7.

Nunez C, Dymyna F, Marjolein V, Pi-Sunyer FX, Wang Z, Heymsfield SB. Bioimpedance analysis: evaluation of leg-to-leg system based on pressure contact foot-pad electrodes. *Med Sci Sports Exerc.* 1997; 29 (4): 524-31.

Revis DA, Israel RG. Relationship between body mass indexes and measures of adiposity. *Am J Public Health.* 1986; 76: 992-4.

Roubenoff, R. Applications of bioelectrical impedance analysis for body composition to epidemiological studies. *Am J Clin Nutr.* 1996; 64 (suppl): 459S-62S.

Schutte JE, Townsend EJ, Hugg J, Shoup RF, Malina RM, Blomqvist CG. Density of lean body mass is greater in blacks than in whites. *J Appl Physiol.* 1984; 56: 1647-9.

Segal KR, Wang I, Gutin B, Pierson RN, Van Itallie TB. Hydration and potassium content of lean body mass: effects of body fat, sex, and age. *Am J Clin Nutr.* 1987; 45: 865

Segal KR, Van Loan M, Fitzgerald PI, Hodgdon JA, Van Itallie TB. Lean body mass estimation by bioelectrical impedance analysis: a four-site cross-validation study. *Am J Clin Nutr.* 1988; 47: 7-14.

Siri, WE. Body composition from fluid space and density: Analysis of methods. In: Brozek J, Henschel A, eds. *Techniques for Measuring Body Composition*. Washington, DC: National Academy of Sciences, 1961: 223-44.

Solomon CG, Mansen JE. Obesity and mortality: a review of the epidemiologic data. *Am J Clin Nutr.* 1997; 66 (suppl): 1044S-50S.

Stolarczyk, LM, Heyward V, Van Loan MD, Hicks VL, Wilson WL, Reano LM. The fatness-specific bioelectrical impedance analysis equations of Segal et al: are they generalizable and practical? *Am J Clin Nutr.* 1997; 66: 8-17.

Utter AC, Nieman DC, Ward AN, Butterworth DE. Use of leg-to-leg bioelectrical impedance method in assessing body-composition change in obese women. *Am J Clin Nutr.* 1999; 69: 603-7.

Van Itallie TB. Topography of body fat: Relationship to risk of cardiovascular and other diseases. In: Lohman TG, Roche AF, Martorell R, eds. *Anthropometric Standardization Reference Manual*. Champaign, IL: Human Kinetics Books, 1988; 143-9.

Waki M, Kral JG, Mazariegos M, Wang J, Pierson RN, Heymsfield SB. Relative expansion of extra cellular water in obese versus non-obese women. *Am J Physiol Endocrinol Metab.* 1991; 261: E199-203.

Williams C, Bale P. Bias and limits of agreement between hydrodensitometry, bioelectrical impedance and skinfold calipers measures of percentage body fat. *J Appl Physiol.* 1998; 77: 271-7.

Wilmore J. A simplified method for determination of residual lung volumes. *J Appl Physiol.* 1969; 27: 96-100.

APPENDICES

APPENDIX A
INFORMED CONSENT

INFORMED CONSENT

TITLE OF STUDY: Comparison of body fat measurement techniques in females.

PURPOSE

You are invited to participate in a research study, the purpose of which is to compare different methods of determining body fat percentage. This form explains the procedures, risks and benefits of participation. If you have any questions about the information found in this form, please ask a member of the research team before signing.

PROCEDURES

You will attend 1 testing session in the Applied Physiology Laboratory in the Health, Physical Education, and Recreation (HPER) Building on the University of Tennessee campus. This session will last approximately 1.5 hours. For 4 hours prior to this session, we ask that you do not eat or drink anything other than water. Also, we ask that you not participate in exercise for 12 hours prior to this visit and avoid all alcohol consumption for 48 hours before this test. During the session, several different measurements will be made: (1) body fat measurement using underwater weighing; (2) body fat measurement using electrical currents in your body (bioelectrical impedance); (3) measurements such as your height, weight, and waist and hip circumference (anthropometric measurements); (4) survey information regarding medications, nutritional supplements, and dietary habits, and (6) body size using the Bod Pod. Each of these procedures is explained below.

Underwater Weighing

To perform this procedure, you will need to wear a lycra swimsuit or your undergarments. Prior to this, your lung size will be measured as you breathe into a spirometer (a machine that measures volumes of air). During this procedure you will inhale a small amount (less than 6 liters) of pure oxygen while performing a series of breathing maneuvers. 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 dunk your head underwater for a few seconds. This test will be repeated 5-10 times.

Bioelectrical Impedance (Electrical Currents)

For this test you will stand on a set of scales that estimates your body fatness through the movement of electrical currents in your body. This test is harmless and takes about 30 seconds. The Bodystat tetrapolar method requires that you rest on your back for approximately 5-10 minutes while 4 electrodes are placed on your ankle, foot, hand, and wrist. The electrodes will measure the electrical current in your body which will allow calculation of your body fatness.

Whole Body Plethysmography (Bod Pod)

You will be asked to perform the Bod Pod while wearing a lycra swimsuit. The Bod Pod measures body volume as you sit for approximately 3 minutes in a sealed chamber. While in the chamber, you will be able to breathe normally and see your surroundings. This information will provide another means for determining body fatness.

Anthropometric Measurements

These tests include: measurements of height, weight, and the distance around your hips and waist. These measurements will provide valuable information about your body fatness.

Survey Information

For our study we will ask that you provide information about current medications, nutritional supplements, and dietary habits.

POTENTIAL RISKS OF PARTICIPATION

There are no known risks to underwater weighing, bioelectrical impedance, or the Bod Pod. To ensure your comfort, these procedures will be performed in private with only female members of the research team present.

BENEFITS OF PARTICIPATION

From the results of your tests, you will be told your body fat percentage. This value has important health implications. We will also provide valuable interpretive information regarding healthy body composition ranges.

RIGHT TO ASK QUESTIONS AND/OR WITHDRAW FROM THIS INVESTIGATION

If you have any questions or concerns at any time during the time course of this investigation or after you complete this study, you may contact Colleen McMahon, (room 144 HPER; 974-8768) or Dixie L. Thompson (room 347 HPER; 974-8883).

As a volunteer in this study, it is your right to withdraw from this investigation at any time. If you decide to withdraw, you will in no way be penalized.

CONFIDENTIALITY

Only you and members of the research team will have access to your results. All data will be coded by a subject number rather than by name and will be kept in a locked file cabinet in Dr. Thompson's office. The results of the study will be published; however, no publication will contain information to allow you to be identified.

AUTHORIZATION

By signing this form, I am indicating that I have read this form, understand its contents, and have received a copy of this form for my files. I have also been given the opportunity to ask questions to clarify my role in the study. My signature indicates that I agree to serve as a subject in this research study.

Participant's Signature _____ Date _____

Investigator's Signature _____ Date _____

APPENDIX B
SURVEY

SURVEY

SUBJECT NUMBER _____

This information is confidential and will only be used by the researchers involved in this investigation. Please answer each of the following questions to the best of your knowledge. If you have any questions or need clarification, please ask a member of the researcher team. Thank you for your time.

MEDICATIONS AND NUTRITIONAL SUPPLEMENTS

Are you currently taking any medications? If so, please list and describe both prescription and non-prescription medications

Are you currently taking any nutritional supplements including vitamins? If yes, please list and describe.

DIET AND EXERCISE

Are you currently on a physician prescribed diet? If yes, please describe in detail.

Have you consumed any alcoholic beverages in the last 48 hours? Have you consumed caffeine in the last 12 hours?

Have you exercised in the last 12 hours?

Have you consumed food or drink in the last 4 hours?

VITA

Colleen Grace McMahon was born in Crossville, TN on October 5, 1976. She attended middle school in both Crossville, TN and Staten Island, NY. She graduated with honors from Cumberland County High School in June, 1994. It was during high school that she developed a love for sports and exercise, and she was voted "most athletic" by her classmates. She attended the University of Tennessee, Knoxville, where she obtained her Bachelor's degree in Biology in August, 1998. As an undergraduate she was given the opportunity to complete a research project in the Exercise Science Department under the supervision of Dr. Ed Howley and Dr. David Bassett. It was during this time that she developed an interest in the field of Exercise Physiology. In August, 1998 she entered graduate school at the University of Tennessee, Knoxville in the department of Exercise Science and Sports Management.

During her curriculum studies in Knoxville, Colleen worked as a graduate teaching assistant for the Physical Education Activities Program. She was twice awarded the Albert Hobt Memorial Scholarship for Excellence in Teaching (1999, 2000). In the Spring of 2000, Colleen was awarded the Chancellor's Citation for Extraordinary Professional Promise and the Exercise Science Student of the Year Award. She will graduate summa cum laude receiving a Master of Science degree with an emphasis in Exercise Physiology in August, 2000.