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Comparison of Body Composition Assessment Techniques in Older Adults

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To the Graduate Council:

I am submitting herewith a thesis written by Rebekah Ann Wilson entitled "Comparison of Body Composition Assessment Techniques in Older Adults." I have examined the final electronic 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 Exercise Science.

Dixie Lee Thompson, Major Professor

We have read this thesis and recommend its acceptance:

Edward T. Howley, David R. Bassett, Jr.

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Comparison of Body Composition Assessment Techniques in Older Adults

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Rebekah Ann Wilson

August 2005

DEDICATION

This thesis is dedicated to my dearest friends, my family. To Mom and Dad, thank you for raising me to be the person I am today. I would never have gone this far without your love and encouragement. To my husband and best friend, Corey, thank you for helping me have the opportunity to pursue my ambitions. Your constant support and encouragement keep me strong. I love you all.

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The author would like to express her thanks and appreciation to several people who helped this project.

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To my husband, Corey, thank you for believing in me from the very first day. Your motivation and drive in life inspire me.

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ABSTRACT

Body composition is an important measurement for health assessments in older adults. The purpose of this study was to evaluate percent body fat (%BF) estimations in older adults by the Tanita, a two-compartment model (Siri 2-C) and dual energy x-ray absorptiometry (DXA) compared to a three-compartment model (Lohman 3-C). Fifty-two females and fifty men between the ages of 54 and 75y volunteered for the study. The estimate of % BF from the Tanita was measured using the 'adult' mode. The Bod Pod was used to determine body density (D_b) for the 2-C and 3-C. DXA was used to obtain an estimate of %BF, and determine BMC for use in the 3-C. Compared to the 3-C estimate of %BF (26.1 ± 1.0%), %BF in males was significantly underestimated by Tanita (22.1 ± 0.8%), and overestimated by 2-C (27.6 ± 0.9%) and DXA (28.6 ± 0.9%) ($P < 0.001$). The bias and limits of agreement for all methods in males were: Tanita, -3.93 ± 10.3; 2-C, 1.53 ± 3.38; DXA, 2.51 ± 6.36. Compared to the 3-C estimate of %BF (39.2 %), %BF in females was significantly underestimated by Tanita (36.4 ± 1.2%; $P < 0.001$) and overestimated by DXA (40.5 ± 1.2%; $P = 0.013$). There was no significant difference in females between the 3-C and 2-C estimates of %BF (39.2 ± 1.2% vs. 39.3 ± 1.2%, respectively, $P > 0.05$). The bias and limits of agreement for all methods in females were: Tanita, -2.85 ± 8.66; 2-C, 0.05 ± 3.24; DXA 1.27 ± 5.64. This study suggests that the techniques used in this investigation are not interchangeable when estimating %BF in older adults.

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ABBREVIATIONS

Abbreviations

Behavioral Risk Factor Surveillance System (BRFSS)

National Health and Nutrition Examination Survey (NHANES)

Four-compartment (4-C)

Three-compartment (3 C)

Two-compartment (2 C)

Fat mass (FM)

Fat-free mass (FFM)

Body fat percentage (%BF)

Total body density (D_b)

Bioelectrical impedance analysis (BIA)

Body Mass Index (BMI)

Dual Energy X-ray Absorptiometry (DXA)

Under Water Weighing (UWW)

Air Displacement Plethysmography (Bod Pod)

CHAPTER 1

INTRODUCTION

Obesity is currently considered one of the major preventable causes of morbidity and mortality (U.S. Department of Health and Human Services, 2000). In the U.S., obesity is a significant predictor of poor physical health and may be as great of a risk for morbidity as poverty, smoking or problem drinking (Sturm & Wells, 2001). The 1999-2002 National Health and Nutrition Examination Survey (NHANES) showed that 65% of U.S. adults were overweight or obese (Flegal *et al.*, 2002). Not only does obesity affect an individual's well-being and health, but it affects the cost of healthcare. Obesity-related medical spending was as high as $75 billion in 2003, with Medicare and Medicaid paying for half of this cost (Finkelstein *et al*, 2004) . Fittingly, one of the National Health Objectives, from the U.S. Department of Health and Human Services, for the year 2010 is to decrease the prevalence of obesity among U.S. adults to less than 15% (U.S. Department of Health and Human Services, 2000).

An accurate estimation of body composition is an important fitness component when assessing an individual's health status. There are many undesirable health outcomes from being overweight or obese. These include, but are not limited to, type 2 diabetes, stroke, hyperinsulinemia, hypertension, and coronary heart disease (National Institutes of Health, 1998; Mokdad *et al.*, 2003). Health professionals need an accurate assessment to classify individuals for a proper intervention or health education. In a review done by Poirier and Despres (Poirier & Despres, 2001), overweight and obese individuals who lost weight by exercising improved risk factors for diabetes and heart disease. These risk factors included lowering blood pressure, lowering triglyceride levels and increasing high-density lipoprotein cholesterol levels. Because positive health outcomes may result from weight loss, it is important that practitioners accurately assess and help clients define goals for weight loss.

The common methods used to analyze body composition involve a two-compartment (2-C) model. A frequently used 2-C model, the Siri 2-C model, assumes that the body's compartments, fat-free mass (FFM) and fat mass (FM), have a constant density of 1.1 $kg{\cdot}L^{-1}$ and 0.9 $kg{\cdot}L^{-1}$, respectively (Siri, 1961).

Body fat percentage (%BF) can be estimated using these assumptions if total body density is known:

$$\%BF_{Siri\ 2\text{-}C} = [(4.95/D_b) - 4.50]100$$

% BF = body fat percentage
D_b = total body density

Methods that use this modelinclude hydrostatic weighing, which uses water displacement, and whole body plethysmography (Bod Pod, Life Measurement Instruments, Concord, CA), which involves air displacement.

Another approach to body composition assessment is Lohman's three-compartment (3-C) model. This has an advantage over a 2-C model because it adjusts for differences in bone mass (Lohman, 1986). Bone mass is a component of FFM and as bone mass changes, the percentage of the body that is mineral changes, and likewise FFM density changes. In a 2-C model, the density of bone is assumed to be a constant. Lohman's 3-C model requires the measurement of bone mineral content (BMC), in addition to D_b. BMC is used to estimate total body mineral which is then expressed as a fraction of body weight (Lohman, 1992).

$$\%BF_{Lohman\ 3\text{-}C} = [(6.386/ D_b) + 3.961m - 6.090]\ 100$$

m = mineral as a fraction of body weight

Because FFM density is not constant across populations, a standard 2-C model does not accurately estimate %BF in all individuals. For example, in older individuals with reduced bone mass, the Siri equation will overestimate %BF.

A technique used for bone mineral assessment is dual energy X-ray absorptiometry (DXA). It provides an estimate of bone mineral mass (g), bone mineral content (g) (BMC), and bone mineral area density ($g \cdot cm^{-2}$) (BMD) (Lohman & Chen, 2005). DXA uses low-dosage energy beams to identify fat, bone, and non-bone lean tissue. Prior to the development of DXA, DPA (dual-photon absorptiometry) was used to estimate BMD for the lumbar vertebrae and sections of the femur (Lohman & Chen, 2005). However, restrictions of DPA led to the development of a new, more precise technique, DXA. DXA uses a full body scan in estimating soft tissue composition, with correction for regional differences in fat content, and gives a better estimate of BMD and soft tissue composition. Mazess et al. (Mazess *et al.*, 1990) conducted full body scans with DXA (Lunar DPX) on 12 young adults (6 males, 6 females) to assess total-body and regional bone mineral and soft-tissue composition. Measurements were done on one skeleton 34 times with one scanner, and then additional measurements done with another skeleton on 37 different DXA-DPX scanners. There was a low precision error (< 0.01 $g \cdot cm^{-2}$) for both comparisons for total body BMD.

To utilize the Siri 2-C model or the Lohman 3-C model, D_b must be assessed. One technique used to determine D_b is the Bod Pod. The Bod Pod System includes the Bod Pod plethysmograph, electronic weighing scale, calibration weights and cylinder, computer, and software. Because density equals mass divided by volume $(D=M/V)$, the Bod Pod system uses the scale to determine body mass, and the dual chamber plethysmograph to determine body volume. The Bod Pod calculates body volume with an air displacement method (McCrory *et al.*, 1995). The dual chamber compartment has a front (test) chamber of ≈ 450L, and rear (reference) chamber of ≈ 300L (Fields *et al*, 2002), which are separated by a common wall. In this wall is a diaphragm, that when precisely oscillated, creates sinusoidal volume changes of the same magnitude in both chambers (Dempster & Aitkens, 1995). When a person is in the front chamber, the volume of that chamber will be reduced by the volume of the person's body, V_b. Therefore:

$$V_b = \text{Chamber Volume}_{\text{empty}} - \text{Chamber Volume}_{\text{person inside}}$$

A technique of body composition assessment that does not rely on the measurement of body volume is bioelectrical impedance (BIA). BIA is a popular method used to estimate %BF due to its ease of use. It is based on the premise that muscle, which is assumed to be 73.8% water, conducts a current better than fat, which contains little water (Kushner, 1992). An alternating current is sent through the body from one contact point to another. The conventional method of BIA uses a tetrapolar arrangement of electrodes with one electrode placed on the following body parts: wrist, hand, ankle and foot. This is referred to as a whole body BIA or hand-to-foot BIA. The impedance, or resistance to current flow, is then used to predict total body water (TBW), FFM, FM and %BF (Foster KR, 1996). There are a wide variety of BIA equations that are population specific for gender, age, and race. When using traditional BIA, it is best to use an equation that was derived from a population with similar characteristics as the individual or group being tested. A separate equation for older adults may be necessary due to changes that occur with age including: a decrease in FFM, increase in FM, and a change in ratio of intra to extra cellular water. There are equations that have been developed specifically for older adults byRoubenoff (Roubenoff *et al*, 1997) , Deurenberg (Deurenberg *et al.*, 1990) and Baumgartner (Baumgartner *et al.*, 1991) while others have developed equations that use age as a variable in the equation (Deurenberg *et al.*, 1991).

An instrument using foot-to-foot BIA was introduced by Tanita Incorporated (Tanita, Inc, Tokyo, Japan). It is used to measure the same variables as hand-to-foot BIA, but uses a foot-to-foot method. Rather than an alternating current going from the hand-to-foot as in the tetrapolar method, the current goes from foot-to-foot. The Tanita TBF-305 resembles a scale with two stainless steel foot-pad electrodes used to send the current through the body and measure the impedance of the current. Body fatness is then estimated by a regression equation. Its accuracy has been studied in the general population (Jebb *et al*, 2000; Dittmar, 2004) as well as in specific populations such as young men (Swartz *et al*, 2002) , middle-aged men (Cable *et al*, 2001) , obese women (Hainer *et al.*, 1995), and children (Sung *et al*, 2001; Goss *et al*, 2003) . The TBF-305 uses age strictly as a categorical variable in which one is classified as either a child (ages 7-17) or an adult (ages 18+). It is unclear whether the TBF-305, with its manufacturer supplied equation, can accurately estimate body fat percentage in older adults. A few studies have looked specifically at the accuracy of the TBF-305 populations over the age of 55. Xie et al. (1999) had postmenopausal women (ages 51-63) as subjects and found the TBF-305 to have high reproducibility, but gave %BF estimates between 0.88 and 1.45

times the reference value. The Tanita %BF estimates limits of agreement were- 4.5% to 12.9% (Xie *et al*, 1999) . Jebb et al. (2000) compared the TBF-305, as well as other methods of body composition assessment, to a 4-compartment (4 C) model on men and women ages 16-78y. For males and females in all age groups combined, the 4-C criterion method and the TBF-305 had correlation coefficients of 0.933 for FM, and 0.889 for %BF. These results were comparable to %BF estimates fromother prediction methods such as skinfold (r = 0.944), tetrapolar BIA (r = 0.952) and two BMI (body mass index – weight in kilograms and height in meters,(kg/m^2)) (r = 0.924, r = 0.928) based formulas. However, the TBF-305 values were not as accurate compared to reference methods such as hydrostatic weighing (r = 0.986), DXA (r = 0.978) and deuterium-dilution TBW (D_2O-TBW) (r = 0.989) (Jebb *et al.*, 2000).

PURPOSE

The purpose of this study was to compare body composition assessment techniques in older adults, age 55-75 years old, to a criterion method. The Lohman 3-C model (Lohman, 1986), which served as the criterion method, was compared to the Tanita TBF-305, Siri 2-C model (Siri, 1961), and DXA in older adults age 55-75.

HYPOTHESES

1. The Tanita body composition values for older men and women will be significantly different from values obtained from a 3-compartment model.
2. DXA body composition estimates will be significantly different from 3-C estimates.
3. The 2-C estimates of body composition will be significantly different from 3-C estimates.
4. There will be a high and significant correlation among all techniques.

CHAPTER 2

REVIEW OF LITERATURE

Many of the underlying principles of body composition assessment date back to the early 20th century (Martin & Drinkwater, 1991). Researchers investigated body composition with the only direct method of measurement: human cadaver dissection with chemical analysis. Data from these studies were then used by researchers such as Siri (Siri, 1961) and Brozek (Brozek *et al*, 1963) to develop the prediction equations currently used. The density of each of the four main constituents of body composition (fat, water, protein and mineral) were determined and used as reference values. The assumption made is that each individual has the same proportion of body weight and density values for water, protein, and mineral and only vary in the proportion that is fat (Wang *et al*, 2005) . This method is referred to as a 2-compartment model, fat being fat mass (FM) and water, protein and mineral being fat free mass (FFM). However, these reference values may not be valid assumptions for all ages of all populations. More specific multi-compartment prediction equations were developed that take into account proportions and densities of constituents that may vary. For example, Lohman's 3-compartment (3-C) model (Lohman, 1986) is based on the assumption that individuals differ from reference values not only in fat, but in bone mineral, which makes up varying percentages of the FFM.

While body composition assessment was pioneered with a direct method of measurement (i.e., cadaver dissection), there have since been many different methods introduced to estimate body composition. Some of these methods are indirect, such as underwater weighing (UWW), air-displacement plethysmography (Bod Pod) and total body water (TBW). Other methods are doubly indirect, such as skinfolds, bioelectrical impedance (BIA), and anthropometry (Martin & Drinkwater, 1991) Indirect methods use a variable, such as body density (D_b), to make one or more quantitative assumptions about the relationship between that variable and the amount of fat an individual has (Martin & Drinkwater, 1991). Doubly indirect methods use equations derived using from values obtained with an indirect method such as UWW, TBW or the Bod Pod. The values obtained from the indirect and doubly indirect method are used create a regression line for the population tested, which then gives the estimation equation. Measurements such as skinfold thickness or impedance (from BIA) are then used in the equation (Faires, 1962) in order to estimate body composition.

CRITERION METHODS

Multi-compartment models are considered to be criterion methods of body composition assessment. They require the measurement of D_b along with one or more variables that make up FFM, which theoretically increases the accuracy of %BF assessment by accounting for more biological variability. The density and proportion of FFM can be broken down further at the molecular level into bone (m), protein (p), and water (w). There are even six compartment methods that control for fat, water, protein, bone mineral, soft tissue and glycogen (Shen *et al.*, 2005). While multi-compartment models may account for more biological variability in one or more constituents of FFM, they still must rely on a method of measurement to estimate these constituents. Multi-compartment methods rely on technology such as dual energy x-ray absorptiometry (DXA) to measure bone mineral content (BMC), isotope dilution to measure TBW, and UWW or the Bod Pod to measure D_b.

4-compartment model (4-C)

A four-compartment (4-C) model is theoretically more valid than a 3-C or a 2-C model due to the ability to control for more inter-individual variability. A 4-C model provides estimates of four molecular level components: fat, water, protein and bone mineral. With the 4-C, the mass and volume of TBW and bone mineral are used in the equation to estimate body fatness. One such equation was developed by Lohman (Lohman, 1992):

D_f = density of fat = 0.9007 g/cc

D_b = density of osseous mineral = 2.982 g/cc

D_m = density of nonosseous mineral = 3.317 g/cc

D_w = density of water = 0.9937 g/cc

D_p = density of protein = 1.34 g/cc

$$\%BF_{\text{Lohman 4-C}} = [(2.747/\text{Db}) - (0.714w) + (1.146b) - 2.053]\ 100$$

where the *m* (nonosseous mineral) increase is proportional to *b* (osseous mineral), and *w* and *m* are water and mineral as a fraction of body weight.

Due to TBW being one of the most variable components of the body, using a model that includes this measurement is important in populations in which it may vary. A traditional method for measuring TBW is to use an isotope (deuterium, tritium, or ^{18}O) dilution technique. Determining TBW with isotope dilution is based on a basic dilution principle (Withers *et al*, 1999) :

$$C_1M_1 = C_2M_2$$

Where C_1 = concentration of tracer in dose solution, M_1 = mass of dose solution, C_2 = equilibrium concentration of tracer in the biological fluid of interest (plasma, urine or saliva), M_2 = mass of TBW. Deuterium is a preferred tracer because it is a stable isotope of hydrogen without the radiation risks involved with the use of tritium and is less expensive than $H_2{}^{18}O$ (Withers *et al.*, 1999). Deuterium can be given in an oral dose with distilled water after a 6-12 hour fast. It takes 3-3.5 hours for deuterium to equilibrate with the TBW pool. Four hours after administration of the tracer, a sample of the body fluid (blood, urine, or saliva) to be measured for TBW is taken. TBW is then calculated as deuterium-dilution space (liters) divided by 1.042, to yield kilograms of TBW (Tylavsky *et al.*, 2003).

Another important variable that is estimated for use in a 4-C model is total body mineral. As mentioned in Chapter one and further described in following pages, a DXA scan provides an estimation of bone mineral mass (g), BMC (g), and BMD ($g \cdot cm^{-2}$).

3-compartment model (3-C)

A 3-C method is theoretically less accurate than a 4-C model, but more accurate than a 2-C model because it controls for inter-individual variability of one of the four FFM constituents. The mass and volume of the constituent is accounted for as part of D_b. Two 3-C models commonly used are that of Lohman (Lohman, 1986) and Siri (Siri, 1961). The Siri 3-C model combines the measurement of D_b and TBW, therefore controlling for inter-individual variability in body water. Using the same assumptions as the Siri 2-C model (listed in following pages), the equation is as follows:

$$\%BF_{Siri\ 3\text{-}C} = (2.118/D_b - 0.780w - 1.354)\ 100$$

where w = water as a fraction of body weight.

Lohman developed a body composition equation that corrects for variations in mineral content of the body using the following assumptions and putting them into a simplified equation (Lohman, 1992):

D_f= density of fat = 0.9007 g/cc

D_s = density of mineral = 3.037 g/cc

D_w = density of water = 0.99007 g/cc

D_{pw} = density of protein + water = 1.0486

$$\%BF_{\text{Lohman 3-C}} = [(6.386/ D_b) + 3.961m - 6.090]\ 100$$

where m = mineral as a fraction of body weight (m=(BMC*1.25)/BW(kg)) (Salamone *et al.*, 2000).

There is controversy regarding the role of the mineral content of FFM and its effect on body composition analysis. Mineral is the densest major constituent of FFM, therefore variations in its percentage of FFM are believed to have a significant impact on %BF (Wang *et al*, 1989; Martin & Drinkwater, 1991) . Wang et al. (Wang *et al.*, 1989) proposed that a change in the mineral-to-FFM ratio of just 1% could change D_b by 0.01 g/cm, resulting in a change in %BF of 5%. Martin and Drinkwater (Martin & Drinkwater, 1991) did a similar investigation on cadavers and suggested that even typical variations in bone, which is primarily mineral, can affect the assumed constant of the density of FFM, 1.1 g/cm, to be altered by 0.01 g/cm. This would result in a 4% change in %BF. Conversely, Lohman and Going (Lohman & Going, 1993) state that for %BF to be altered by 4%, it would require a decrease in the mineral-to-FFM ratio of 2% (from 6.87% to 4.8%). Two studies done by Modlesky et al. (Modlesky *et al*, 1996; Modlesky *et al.*, 1999) found similar results. The first study (Modlesky *et al.*, 1996) found that an alteration in mineral by 1% FFM would only alter %BF by 0.8%. The second study (Modlesky *et al.*, 1999) compared 2 different DXA machines and found that even though there was a difference of 11% in BMC between the two machines, it minimally affected %BF assessment with a 4-C model using the values from each machine. The authors stated that even though mineral is the densest variable of FFM, it seemed to only contribute slightly to FFM compared to water. Therefore an 11% error in total body mineral would not significantly affect %BF whereas an 11% error in measuring body water would alter %BF by 4.5% (Modlesky *et al*, 1999) . Water is the largest contributor of the four main constituents of body composition and possibly the largest source of error in the Siri 2-C model (Siri, 1961).

In populations that may have differing bone mineral proportions and densities than the reference man, the use of a 3-C model that measures bone mineral is appropriate. In such populations, using a 2-C model could cause an overestimation of %BF because bone mineral would be a reduced percentage of FFM. Even a small variation of ± 0.5% in the percentage of BMC/FFM could lead to an error of ± 2% body fat using a 2-C model such as UWW or a dilution method (Mazess *et al*, 1990) .

2-compartment model (2-C)

The two compartment (2-C) models divide body mass into two main compartments, FM and FFM. FM consists of adipose tissue (lipid, *f*) and FFM consists of mineral (*m*), protein (*p*) and water (*w*). The Siri 2-C model assumes that the density of each constituent is a constant at 37°C and is as follows (Siri, 1961):

$d_f = 0.900$ gm/cc

$d_w = 0.993$ gm/cc

$d_p = 1.340$ gm/cc

$d_m = 3.000$ gm/cc

Any body composition method that does not estimate each of these constituents of an individual assumes that they are the same as a reference body, and differ only in the amount of adipose tissue. It is this assumption that increases potential error with a 2-C model compared to a 3-C or 4-C model. Two factors that are the most variable constituents of FFM are TBW and BMC. The 2-C model may not be well suited for populations that could have varying densities of FFM or hydration levels, such as an older population (Baumgartner *et al.*, 1991).

The two most frequently used 2-C equations are that of Siri (Siri, 1961) and Brozek (Brozek *et al*, 1963) . The assumed densities of the Siri model are those listed above. The main difference between the two models is that the Brozek model assumes the temperature of FM is 36°C, with a corresponding density of $0.9007\ g/cm^3$. The equations are as follows:

$\%BF_{Siri} = (495/D_b) - 450$

$\%BF_{Brozek} = (457.1/D_b) - 414.2$

Body density can be determined using hydrodensitometry (UWW) and air displacement plethysmography (Bod Pod). Hydrodensitometry is based on Archimedes' Principle which states that an "immersed body is buoyed up by a force which equals the weight of the displaced water volume; hence, if a person's mass is measured in air and when completely immersed in water, density can be calculated" (Withers *et al.*, 1999). The Bod Pod system uses a scale to determine body mass, and a dual chamber plethysmograph to determine body volume, therefore determining D_b (D=M/V)

(McCrory *et al.*, 1995). Further description of this method is given later in a section of this chapter.

BIOELECTRICAL IMPEDANCE ANALYSIS (BIA)

Bioelectrical impedance analysis (BIA) is a doubly indirect method commonly used to estimate body fatness. It is a popular method due to its ease of use for both the tester and subject. A known amount of current is passed through the body and the impedance to this flow of current is measured. Muscle tissue is composed mostly of water and electrolytes, making it highly conductive, allowing the current to pass through. Fat tissue has little water content so is dielectric, an insulator, making it a poor conductor (Kushner, 1992). Therefore, the more fat tissue a person has, the more flow of current will be impeded. BIA does not measure body fat directly but rather measures the electrical impedance of tissues in the body which is then used to determine total body water (TBW) (National Institutes of Health, 1994). Fat-free mass (FFM) and fat mass (FM) can then be estimated if 0.732 is considered the hydration constant of FFM (Pace & Rathbun, 1945):

$$\mathrm{FFM(kg)} = \mathrm{TBW(kg)}/0.732$$

$$\mathrm{FM(kg)}=\mathrm{body\ weight(kg)} - \mathrm{FFM(kg)}$$

BIA works by sending a current between two electrodes; one electrode sends the current (source) and the other electrode receives the current (sink or detector). The electrodes are placed at opposite ends of the body: hand-to-foot, foot-to-foot, or hand-to-hand. An underlying principle of BIA is Ohm's law which states that "the resistance of a substance is proportional to the voltage drop of an applied current as it passes through the resistive substance" (Kushner, 1992). The variable actually measured is voltage (V).

Impedance values in an equation are the ratio of the applied voltage to the measured current: Impedance (Z) = applied voltage drop (V) / current (I) (National Institutes of Health, 1994). This is the reason the measuring instrument is called a bioelectrical impedance analyzer (National Institutes of Health, 1994).

A classic study frequently cited is that of Hoffer et al. (Hoffer, 1969). They studied the relationship between BIA and TBW. A high correlation ($r = 0.92$) was found between a tritium-dilution technique and the BIA method for estimating TBW. There was also a high correlation ($r = 0.92$) between TBW and Ht^2/Z, where Ht = patient height and Z = impedance in Ohms (Hoffer, 1969). A study affirming the findings of Hoffer et al. (Hoffer, 1969) was done by Kushner and Schoeller (Kushner & Schoeller, 1986). Deuterium-dilution (D_2O) space was used as the criterion method to determine TBW (D_2O-TBW) (Kushner & Schoeller, 1986). Of multiple predictors tested, D_2O-TBW was best predicted by Ht^2/R, where R = resistance or impedance in Ohms, ($r = 0.97$), and was further enhanced with the addition of body weight ($r = 0.99$) (Kushner & Schoeller, 1986).

Impedance

The foundation of BIA relies on the relationship between the impedance of a geometrical shape and its length, configuration, cross-sectional area and applied signal frequency (Kushner, 1992). It is explained by the following equation:

$$V = \rho L^2/Z$$

where ρ is the specific resistivity (ohm-cm), V is volume, L is the length of an object and Z is the impedance (ohm). L is often expressed as H, the height of the object (Kushner, 1992). This equation applies most accurately to cylindrical objects having the same ρ

(resistivity). Geometric objects, like a cylinder, that are similar in shape and made of the same material having the same ρ can be compared in volume to one another (Foster & Lukaski, 1996). Human bodies, however, are not geometrical cylinders. Cross-sectional areas and ρ of human bodies vary depending on hydration status and fluid distribution (Kushner, 1992). The body is best described as five cylinders, two arms, two legs and a trunk. If the body was one geometrical cylinder, % BF could be estimated with BIA using a simple equation. Instead, impedance is an independent variable in the statistical regression procedure to predict % BF (National Institutes of Health, 1994). BIA is used due to high correlations between Ht^2/R, TBW and FFM found by numerous studies (Hoffer, 1969; Kushner & Schoeller, 1986; Kushner, 1992).

As mentioned previously, the variable measured with BIA is voltage (V). Impedance values in an equation are the ratio of the applied voltage to the measured current: Impedance (Z) = applied voltage drop (V) / current (I) (National Institutes of Health, 1994). BIA applies a known amount of electrical current that is conducted through the body by water and electrolytes. The conductivity of materials in the body determines whether the current flows through easily or is impeded. Materials like blood and urine have high conductivity, muscle (73% water) has intermediate conductivity and bone, fat and air have low conductivity (National Institutes of Health, 1994). A term often used in place of impedance is resistance. Impedance is a function of the resistance (R) and capacitance (Xc) of conducting materials (Kushner, 1992):

$$Z^2 = R^2 + Xc^2$$

R is the pure opposition to flow of the current and Xc is the opposition to flow of electric current caused by capacitance (Kushner, 1992). Examples of a capacitor in the body are cell membranes. Cell membranes very briefly store the current sent by BIA because they have a protein-phospholipid bilayer with a layer of lipids separating them. Therefore, true impedance of the body is a combination of R and Xc (Kushner, 1992).

Frequency

Frequency is an important variable of BIA. It is the number of waves of current passing a given point in one second. Some models of BIA use a single frequency, typically 50 kHz, and are based on the assumptions previously mentioned; the body can be viewed as a cylinder, an isotropic conductor with uniform cross-sectional area. More recent models of BIA use multi-frequency because at 50 kHz the electrical pathway is primarily extracellular with an uncertain amount of intracellular penetration (Buchholz *et al.*, 2004). Multi-frequency models view the body as an electrical circuit with intracellular and extracellular pathways. When the current is given at low frequencies, ~1 kHz, it cannot flow through cells; so the path of the current is extracellular. At higher frequencies, > 100 kHz, the current can flow through cells so the intracellular and extracellular paths are additive (Health, 1994; National Institutes of Health, 1994; Schoeller, 2000). Segal et al. (Segal *et al*, 1991) found 5 kHz to predict extracellular water and 100 kHz to predict TBW most accurately.

Whole body BIA

This method of BIA, also called tetrapolar BIA, utilizes an impedance measured from the hand to the foot. In total there are four electrodes placed on the body. The first electrode is placed on the dorsal surface of the hand proximal to the metacarpal-phalangeal joint to act as a current source. The current is received by a second electrode, the detector, between the medial and lateral maleoli of the ankle and measures V. The third electrode also acts as a current source and is placed proximal to the metatarsal phalangeal joint. Its current is received by the fourth electrode, a detector, placed on the pisiform prominence of the wrist which also measures V (Kushner, 1992). The individual being tested must lie in a supine position with their limbs abducted to 45°.

A cross-validation study was done by Segal et al. on BIA and densitometrically determined FFM from four different labs across the country (Segal *et al*, 1988) . Each lab performed underwater weighing to determine body density and used a four-terminal impedance analyzer (RJL Systems, Detroit, MI) for BIA. Interestingly, they found Resistance and Ht^2 to be better individual predictors of FFM than Ht^2/R (Segal *et al.*, 1988). They applied the equation from each lab to the data from other labs and found only small changes in the correlation coefficients and standard error estimates (SEE). These small differences were attributed to some labs having fatter subjects. This suggests that in larger subjects, an error in predicting FFM could be related to body fatness. Segal et al. (Segal *et al*, 1988) devised fatness-specific equations that further iprroved the ability to predict FFM; equations for men below and above 20% body fat and equations for women below and above 30% body fat. The use of these equations does require prior knowledge or a guess of an individual's body fatness.

Segal et al. (Segal *et al*, 1991) evaluated the accuracy of multiple-frequency BIA measurements to determine body-water compartments. They found TBW correlated with BIA resistance at a frequency of 100 kHz (R_{100}) and was even more accurate after adjusting for height (Ht^2/ R_{100}) and body weight ($R = 0.947$, SEE = 2.64L) (Segal *et al*, 1991). Extracellular water correlated with resistance at a frequency of 5 kHz (R_5) and was also improved after adjusting for height (Ht^2/ R_5) and body weight ($R = 0.931$, SEE

= 1.94L) (Segal *et al*, 1991) . A study done be Gray et al. (Gray *et al*, 1989) looked at the accuracy of BIA for body composition in normal weight and obese individuals. They compared the generalized and fat-specific BIA equations from Segal (Segal *et al.*, 1988) with the Siri 2-C model (Siri, 1961), using UWW for D_b. There were eighty-seven subjects, 25 males and 62 females, from ages 19-74, with a body fat range of 8.8-59%. The subjects were subdivided into four quartiles according to their body fat; quartile 1, 8-29% body fat; quartile 2, 29-41% body fat; quartile 3, 41-47% body fat; quartile 4, 47-59% body fat. The correlation coefficients between FFM calculated from BIA and UWW for the generalized Segal equation were 0.95-0.99 over the four quartiles, and 0.94-0.99 for the fat-specific equations. The fat specific equations offered the most improvement over the generalized equations for quartile 1 ($r = 0.95$ to $r = 0.98$). For the other quartiles, there was little or no improvement. For subjects up to 48% body fat, they found BIA to accurately predict FFM.

Population specific equations

There are different equations to choose from when using BIA to estimate body composition. Using the correct BIA equation for a person or population will result in a more accurate estimate. There are many variables such as age, race and gender that may affect BIA. When choosing an equation, it is important to utilize one that has been derived from a population with similar characteristics as the one being tested.

Goran et al. tested five different BIA equations with a 4-C model on 41 women age 68.2 ± 6.6 years and 41 men age 70.2 ± 7 years (Goran *et al.*, 1997). The Baumgartner equation (Baumgartner *et al.*, 1991) most accurately estimated body composition for males. The same equation underestimated FM in females by an average of 4.6 kg, but with the addition of a correction factor (+4 kg FM), the accuracy significantly improved. This equation may have performed better than the other equations because it was derived from a population of men and women 65-94 years old (Baumgartner *et al.*, 1991). Roubenoff et al. (Roubenoff *et al*, 1997) took a BIA equation formulated from a young healthy population and applied it to 455 participants in the Framingham Heart Study (FHS). The young-population BIA equation overestimated FFM in the FHS participants compared to FFM_{DXA} (FFM determined with DXA), with a mean difference of 2.13 kg in men and 2.64 kg in women ($P < 0.01$) (Roubenoff *et al*, 1997). The author derived new BIA equations (BIA_{FHS}), using DXA as the reference method, to be used with older population populations. As expected, the new equation had mean difference in FFM of 0.00 compared to FFM_{DXA}. Both BIA equations, the young-population equation and BIA_{FHS}, were then applied to an independent sample of 283 participants in a longitudinal study called the New Mexico Aging Process Study (NMAPS). Interestingly, the young population equation was more accurate than BIA_{FHS} (Roubenoff *et al*, 1997) . One explanation from the authors is that a BIA equation should be validated in a statistical sample of the population it was derived from before being accepted as accurate and applied to another similar population. A second explanation was the use of two different DXA scanners with the FHS and NMAPS participants. The Lunar DPX-L, version 1.3, fast mode, was used as the reference method to determine FFM and create BIA_{FHS}. The Lunar DPX, version 3.6z, medium speed, was used as the reference method for FFM with NMAPS participants.

Foot-to-foot BIA

A newer method of BIA utilizes a foot-to-foot impedance instead of a hand-to-foot impedance and is manufactured by Tanita Inc. (Tanita, Inc, Tokyo, Japan). The Tanita TBF-305 is a non-invasive, portable, safe and widely used model using foot-to-foot technology. It does not require proper gel electrode placement and eliminates the need for special technical skills (Nunez *et al*, 1997) . It is a scale with two stainless steel foot-pad electrodes that measures body weight and foot-to-foot impedance as a person stands on it barefoot. Each foot-pad is divided into an anterior and posterior electrode. The anterior part of the electrode sends a 50 kHz single-frequency current and the posterior electrode measures the voltage drop from the current passing up one leg and down the other. It has an impedance range of 150-900 Ω and a measuring current of 500 μA (Tanita Incorporated). Foot-to-foot impedance is then used to estimate body composition.

In 1993, Sakamoto et al. (Sakamoto *et al.*, 1993) from the Tanita Institute of the Jikei University School of Medicine published information on this newly developed method of BIA referred to as foot-to-foot bioelectrical impedance. The TBF-101 was the first model of their foot-to-foot bioelectrical impedance method. Their first publication (Sakamoto *et al*, 1993) reported a high correlation coefficient between the estimation of %BF from the Tanita and other body composition techniques. In 1994, Sakamoto et al. (Sakamoto *et al*, 1994) assessed the accuracy of the Tanita to estimate %BF compared to DXA (Lunar DPX-L). They found a significant positive correlation between %BF from the Tanita and DXA ($r = 0.893$, $P < 0.001$). Correlation coefficients were the only statistics given, no mean differences or biases were published.

Nunez et al. (Nunez *et al.*, 1997) explored the validity of impedance values from the TBF-105 against gel electrodes (placed on the volar aspect of each foot) and the estimation of FFM. They tested males and females across a wide range of ages, 18-79 years old (N=97 men; N=134 women). While they found a high correlation between the TBF-105 and gel electrodes ($r = 0.99$, SEE = 5.9 ohms, $p < 0.001$), the mean impedance measured was significantly different ($t = 7.2$, $P < 0.001$). This difference was attributed to differences in skin contact area, electrode composition and the presence of conducting gel. There was a strong correlation between Ht^2/Z from the Tanita and FFM_{UWW} (determined with under water weighing) ($r = 0.89$, SEE = 5.82kg, $P < 0.001$) and FFM_{DXA} ($r = 0.89$, SEE = 6.1 kg, $P < 0.001$). Two multiple regression analyses were derived with Ht^2/Z as an independent variable and FFM_{UWW} and FFM_{DXA} as dependant variables. The simple model with Ht^2/Z as the only independent variable had an R^2 of 0.79. With the addition of three independent variables, age, gender and waist-to-hip ratio, the correlation increased from the simple model of $R^2 = 0.79$ to $R^2 = 0.86$ (FFM_{UWW}) and $R^2 = 0.89$ (FFM_{DXA}) (Nunez *et al*, 1997) . The authors stated that age and gender could have been important independent variables to add to the regression model because of possible fluid distribution differences between genders and fluid changes with age.

Another study that compared the Tanita (TBF-538) to a hand-to-foot BIA method was done by Dittmar (Dittmar, 2004). The Tanita (foot-to-foot, FF) was compared to hand-to-foot BIA (HF) as well as hand-to-hand BIA (HH) in 146 subjects between the ages 18-84 years old. Significant interactions were found between BIA technique and sex, and BIA technique and age. For males and females ages 60-84, the HH estimate of

%BF was significantly better than the HF and FF estimate ($P < 0.001$). The opposite was true for males and females ages 18-39, the HF estimate was significantly better than the HH ($P < 0.001$), and FF ($P = 0.002$). The FF was significantly better than the HH ($P = 0.003$). For the middle aged adults, 40-59 years old, there were no significant differences between estimates for any method in the males. In the females the FF estimate was significantly better than the HH ($P = 0.004$) and the HF ($P = 0.002$). The authors attributed these results to changing patterns of body fat accumulation in the trunk area that occur with aging. Another explanation for varying estimates could be due to differences in body type, a gynoid figure or an android figure.

Bell et al. (Bell*et al*, 1998) investigated the use of the TBF-305 to predict TBW. Using deuterium oxide dilution as the reference method, they found no significant difference between the two methods with a bias (predicted TBW-measured TBW) of -0.7 ± 3.1 liters. In terms of FFM, this is approximately 1.1 kg. There was a significant negative correlation ($r = -0.68$, $P < 0.01$ for males and $r = -0.55$, P 0.01 for females) between measured and predicted TBW, meaning that as the water content of the body increased, the TBF-305 showed a trend to underestimate TBW (Bell*et a l.*, 1998).

A more recent study was done by Jebb et al. (Jebb *et al.*, 2000) evaluating the TBF-305 against a 4-C model. Similar to Nunez et al. (Nunez *et al*, 1997) , their participants represented a wide range of ages, 16-78 years old (N=104 men; N=101 women). In the age group of 55-78 years old, there were 25 males and 21 females. The authors did not break down the results by age groups, but did separate males from females. For females the correlation for %BF between the TBF-305 and 4-C model was $r = 0.854$ and for males was $r = 0.810$. The mean bias for % BF in females was 2.7 ± 8.1

and in males was -0.9 ± 10.9. For FFM, the mean bias for females was 1.9 ± 5.9 and for males was -0.3 ± 9.0. The authors took a subset of their subjects and developed a new prediction equation to be used with the TBF-305. This equation includes variables such as sex, age, and a log-transformation of height, weight and impedance (Jebb *et al.*, 2000). When cross-validated with another subset of their sample, the mean residual bias (observed-predicted) %BF for men and women was 0.3% and 1.5% with standard deviations of 4.8% and 3.3%, respectively. The new equation used in conjunction with the TBF-305 on both subsets had a mean residual bias %BF for men and women of -0.9% and 2.7% with standard deviations of 10.9% and 8.1%, respectively (Jebb *et al*, 2000) . So far, this equation has not been cross-validated by other investigators.

A variable of interest on the Tanita is activity level, of which there are two choices available, 'athlete' or 'adult' mode. Swartz et al. (Swartz *et al*, 2002) studied the accuracy of these two modes in young males (18-35 years old) of varying activity levels. According to the manufacturer, an 'athlete' is classified as an individual participating in ≥ 10 hours of aerobic activity a week. Therefore, Swartz et al. divided their subjects into three categories: highly active (HA), participating in ≥ 10 hours per week of aerobic activity; moderately active (MA), participating in 2.5-10 hours per week of aerobic activity; and less active (LA), participating in < 2.5 hours per week of aerobic activity. The Tanita estimates were compared to UWW estimates. There was no difference between estimates from the 'athlete' mode and UWW for HA and MA (P = 0.309, P = 0.091). As expected there was a difference between the 'athlete' mode and UWW for LA (P = 0.001). The opposite was true for the 'adult' mode, no difference for LA (P = 0.395), but differences for HA and MA (P < 0.001). An interesting finding was that impedance values from the 'athlete' and 'adult' mode were not significantly different (500.7 vs. 500.2 Ω, P = 0.147). The lack of difference in impedance, but significant difference in %BF estimates was believed to be due to the pre-programmed regression equations used by the Tanita. The authors concluded that with the proper choice of activity mode, there was no significant difference between UWW and the Tanita.

Xie et al. (Xie *et al.*, 1999) attempted to validate the TBF-305 against DXA with 124 postmenopausal women (51-63 years old) as subjects. Compared to DXA, the TBF-305 overestimated %BF by a mean of 4.2% and FM by 3.1 kg. This overestimation resulted in an underestimation of FFM by 2.7 kg. The %BF from the TBF-305 gave estimates between 0.88 and 1.45 times the reference value, resulting in a limits of agreement -4.5% to 12.9% (Xie *et al*, 1999) . The authors attribute the varying %BF values between DXA and the Tanita to possible differences in the population in which the Tanita equation was derived compared to their population. Lastly, the authors state that predicting %BF with a foot-to-foot impedance may be limited by the change in fat distribution associated with menopause. A similar study was done by Rubiano et al. (Rubiano *et al*, 1999) in elderly subjects with a mean age of 64 years old (N=74). Similar to Xie et al. (Xie *et al.*, 1999) the authors used DXA as their reference method. The mean %BF from the TBF-305 was 32.8 ± 9.5%, and 33.7 ± 9.9% from DXA. Unlike Xie et al.(Xie *et al.*, 1999), Rubiano et al. (Rubiano *et al*, 1999) found no significant difference between the two methods in 74 subjects with a mean age of 64. There was a high correlation between the Tanita and DXA %BF estimations (r = 0.90, P < 0.001, SEE = 4.4). The mean %BF estimates from the Tanita (32.8 ± 9.5) were not significantly different than those from DXA (33.9 ± 9.9) (P = 0.58) (Rubiano *et al*, 1999) . Another study in an older population was done by Young et al. (Young *et al*, 1998) , who evaluated body composition methods on older men with cardiac disease. There were 24 subjects between 46-82 years old that had medical events documenting coronary artery disease. The authors found the TBF-150 to significantly underestimate %BF compared to hydrostatic weighing, 24.6 ± 7.2% versus 29.3 ± 6.5% ($p < 0.05$). The authors concluded that the use of the TBF-150 in the cardiac population is not recommended due to altered hydration levels from medications, physical conditions such as peripheral edema, and the tendency for BIA to underestimate %BF in obese subjects.

Research on hand-to-foot and foot-to-foot BIA suggests that age may be an important variable in a regression equation used to estimate %BF. However, on the TBF-305 manufactured for public use, age is strictly a categorical variable in which one is classified as either a child (ages 7-17) or an adult (ages 18+). It is unclear whether the Tanita, with its manufacturer supplied equation, can accurately estimate %BF in older adults. Alterations in fat distribution patterns and changes in hydration level of tissues are two possible reasons the TBF-305 BIA may be less effective in predicting body composition in older adults

AIR DISPLACEMENT PLETHYSMOGRAPHY

The Bod Pod Body Composition System (Life Measurement Instruments, Concord, CA) assesses body composition using air-displacement plethysmography. The D_b measurement from the Bod Pod can be used in any 2-C model. Underwater weighing (UWW-hydrodensitometry) is still considered by many as a criterion method for obtaining total body density. However, the estimation of D_b by the Bod Pod has made body composition testing easier and more efficient because it does not require submersion under water, maximal exhalation or depend on the skill of a technician. A review by Fields et al. (Fields *et al*, 2002) found the Bod Pod to be an acceptable method for obtaining D_b. Across studies they found the average mean of the Bod Pod and UWW to agree within 1%BF. While UWW applies Archimedes' Principle to determine body volume, the Bod Pod applies Boyle's and Poisson's Gas Laws. Boyle's law states that under isothermal conditions (air temperature is a constant), the product of pressure and volume is constant (Faires, 1962) and is shown below:

$P_1/P_2=V_2/V_1$ (Faires, 1962)

Therefore, the amount of air that is compressed under an isothermal condition will decrease in volume proportional to the increasing pressure. The first paired condition is represented as P1 and V1, and the second paired condition being P2 and V2 (Faires, 1962).

Poisson's law describes this relationship in an adiabatic condition where air temperature is not a constant as volume changes; the molecules gain or lose kinetic energy (Dempster & Aitkens, 1995). "The ratio of the specific heat of the gas at constant pressure to that at constant volume and is equal to 1.4 for air" and is represented as γ in the equation below:

$P_1/P_2=(V_2/V_1)^\gamma$ (Dempster & Aitkens, 1995)

The part of the Bod Pod system that measures body volume is a dual chamber compartment. The dual chamber compartment has a front (test) chamber of $\approx$ 450L, and rear (reference) chamber of $\approx$ 300L (Fields *et al*, 2002) , which are separated by a common wall. Small pressure changes are created by an oscillating diaphragm between the two chambers, at a frequency of 3 Hz, and are monitored by transducers and analyzed for pressure. The ratio of the pressures between chambers will indirectly measure the volume of air that is displaced by the subject in the test chamber (Fields *et al.*, 2002). The Poisson equation is used so that measurements do not have to be made under purely isothermal conditions, allowing air in the chambers to compress and expand adiabatically (air freely gains and loses heat during compression and expansion) (Fields *et al.*, 2002). However, there are still sources of isothermal air that must be accounted for such as the lungs, skin, hair or clothing. Air in the lungs is accounted for by either measuring thoracic gas volume (V_{TG}) or using a predicted value for V_{TG} (Fields *et al*, 2002) . Air from the skin's surface area is accounted for by determining surface area artifact (SAA). The Bod Pod calculates body surface area when height and weight are entered using an equation by DuBois and DuBois (DuBois & DuBois, 1916).

$\text{BSA (cm}^2) = 71.84 \cdot \text{Weight (kg)}^{0.425} \cdot \text{Height (cm)}^{0.725}$

BSA is then multiplied by the constant k to yield the SAA:

$\text{SAA (L)} = \text{k (L/ cm}^2) \cdot \text{BSA (cm}^2)$ (Fields *et al*, 2002)

For this reason, an accurate height measurement is a required entry prior to having a subject tested.

Measuring body volume with the Bod Pod requires two main steps. First, the test chamber must be calibrated while empty to create a baseline, and with a calibration cylinder of a known volume (usually ≈50L) to create a range. The second step is to measure the subject. An accurate height measurement must be entered into the Bod Pod software for optimal analysis before proceeding. Body mass (M) is then measured by a scale that is part of the Bod Pod system. This scale is calibrated each time the Bod Pod is turned on. Once M is measured, the subject then enters the test chamber, the chamber is closed and the subject's volume is measured. Two trials are performed, and if the two volume measurements are within 0.2% or 150 ml they are averaged (Fields *et al.*, 2002). If this criterion is not met, then a third trial is done. Each trial is 50 seconds in duration. The final step taken by the Bod Pod is to compute a final volume measurement corrected (Vb_{corr}) for SAA and V_{TG} (thoracic gas volume).

$$Vb_{corr} = Vb_{raw} - SAA + 40\%\ V_{TG}$$

The Bod Pod software includes the option of measuring V_{TG} or using a predicted V_{TG}. V_{TG} is the amount of air in the lungs during normal tidal breathing. The V_{TG} prediction equation used by the Bod Pod (software version 1.69; Life Measurement, Inc.) was established from predictions made by Crapo et al. (Crapo *et al*, 1982) . McCrory et al. (McCrory *et al.*, 1998) investigated the difference between predicted and measured V_{TG} and its effect on %BF with software versions 1.50 and 1.53 (Life Measurements, Inc.). In 50 men and women aged 18-56 years old, they found no significant difference between the two methods. For 82% of their subjects, using the predicted V_{TG} yielded a value within ±2% of the measured V_{TG} (McCrory *et al.*, 1998). The *M* and Vb_{corr} measurements from the Bod Pod can then be used in any body composition equation that requires the knowledge of D_b such as the Siri 2-C (Siri, 1961) or Lohman 3-C (Lohman, 1986) model

Dempster and Aitkens (Dempster & Aitkens, 1995) tested the Bod Pod for accuracy and reproducibility by using a cylinder with a known volume of 50,039 ml. They ran twenty consecutive tests on 2 separate days and had mean values of 50,037 ± 12.7 ml on the first day and 50,030 ± 13.5 ml on the second day. Volume errors of this size would equal a percent fat error of only 0.1% fat. They proceeded to test the Bod Pod with 6 cubes of a known volume varying from 25-150 liters and developed the following regression equation: $y = 0.9998x - 0.0274$, $r^2 = 1.00$, SEE = 0.0041 (Dempster & Aitkens, 1995). A study that investigated how D_b measured by the Bod Pod compared to UWW in both children and adults was done by Nunez et al. (Nunez *et al*, 1999) . The D_b measurements done with both methods on all 72 adults (mean age 42.7±18.4 for females and 38.8 ± 16.4 for males) showed no significant difference ($P = 0.69$) and a high correlation ($r = 0.95$, SEE = 0.007 $g \cdot cm^{-3}$, $P < 0.0001$) (Nunez *et al*, 1999) . The D_b estimates in the children (mean age 13.1 ± 3.3 for females and 12.5± 3.0 for males) between both methods were also not significantly different ($P = 0.58$) and were highly correlated ($r = 0.91$, SEE = 0.007 g/cm^3, $P<0.0001$) (Nunez *et al*, 1999) . They also found a high correlation between $\%BF_{Bod\ Pod}$ and $\%BF_{UWW}$ ($r = 0.949$, $P < 0.0001$).

In a review article by Fields et al. (Fields *et al*, 2002) , they found seven studies on the reliability of the Bod Pod to assess %BF. These studies showed mean within subject CVs of 1.7% to 4.5% within a day, and from 2.0% to 2.3% between days (Fields *et al.*, 2002). One of the studies included in Fields' review was done by Millard-Stafford et al. (Millard-Stafford *et al.*, 2001). They compared D_b measurements from the Bod Pod to those from UWW in men and women ages 25.3 ± 0.8. The D_b measurements were well correlated ($r = 0.89$, SEE = 0.008 $g \cdot ml^{-1}$), but $D_{b\text{-}Bod\ Pod}$ was significantly higher than $D_{b\text{-}UWW}$ ($P < 0.05$) (Millard-Stafford *et al.*, 2001). This resulted in a mean difference of 2.8%BF. McCrory et al. (McCrory *et al*, 1995) also evaluated the Bod Pod for estimating body composition. The subjects were both male ($n = 42$, mean age 38.6 ± 9.1) and female ($n = 26$, mean age 32.1 ± 5.6,) of varying ethnic backgrounds. Measurements of %BF taken with the Bod Pod showed good agreement with those taken by UWW for both males and females (r = 0.93, SEE 1.81). The limits of agreement (mean ± 2SD) between the two methods were -4.0 to 3.4 %BF, showing no observed bias in $\%BF_{\text{Bod Pod}}$ - $\%BF_{\text{UWW}}$ (McCrory *et al.*, 1995). Another study on the Bod Pod was done by Bosy-Wesphal et al. (Bosy-Westphal *et al*, 2003) . They specifically looked at its accuracy in a healthy elderly population using a Selinger 4-C model as the criterion method. They found the bias between $\%BF_{\text{Bod Pod}}$ and $\%BF_{\text{4-C}}$ to be significant for females ($p < 0.01$), but not for males. In this study, water content explained 96% of the variance in the density of FFM and BMC only explained 4% (Bosy-Westphal *et al*, 2003) . However, TBW was measured using BIA based on an equation developed using isotope dilution, and not an actual isotope dilution method. The optimal method to look at the validity of any body composition technique is with a multi-compartment method. Fields et al. (Fields *et al*, 2001) used a Baumgartner 4-C model (Baumgartner *et al.*, 1991) to compare %BF results with the Bod Pod in women 19-54 years old. There was no significant difference between the D_b values from the Bod Pod and UWW ($P = 0.35$). However, %BF was significantly underestimate by the Bod Pod (28.8%) compared to the 4-C model (30.6%) ($p < 0.01$).

The air-displacement plethysmography technology used by the Bod Pod has had an impact on body composition estimation. While one could argue that UWW remains the gold standard for the measurement of D_b, the Bod Pod involves easier methods that do not required a highly skilled technician. Another benefit to using the Bod Pod is the comfort of the participant being tested. Populations, such as older adults, have difficulties with UWW due to discomfort or nervousness. Such a participant would feel much more comfortable with the Bod Pod.

DUAL ENERGY X-RAY APSORPTIOMETRY

DXA is an abbreviation for dual energy X-ray absorptiometry. It isprimarily used to measure bone mineral content (BMC) (g), and bone mineral density (BMD) ($g \cdot cm^{-2}$). BMD is used to describe the bone mass per unit of projected bone area, an area density. (Mazess *et al*, 1990) . DXA can also differentiate fat-free soft tissue and fat tissue, which can be used to estimate body composition. The DXA scan emits a low-dose of radiation to the individual being scanned (whole body effective dose equals 0.6μSv- note that μSv stands for microSieverts, a radiation exposure unit) (enCore^{TM}, 2001). The radiation a participant is exposed to is roughly equivalent to that of a round-trip transcontinental plane ride (Lloyd *et al.*, 1998).

Dual-photon absorptiometry (DPA) was used to estimate BMD prior to the use of DXA. Gotfredsen et al. (Gotfredsen *et al.*, 1984) investigated the accuracy of dual photon absorptiometry with skeletons, soft tissue equivalent materials and whole cadaver extremities. They found the weight of five skeletons to be highly correlated with their scanned total body bone mineral ($r = 0.991$, SEE = 1.5%). There was also a high correlation between the BMC of seven extremities scanned intact and excised ($r = 0.995$, SEE = 6.3%) (Gotfredsen *et al*, 1984) . However, restrictions of DPA led to the development of a new, more precise technique, DXA. DXA conducts a full body scan with better precision than DPA. DXA can estimate soft tissue composition with correction for regional differences in fat content, which gives a better estimate of BMD and soft tissue composition. Mazess et al. (Mazess *et al*, 1990) conducted full body scans with DXA (Lunar DPX) on 12 young adults (6 males, 6 females) to assess total-body and regional bone mineral and soft-tissue composition. Scans were done over the time period of one week at both a medium speed and a fast speed (five scans for each speed). They found mean values for BMC and BMD to be 1-2% higher at the fast speed, but the values were not significantly different from the medium speed. The precision of the DXA-DPX scanner was determined with 34 measurements of a skeleton with one scanner. Measurements were then made with another skeleton on 37 different DXA-DPX scanners. There was a low precision error ($< 0.01\ g{\cdot}cm^{-2}$) for both comparisons for total body BMD. An additional measurement taken with a third skeleton, added to the results of the first two skeletons showed a high correlation between BMC and dry weight ($r = 0.99$, $P < 0.001$).

Researchers have also explored the use of DXA to determine body composition. One such study comparing DXA (Lunar DPX-L densitometer, version 1.3) to a 4-C model (Baumgartner *et al.*, 1991) in elderly men and women was done by Goran et al. (Goran *et al.*, 1998). The individual accuracy of DXA vs. 4-C to measure FM significantly deviated from the line of identity for both men and women. The correlation for the DXA compared to the 4-C modelwas $r = 0.73$, SEE = 4.0 kg for the males and $r = 0.77$, SEE = 3.6 kg for the females. However, there was no significant bias for either gender in FM (kg) estimates ($FM_{DXA} – FM_{4\text{-}C}$) (Goran *et al*, 1998) . The authors suggested a correction factor to improve FM estimates on an individual basis:

$$\text{Actual FM (males)} = 0.81 * FM_{DXA} + 3.4\ \text{kg}$$
$$\text{Actual FM (females)} = 0.76 * FM_{DXA} + 5.9\ \text{kg}$$

Another study comparing DXA (Hologic QDR 4500A, Hologic, version 8.21) measurements of FM in elderly to a 4-C model (Lohman & Going, 1993) was done by Salamone et al. (Salamone *et al.*, 2000). Although the means were only 1-2 kilograms apart, 22.3±7.3 (4-C) vs. 21.6±6.6 (DXA) for men and 26.3±8.4 vs. 25.5±8.0 for women, DXA significantly underestimated total FM compared to the 4-C model (men: $P < 0.010$, women: $P <0.002$) (Salamone *et al*, 200 0). However, there was a strong linear relationship between the two measurements (men: $R^2 = 0.94$, women: $R^2 = 0.97$).

Norcross and Van Loan (Norcross & Van Loan, 2004) validated the use of DXA (Prodigy model; GE/Lunar Corp, Madison, Wisconsin, USA) with the Siri 2-C (Siri, 1961) and the Lohman 3-C (Lohman, 1986) model in males and females in between ages 18-41 years old. An analysis of variance showed no significant difference between the three methods for %BF or FFM. A regression analysis showed a high correlation between $\%BF_{DXA}$ and $\%BF_{2\text{-}C}$ ($r = 0.919$) and $\%BF_{DXA}$ and $\%BF_{3\text{-}C}$ ($r = 0.943$). The bias for $\%BF_{DXA}$ values compared to $\%BF_{2\text{-}C,\,3\text{-}C}$ were only 0.68-1.45% (Norcross & Van Loan, 2004). These results were anticipated by the authors because their population was relatively young, healthy men and women, similar to the cadavers used to obtain reference values. Therefore, the density of their body constituents would be expected to be close to reference values.

Tylavsky et al. (Tylavsky *et al.*, 2003) compared DXA (QDR 4500A) to a 4-C model (Lohman & Going, 1993) in 58 male and female adults between 70-79 years old. The mean FFM_{DXA} was 5.5% higher than $FFM_{4\text{-}C}$ ($P < 0.0001$). The absolute error between the two methods increased as FFM increased. The authors proposed an equation to correct values from DXA to the 4-C model (Tylavsky *et al*, 2003) :

$$FFM\ (kg) = 0.964\ FFM_{DXA}\ (kg)$$

Once this equation was applied to a subset of 13 subjects from the 58 males and females, and 37 individuals (2 males, 35 females – not included in the original 58) the mean values of FFM from DXA were equivalent to the 4-C or TBW.

BODY COMPOSITION AND AGING

Factors that can affect the assessment of body composition in older adults are related to changes in the composition of FFM(Baumgartner *et al*, 1991) . A change in the composition of FFM with aging could be due to a decrease in bone mass (Mazess, 1982), variations in TBW (Virgili *et al*, 1992; Hewitt *et al*, 1993) and a change of the intra to extra cellular fluid ratio (Schoeller, 1989). TBW is a potential source of error in body composition assessment because it is a large fraction of FFM (Schoeller, 1989). In an older population, the hydration of FFM can vary, and is thus an important parameter to measure if possible. Baumgartner et al. (Baumgartner *et al*, 1991) found a decrease in the density of FFM to be due to either a decrease in TBW or a decrease in bone mineral. In some subjects, the effect of decrease in TBW was offset by a decrease in bone mineral, and vice versa. In a review on changes in TBW with age, Schoeller (Schoeller, 1989) found cross-sectional data to show a decrease in intracellular water with no change in extracellular water. However, longitudinal data showed the opposite, a decrease in extracellular with no change in intracellular water. The author concluded that TBW does decrease with age, but it is not clear if it is due to a change in intra- cellular water, extra-cellular water, or both. Because the review found the average hydration of FFM to not change significantly enough to effect body composition estimation, the decrease in TBW may simply reflect a decrease in FFM with age. Hewitt et al. investigated (Hewitt *et al*, 1993) the hydration of FFM and its effect on %BF estimates in three age groups: children (n = 28, ages 5-10 yr), young adults (n = 31, ages 22-39 yr), and older adults (n = 62, ages 65-84 yr). The older adults had significantly higher TBW/FFM than the young adults (72.5 ± 1.4% vs. 70.8 ± 1.2%, $P < 0.01$). The differences in %BF between the Siri 2-C and a multi-compartment model were significantly associated with TBW/FFM ($r = -0.62$, $P < 0.0001$). The authors concluded that TBW/FFM accounts for a large fraction of %BF estimation errors that occur with the use of a 2-C model However , Virgili et al. (Virgili *et al.*, 1992) had contrasting findings in a study group of 30 men and 30 women between the ages of 60-90 years. In men, TBW decreased from the seventh decade, 70.2 ± 7.7%, to the tenth decade, 65.9 ± 8.2%. Women had a higher TBW on average and showed less of an age-associated decline, 72.5% to 68.5%, respectively. These discrepant findings may be due to population differences or the measurement methods applied, but overall do suggest that TBW is in an important variable to measure for %BF estimations in older adults.

Another important variable to measure for older adults is bone mineral, due to bone mass changes that occur with age. Compact bone is lost at a rate of 3% per decade for both sexes starting around 40 years old. Women between the ages of 45-75 have a loss at the rate of 9% per decade (Mazess, 1982). Trabecular bone loss starts earlier, between 20-40 years old, and stays around 6-8% per decade for both sexes (Mazess, 1982). Bone mass is a part of FFM, therefore makes up a percentage of that value along with muscle, connective tissue and organs. Mazess et al. (Mazess *et al*, 1984) demonstrated that in normal subjects, total body bone mineral (TBBM) could range from 4-8% of FFM. For example, a 2-C model such as UWW could overestimate %BF by 9.5% in an older person with a 30% loss of TBBM. Likewise, those with osteoporosis could very well have a 50% loss in TBBM resulting in a 14% overestimation of %BF by UWW (Mazess *et al*, 1984) . The authors showed that differing skeletal masses do affect body density and therefore affects estimation of %BF. Lohman and Going (Lohman & Going, 1993) found their estimation of mineral loss to be too high, therefore corrected their example from a 9.5% overestimation in %BF to 4%.

Using a multi-compartment method, such as a 3-C model or a 4-C model, is necessary to validate any body composition technique in the elderly. The 2-C model is insufficient for validation purposes because it only subdivides the body into two compartments, fat mass (FM) and fat-free mass (FFM) where the density of FM, FFM and hydration of FFM are assumed constants, 1.1 kg/L, 0.9 kg/L and 73.8% (Siri, 1961), respectively. However, older populations may differ from these assumed constants; the percentage of FFM from bone mineral may vary. Based on four male cadavers, Brozek et al. (Brozek *et al*, 1963) found the mineral contents of FFM to be 6.8%. However, Heymsfield et al. (Heymsfield *et al*, 1989) found the mineral content in five males between ages 42 to 94 to be 6.1% of FFM, and in eight females between ages 24 to 85 the mineral content was 6.4% of FFM. In an investigation on body composition in middle aged and elderly Japanese, Koda et al. (Koda *et al.*, 2000) found BMC/FFM% for females to be 4.4% and 4.3% for males. Tylavsky specifically looked at male and female adults ages 70-79 years old and found the total body mineral mass to be 5.8-6.2% of FFM (Tylavsky *et al*, 2003) . Typical changes in BMC that occur with age can affect the percentage of BMC/FFM. For example: a 30% change in BMC, which can occur with age, would cause a 5% overestimation of %BF with a 2-C such as UWW or a dilution method (Mazess *et al*, 1990) . This error would be due to the reduced portion of bone mineral assumed to be a part of FFM. Using a Lohman 3-C model improves the accuracy of %BF estimation by taking into account the percentage of FFM that in bone mineral, as it may vary.

In summary, the accuracy and validity of a body composition assessment technique should be determined with a criterion such as a multi-compartment method. The use of a multi-compartment method allows the investigator to measure a constituent of FFM that is believed to vary, and potentially cause error in %BF assessment in the population of interest. In this case, the use of the Lohman 3-C is an appropriate multi-compartment model due to the known decrease in bone mineral with age. The Tanita TBF-305 is a method of body composition assessment that is easy to use and is growing in popularity compared to other techniques. It is common to find a Tanita bodyfat analyzer at health fairs, health screenings, fitness centers and even doctor's offices. However, the Tanita TBF-305 has not been a firmly established accurate and valid method in all populations. Multiple BIA studies have shown age to be a significant factor when developing a regression equation to be used to estimate %BF. Yet, the Tanita only has age as a categorical variable in which one is classified as either a child (ages 7-17) or an adult (ages 18+). The Tanita must continue to be examined in older males and females to determine its accuracy and validity in this population. It must continue to be studied to support previous research which suggests the need for age to be added as a variable of the regression equation it uses to predict %BF.

CHAPTER 3

MANUSCRIPT

ABSTRACT

Body composition is an important measurement for health assessments in older adults. The purpose of this study was to compare percent body fat (%BF) estimates in older adults obtained using a Tanita bioelectrical impedance analyzer (TBF-305), a two-compartment model (Siri 2-C) and dual energy x-ray absorptiometry (DXA) to a three-compartment model (Lohman 3-C) Fifty -two females and fifty men between the ages of 54 and 75y volunteered for the study. The estimate of % BF from the Tanita was measured using the 'adult' mode. The Bod Pod was used to determine body density (D_b) for the 2-C and 3-C. DXA was used to obtain an estimate of %BF, and determine BMC for use in the 3-C. Compared to the 3-C estimate of %BF (26.1 ± 1.0%), %BF in males was significantly underestimated by Tanita (22.1 ± 0.8%), and overestimated by 2-C (27.6 ± 0.9%) and DXA (28.6 ± 0.9%) ($P < 0.001$). The bias and limits ofagreement for all methods in males were: Tanita, -3.93 ± 10.3; 2-C, 1.53 ± 3.38; DXA, 2.51 ± 6.36. Compared to the 3-C estimate of %BF (39.2 %), %BF in females was significantly underestimated by Tanita (36.4 ± 1.2%; $P < 0.001$) and overestimated by DXA (40.5 ± 1.2%; $P < 0.05$). There was no significant difference in females between the 3-C and 2-C estimates of %BF (39.2 ± 1.2% vs. 39.3 ± 1.2%, respectively, $P > 0.05$). The bias and limits of agreement for all methods in females were: Tanita, -2.85 ± 8.66; 2-C, 0.05 ± 3.24; DXA 1.27 ± 5.64. This study suggests that the techniques used in this investigation are not interchangeable when estimating %BF in older adults.

INTRODUCTION

An accurate estimation of body composition is an important fitness component when assessing an individual's health status. There are many undesirable health outcomes as a result of being overweight and to a greater degree for being obese. These include, but are not limited to, hypertension, coronary heart disease and type 2 diabetes. Obesity is currently considered one of the major preventable causes of morbidity and mortality (U.S. Department of Health and Human Services, 2000). In the U.S., obesity is a significant predictor of poor physical health and may be as great of a risk for morbidity as poverty, smoking or problem drinking (Sturm & Wells, 2001) . This association of negative health consequences with obesity is why accurate body composition analysis is imperative. Health professionals need an accurate assessment to classify individuals for a proper intervention or health education.

Body composition analysis is done in many different settings using various methods. One bioelectrical impedance analysis (BIA) tool is the Tanita body fat analyzer (TBF-305). The Tanita is non-invasive, portable, safe, and widely used. In 1993, Sakamoto et al. (Sakamoto *et al*, 1993) from the Tanita Institute of the Jikei University School of Medicine published information on this newly developed method of BIA referred to as foot-to-foot bioelectrical impedance. The TBF-101 was the first model of their foot-to-foot bioelectrical impedance method. Researchers reported a high correlation coefficient between the estimation of %BF from the Tanita and other body composition techniques.

The Tanita has been validated in healthy adults, but not as firmly for older populations. Xie et al. (Xie *et al*, 1999) found the Tanita to have high reproducibility in postmenopausal women between ages 51-63. Unfortunately it gave percent fat numbers 0.88 to 1.45 times the reference value, resulting in limits of agreement -4.5% to 12.9% (Xie *et al.*, 1999). Two shortcomings of this study are (1) there were no males included and (2) they used dual energy x-ray absorptiometry (DXA) as their criterion method for %BF estimation. Jebb et al. (2000) conducted a study sponsored by Tanita on 205 men and women ages 16-78. The authors suggested that an age-adjusted equation might be better for predicting %BF in older adults. However, on the Tanita manufactured for public use, age is strictly a categorical variable in which one is classified as either a child (ages 7-17) or an adult (ages 18+). It is unclear whether the Tanita, with its manufacturer-supplied equation, can accurately estimate body fat percentage in older adults. Alterations in fat distribution patterns and changes in hydration level of tissues are two possible reasons the Tanita BIA may be less effective in predicting body composition in older adults.

While DXA has primarily been used to measure bone mineral content (BMC) and bone mineral density (BMD), it can also differentiate fat-free soft tissue and fat tissue, which can be used to estimate body composition. Goran et al. (Goran *et al*, 1998) compared DXA and 4-C model estimates of %BF in male and female older adults. They found no significant effect of method (P >0.9), no significant method-by gender interaction (P = 0.5), and no significant bias in body fat estimates in men or women. However, they did propose a correction equation for the DXA estimation of FM, due to a significant deviation from the line of identity for both men and women. Another study proposing a correction equation for DXA in older adults is from Tylavsky et al. (Tylavsky *et al*, 2003) , who found DXA to overestimate FFM by 5.5% compared to a 4-

C model ($P < 0.0001$). Salamone et al. (Salamone *et al*, 2000) also evaluated DXA compared to a 4-C model in an older population. Despite a high correlation of FM estimates, DXA significantly underestimated FM for men and women (men: $P < 0.010$, women: $P < 0.002$).

The classic model of body composition analysis is a 2-compartment model, where whole body mass is the sum of fat mass (FM) and fat free mass (FFM). This model presumes that the density of the constituents when summed together to equal the FFM (water, protein and mineral) will be a constant value (Shen *et al*, 2005) . The Siri 2-C model further assumes a constant for the density of FM, FFM and the hydration of FFM, 1.1 kg/L, 0.9 kg/L and 73.8%, respectively (Siri, 1961). These reference values may not be accurate assumptions for older adults as total body water (TBW) (Schoeller, 1989; Baumgartner *et al*, 1991; Virgili *et al.*, 1992; Hewitt *et al*, 1993) and bone mineral (Mazess, 1982) have been shown to vary with age. Multi-compartment prediction equations take into account the variability of one or more constituents of FFM. Lohman's 3-compartment (3-C) model (Lohman, 1986) is based on the assumption that individuals differ from reference values not only in the amount of fat, but also in the relative contribution of bone mineral to FFM. Therefore, a superior method to validate non-criterion methods is with a 3-C model(Lohman, 1986). The incorporation of bone mineral content is an important improvement for predicting body fatness in older adults in whom bone loss occurs, but not always at a predictable rate.

The primary purpose of the present study was to investigate the accuracy of the Tanita in an older population against the Lohman 3-C model. The secondary purpose was to compare other methods of body composition (Siri 2-C and DXA) in older adults against the Lohman 3-C model.

SUBJECTS AND METHODS

Fifty-two females and fifty males between the ages of 54 and 75y (63.8 ± 5.7 years) volunteered for this study. Participants were recruited from the surrounding community through public postings and word of mouth. Each participant was informed of potential risks and benefits and signed an informed consent (Appendix A) approved by the University of Tennessee Institutional Review Board prior to testing. Exclusion criteria for participants were (1) significant ambulatory limitations, (2) pregnant women, (3) women less than 2 years post-menopause, (4) any joint replacement, (5) weighing more than 300 pounds (due to limits on DXA), (6) implanted defibrillators, and (7) diseases or medications leading to fluid/electrolyte disturbances.

Each participant reported to the Applied Physiology Laboratory for a single testing session. All testing was done in the early to mid-morning time frame, between 0700-1000h. Participants were given the following guidelines over the phone to be followed prior to testing: avoid drinking alcohol for 48 hours before the assessment, avoid eating 4 hours before the assessment, drink enough fluid to maintain hydration before the assessment, and avoid exercise 12 hours before the assessment.

After signing the informed consent, participants removed their shoes and socks to have their height measured with a wall-mounted stadiometer (Seca Corp., Columbia, MD). Height was measured to the nearest 0.01 cm. Females then changed into a lycra form-fitting swimsuit and males changed into a lycra form-fitting swimsuit or lycra form-fitting shorts. Once fitted in the correct attire, participants were asked to remove all jewelry and other accessories for the remaining tests.

Anthropometric measures

Body mass was measured to the nearest 0.1 kg with a Bod Pod scale (Life Measurement Instruments, Concord, CA). Body mass index (BMI) was calculated as the ratio of weight to squared height ($kg \cdot m^{-2}$). Anthropometric measures including waist and hip circumference were taken in a standing position. The waist circumference was measured as the narrowest part of the torso above the umbilicus and below the xiphoid process after a normal expiration. The hip circumference was measured (as participants stood with their feet together) as the maximal circumference of the hips or buttocks region, whichever was larger (American College of Sports Medicine, 2000). Both of these measurements were taken in duplicate with a fiberglass measuring tape with a tension handle (Creative Health Products, Plymouth, MI), and measured to the nearest 0.01cm. Waist to hip ratio (WHR) was calculated by dividing the waist circumference by the hip circumference.

Air displacement plethysmography

The Bod Pod Body Composition System (Life Measurement Instruments, Concord, CA) measures body volume using air displacement plethysmography as previously described (Dempster & Aitkens, 1995). The dual chamber compartment has a front (test) chamber of ≈ 450L, and rear (reference) chamber of ≈ 300L(Fields *et al*, 2002), which are separated by a common wall. In this wall is a diaphragm, that when precisely oscillated, creates sinusoidal volume changes of the same magnitude in both chambers (Dempster & Aitkens, 1995). When a person is in the front chamber, the volume of that chamber will be reduced by the volume of the person's body, V_b. This value is then corrected for body surface area artifact and thoracic gas volume. Thoracic gas volume was predicted by the Bod Pod software with an equation previously validated (McCrory *et al*, 1998) . The Bod Pod was used to determine body density (D_b). This value was used to estimate %BF using the Siri 2-C model (Siri, 1961). The D_b measurement from the Bod Pod was also used in the Lohman 3-C model (Lohman, 1986).

Foot-to-foot (BIA)

The Tanita TBF-305 utilizes a foot-to-foot impedance and is manufactured by Tanita Inc. (Tanita, Inc, Tokyo, Japan). The TBF-305 is a non-invasive, portable, safe and widely used model using foot-to-foot technology. It is a scale with two stainless steel foot-pad electrodes that measure body weight and foot-to-foot impedance as the participant stands on it barefoot. Each foot-pad is divided into an anterior and posterior electrode. The anterior part of the electrode sends a 50 kHz single-frequency current and the posterior electrode measures the voltage drop from the current passing up one leg and down the other. It has an impedance range of 150-900 Ω and a measuring current of 500 μA (Tanita Incorporated). Foot-to-foot impedance is then used to estimate body composition.

Bioelectrical impedance analysis was done in accordance with the instruction manual from the manufacturer (Tanita Incorporated). Gender and height were entered into the Tanita keypad and body mass was measured automatically to the nearest 0.2 kg during the impedance measurement. Each participant's %BF was predicted using the standard 'adult' mode.

Dual energy x-ray absorptiometry

Total bone mineral density (BMD), bone mineral content (BMC) and %BF estimates were determined from a whole-body scan using the Lunar DPX-NT whole-body X-ray densitometer (GE Medical, Milwaukee, WI), with software version 4.0. All scans were performed by one of two individuals certified in Bone Densitometry in the State of Tennessee.

Lohman's 3-compartment model

%BF was estimated from D_b and total body mineral using Lohman's 3-C model (Lohman, 1986):

$$\%BF_{3C} = [(6.386/ D_b) + 3.961m - 6.090]100$$

where D_b = body density (kg/l) via Bod Pod, and m = mineral as a fraction of body weight. BMC was multiplied by a correction factor of 1.25 and then divided by body weight to obtain m (m = (BMC*1.25)/BW(kg)). This correction factor accounts for osseous and nonosseous bone as a fraction of body weight (Salamone *et al.*, 2000).

Statistical analysis

Overall mean subject characteristics for males and females were compared with t-tests. Pearson product-moment correlations were calculated to determine the strength of the relationship between the criterion method (3-C) and the Tanita, 2-C model, and DXA %BF estimates for males and females. Mean %BF, FFM and FM values for males and females were compared using repeated-measures ANOVA. Bland-Altman plots (Bland & Altman, 1986) were used to show possible systematic differences between the 3-C model and the Tanita, 2-C model, and DXA %BF estimates for both males and females. All data were analyzed using SPSS for Windows, version 13.00 (SPSS Inc., Chicago, IL, USA). Significance level was set at $P \leq 0.05$ for all tests.

RESULTS

The characteristics of the study participants are displayed in Table 1. There were no significant differences between males and females for BMI and hip circumference. The males were significantly older, heavier, and taller then the females ($P < 0.001$). They also had a significantly larger waist circumference and WHR (waist to hip ratio) ($P < 0.001$).

A 2-way ANOVA revealed a significant method-by-gender interaction in the estimate of %BF. Therefore, further analyses were separated by gender. For males, %BF estimates (see Table 2) compared to the 3-C model (26.1 ± 1.0%) were significantly different for all methods ($P \leq 0.001$). The Tanita underestimated %BF (22.1 ± 0.8%), whereas the 2-C model(27.6 ± 0.9%) and DXA (28.6 ± 0.9%) overestimated %BF compared to the 3-C model FFM estimates compared to the 3 -C were significantly overestimated by the Tanita, but significantly underestimated by the 2-C model and DXA ($P \leq 0.001$). FM estimates were significantlyunderestimated bythe Tanita , but significantly overestimated by the 2-C modeland DXA ($P \leq 0.001$).

For females, the %BF estimates compared to the 3-C model(39.2 ± 1.2%) were significantly underestimated by the Tanita (36.4 ± 1.1%; $P \leq 0.001$), whereas they were significantly overestimated by DXA (40.5 ± 1.2%; $P < 0.05$). There was no difference between the %BF estimates from the 3-C and 2-C models. FFM estimates compared to the 3-C modelwere significantly overestimated by the Tanita ($P \leq 0.001$) and

Table 1. Descriptive characteristics of participants

	Males (n = 50)		Females (n = 52)	
	Mean	SD	Mean	SD
Age	65.8*	5.1	61.9*	5.5
Weight (kg)	85.10*	12.78	69.66*	15.61
Height (cm)	178.2*	7.7	164.3*	7.0
BMI (kg/m^2)	26.73	3.32	25.78	5.55
Waist (cm)	93.6*	9.5	83.5*	13.3
Hip (cm)	102.0	6.9	103.0	11.9
WHR	0.92*	0.06	0.81*	0.07

WHR, waist to hip ratio
* Mean values were significantly different, $P < 0.001$

Table 2. Percentage body fat, fat-free mass and fat mass estimates from the 2-C model, Tanita, DXA and the Lohman 3 -C model

	3-C		Tanita		2-C		DXA	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Body fat (%)								
Males	26.1	1.0	22.1*	0.8	27.6*	0.9	28.6*	0.9
Females	39.2	1.2	36.4*	1.1	39.3	1.2	40.5†	1.2
Fat-free mass (kg)								
Males	62.6	1.14	65.7*	0.96	61.2*	1.09	60.3*	1.04
Females	41.4	0.85	43.2*	0.66	41.3	0.77	40.5†	0.87
Fat-mass (kg)								
Males	22.5	1.14	19.4*	1.09	23.9*	1.16	24.7*	1.14
Females	28.3	1.62	26.5*	1.61	28.4	1.67	29.1†	1.62

2-C, Siri 2-compartment model
3-C, Lohman 3-compartment model
DXA, dual energy x-ray absorptiometry
Tanita, foot-to-foot bioelectrical impedance
* significantly different from Lohman 3-C, $P \leq 0.001$
† significantly different from Lohman 3-C, $P < 0.05$

significantly underestimated by DXA ($P < 0.05$). FM estimates compared to the 3-C model were significantly underestimated by the Tanita ($P \leq 0.001$) and significantly overestimated by DXA ($P < 0.05$). There were no differences between the 3-C and 2-C models for FM or FFM in females ($P > 0.05$).

The correlation coefficients (see Tables 3 and 4) for %BF by all methods relative to the 3-C model were all significant ($P < 0.001$). For males, the lowest r-value was for the Tanita ($r = 0.681$), the highest for the 2-C model ($r = 0.969$), and the DXA was in the middle ($r = 0.886$). In the same manner, for females the lowest r-value was for Tanita ($r = 0.866$), the highest for the 2-C model($r = 0.982$), and the DXA was in the middle ($r = 0.948$).

Figure 1 and Figure 2 (Bland Altmans) shows the individual differences for %BF from the Tanita, 2-C model and DXA relative to the 3-C model as well as the Pearson product moment correlation for these relationships. For males, the bias and limits of agreement (see Table 5) was the smallest for the 2-C model relative to the 3-C model; 1.53 ± 3.38%, and larger for the Tanita; -3.9 ± 10.3%, and for DXA was 2.51 ± 6.36%. In a similar pattern for the female, the bias and limits of agreement was the smallest for the 2-C modelrelative to the 3 -C modelfor females; 0.05 ± 3.24%, the largest for the Tanita; -2.85 ± 8.66%, and for DXA was 1.27 ± 5.64%.

DISCUSSION

The important finding of this investigation is that the Tanita TBF-305 significantly underestimated %BF and FM, and overestimated FFM compared to the criterion method. The Tanita TBF-305, foot-to-foot impedance, is a method of body composition analysis that is becoming more popular in many settings such as fitness

Table 3. Pearson correlations between body fat measurements for females (n = 52).

	Tanita	2-C	DXA
3-C	0.866 (P < 0.001)	0.982 (P < 0.001)	0.948 (P < 0.001)
Tanita		0.906 (P < 0.001)	0.869 (P < 0.001)
2-C			0.940 (P < 0.001)

3-C, Lohman 3-compartment model
2-C, Siri 2-compartment model
DXA, dual energy x-ray absorptiometry
Tanita, foot-to-foot bioelectrical impedance

Table 4. Pearson correlations between body fat measurements for males (n = 50).

	Tanita	2-C	DXA
3-C	0.681 (P < 0.001)	0.969 (P < 0.001)	0.886 (P < 0.001)
Tanita		0.709 (P < 0.001)	0.773 (P < 0.001)
2-C			0.873 (P < 0.001)

3-C, Lohman 3-compartment model
2-C, Siri 2-compartment model
DXA, dual energy x-ray absorptiometry
Tanita, foot-to-foot bioelectrical impedance

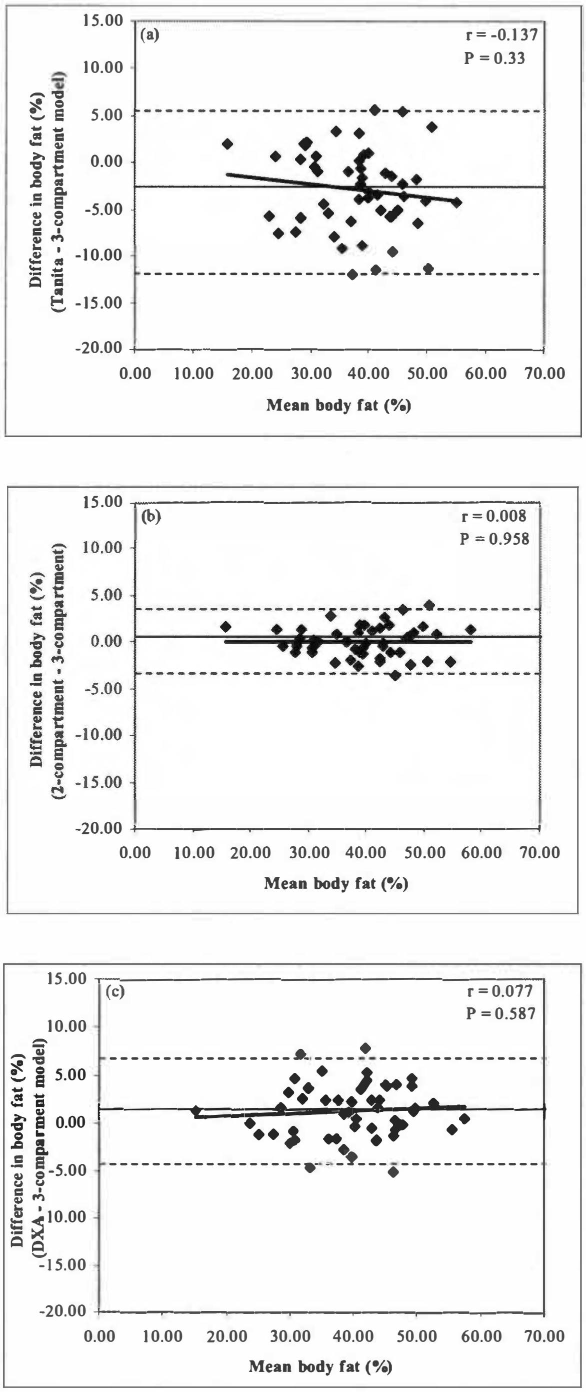

Figure 1. Bland-Altman plots for females to determine systematic differences in % body fat between the 3-compartment model and the Tanita, 2-compartment model, and DXA. For details of means ± 2SD, see Table 5. Mean difference, —; ± 2SD ----.

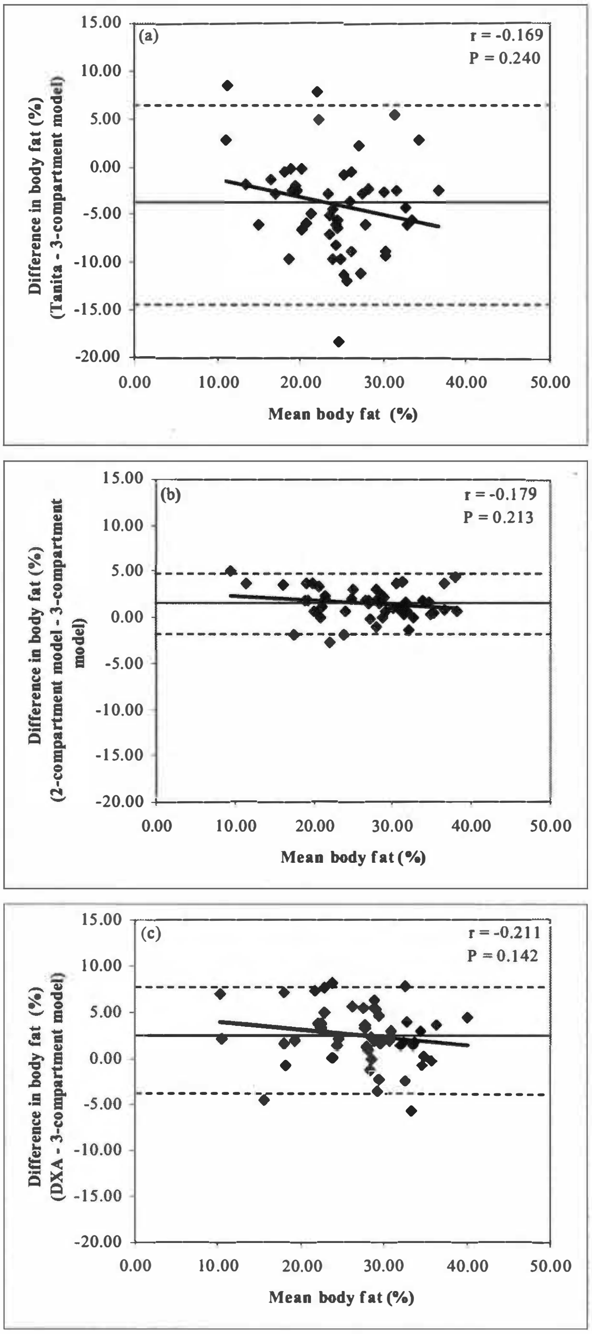

Figure 2. Bland-Altman plots for males to determine systematic differences in % body fat between the 3-compartment model and the Tanita, 2-compartment model, and DXA. For details of means ± 2SD, see Table 5. Mean difference, —; ± 2SD ----.

Table 5. Bias and limits of agreement (±2SD) for % body fat in male and female subjects for all methods relative to a 3-C model (other method - 3-C model)

Method	Males		Females	
	Bias	2SD	Bias	2SD
Tanita	-3.93	10.3	-2.85	8.66
2-C	1.53	3.38	0.05	3.24
DXA	2.51	6.36	1.27	5.64

3-C, Lohman 3-compartment model
2-C, Siri 2-compartment model
DXA, dual energy x-ray absorptiometry
Tanita, foot-to-foot bioelectrical impedance

centers, health facilities, and even individual homes. The main benefit of the Tanita is its ease of use; however, the accuracy of its estimations has not been firmly established in older adults. This study provides an evaluation of varying methods of body composition analysis, including the TBF-305, against a criterion three-compartment model.

Similar to Xie et al. (Xie *et al.*, 1999), we found the Tanita to have limited accuracy compared to the 3-C model for the assessment of %BF. Also in agreement with our findings is Young et al. (Young *et al*, 1998) , who found the Tanita to significantly underestimate %BF in an older male cardiac population compared to underwater weighing (UWW) (29.3±6.5 vs. 24.6±7.2). Although Nunez et al. (Nunez *et al.*, 1997) reported a high correlation between %BF from the Tanita and DXA (r = 0.88), our data showed a high correlation for females (r =0 .866), but not for males (r = 0.681). It is possible that the wide range of body fat values for females contributed to this higher correlation. Our correlation coefficient for females (r = 0.866) corresponded with Jebb et al. (Jebb *et al.*, 2000), who found the correlation for %BF between the TBF-305 and 4-C model to be r = 0.854. However, for males our relationship (r = 0.681) was not as strong as that found by Jebb et al. (r = 0.810). Jebb et al. showed a positive mean bias and limits of agreement for females whereas ours were negative, +2.7 ± 8.1 vs. -2.85 ± 8.66, respectively. Both our results and those from Jebb et al. showed a negative bias for males, but our mean bias was greater, -0.9 ± 10.9 vs. -3.93 ± 10.3, respectively.

The ability of foot-to-foot impedance to predict whole body impedance in older adults has been called into question. A study that compared the Tanita (TBF-538) to a hand-to-foot BIA method was done by Dittmar (Dittmar, 2004). The Tanita was compared to hand-to-foot BIA (HF) as well as hand-to-hand BIA (HH). Significant interactions were found between BIA technique and sex, and BIA technique and age. For males and females ages 60-84, the Tanita estimate of %BF was significantly lower than the HH estimate ($P < 0.001$), and HH was significantly higher than HF ($P<0.001$). The authors attributed this occurrence to changing patterns of body fat accumulation to the trunk area that occur with aging. Another study showing differences between hand-to-hand and foot-to-foot BIA was done by Baumgartner et al. (Baumgartner *et al.*, 1989). The regression model showed arm impedance to account for 49%, and leg impedance to account for 36% of the FFM variation in women (mean age = 36.15). For men (mean age = 34.2) arm impedance accounted for 58% and leg impedance accounted for 40% of the FFM variation. This suggests that arm impedance may reflect whole body impedance more accurately than leg impedance. This may be valid in older populations due to a tendency for fat storage to shift to the trunk area.

Even though there was a high correlation for %BF between the DXA and the 3-C model (males: $r = 0.886$, females: $r = 0.948$), there was a significant overestimation in %BF (males: $P \leq 0.001$, females: $P < 0.05$) as well as a significant underestimation in FFM ($P \leq 0.001$ for both genders). FM was also significantly underestimated for females ($P < 0.05$) and males ($P \leq 0.001$). These findings are similar to Salamone et al. (Salamone *et al*, 2000) who found a high correlation for FM in older adults between DXA and a 4-C model but DXA significantly underestimated FM for both males and females (males: $P < 0.010$, females: $P < 0.002$). Another study comparing DXA to a 4-C model found DXA to overestimate FFM by 5.5% compared to a 4-C model ($P < 0.0001$) (Tylavsky *et al*, 2003). Conversely, Goran et al. (Goran *et al.*, 1998) showed no significant effect of method ($P >0.9$), no significant method-by-gender interaction (P =

0.5), and no significant bias in %BF estimates for DXA vs. a 4-C model in older men and women. Tylavsky et al. (Tylavsky *et al.*, 2003) and Goran et al. (Goran *et al.*, 1998) both proposed correction equations for DXA estimations in older adults.

When considering the agreement of measurements between the 2-C and 3-C models, it is important to note their reliance on a common measurement. Both models require the measurement of D_b, which is a critical variable in both equations. Because the same method (Bod Pod) was used for the D_b measurement for both models, less variation would be expected unless there was a significant variation in bone mineral. Of all the methods compared to the 3-C model, the 2-C modelhas the smallest bias and limits of agreement for males and females, 1.53 ± 3.38% and 0.05 ± 3.24%, respectively. While our findings found the 2-C model to significantly overestimate %BF in males, but not females, both had a high correlation coefficient (males, $r = 0.969$, $P = 0.001$; females, $r = 0.983$, $P = 0.001$) A study by Bosy-Westphal et al. (Bosy-Westphal *et al.*, 2003) compared the 2-C modelto a multi-compartment model (4-C model) in older adults . Their subjects were similar to oursin age (68.2 ± 5.3 years old), and showed a high correlation between the 2-C modeland 4 -C model($R^2 = 0.924$). Unlike our study, they found a significant bias for females (2.9%), but not for males (-0.1%). Their limits of agreement for males and females combined were wider than ours at ± 6.2% BF. Goran et al. (Goran *et al.*, 1998) also compared a 2-C model, with UWW, to a 4-C model. A regression analysis showed FM estimates to be equivalent for men, but not for women. A Bland-Altman plot showed an overestimation of FM to be significantly and inversely related to FM in males (combined: $r = -0.28$; males: $r = -0.33$), but no bias was reported for females.

A 2-C model is based on the assumption that FM and FFM are a constant density, with FFM including the density of water, mineral and protein. Therefore, differences between 2-C and 3-C models measurements could be due to variations in TBW and bone mineral from their assumed densities. Bosy-Westphal et al. (Bosy-Westphal *et al.*, 2003) gave a demonstration of how using a FFM density lower (1.065 g/cm^3) and higher (1.133 g/cm^3) than the assumed value of 1.1 g/cm^3 would result in a 11% overestimation or a 10% underestimation of %BF in an individual assumed to have 25% BF. Therefore, physiologic changes naturally occur with age, such as a decrease in BMD (Mazess, 1982), variations in TBW (Schoeller, 1989; Virgili *et al*, 1992; Hewitt*et al.* , 1993) and a change of the intra-cellular to extra-cellular fluid ratio (Schoeller, 1989), could significantly affect the density of FFM and %BF estimation. A method such as a multi-compartment model is more appropriate than a 2-C model for deriving or validating a method of body composition because it controls for inter-individual variability of one or more of the FFM constituents. We used a Lohman 3-C model to control for an important constituent of FFM that can vary in older adults, bone mineral content (Mazess, 1982). However, a limitation of the Lohman 3-C model is that it does not account for changes in TBW, which is also a component that may also vary in older individuals.

CONCLUSION

In conclusion, the present study found the Tanita to significantly underestimate %BF in males by 4% and 2.8% in females. Estimates from the Tanita in older adults should be used with caution due to the underestimation of %BF and wide limits of agreement. While the mean values from DXA are close to the 3-C model for both males and females, DXA significantly overestimated %BF by in 2.5% males and in 1.3%

females. The use of DXA does involve radiation exposure; a drawback to the use of DXA. The Siri 2-C model showed no significant difference in %BF estimates for females, but a significant overestimation of %BF in males by 1.5%. Additional studies on body composition in older adults are needed to further examine differences in methods. To increase the accuracy of the Tanita in older adults, a regression equation that includes age as a variable needs to be investigated.

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APPENDICES

APPENDIX A

INFORMED CONSENT

CONSENT FORM

Title of the Project: Comparison of Body Composition Assessment Techniques in Older Adults

Student Investigators: Rebekah Wilson and Cherilyn Hultquist
Faculty Advisor: Dr. Dixie Thompson

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Purpose

You are invited to take part in a research study. The purpose of the study is to examine different techniques for measuring body fat in older adults. We will also be looking at physical activity levels in your age group. Testing will occur at the University of Tennessee Applied Physiology Laboratory in the Health, Physical Education, and Recreation Building. The tests you will be participating in should take approximately 2 hours. After this testing you will wear a step counter (electronic pedometer) for 7 days.

Procedure

On a morning that best suits your schedule, you will come in for approximately 2 hours to participate in the tests explained below:

1) DXA: DXA stands for dual-energy X-ray absorptiometry. This test is most often used to screen for osteoporosis. This test requires you to lie on your back on a table and remain still while you are scanned from head to foot. This takes about 20 minutes, with 10-12 minutes of radiation exposure. A DXA scan will tell us how much bone you have in your body.

2) Hand-to-foot bioelectrical impedance: You will lie on your back on a table and relax. Band-Aid like connectors are placed on your hand and foot. A small signal is sent from one electrode to the other. The electrodes are hooked up to a machine which will tell us how much water is in your body.

3) Bod Pod: The Bod Pod is a large box-like piece of equipment that you will sit in to have your body fat measured. Clothing can interfere with the readings, so this test needs to done wearing a bathing suit or your undergarments. The Bod Pod will be done in the privacy of only you and the investigator.

4) Tanita: The Tanita is a platform scale with two stainless steel foot pad electrodes you stand on barefoot. This will tell us your body weight and your body fat. Similar to the hand-to-foot bioelectrical impedance, a small signal will be sent through an electrode under one foot and received by the electrode under the other foot.

5) Body Measurements: Your height, without shoes, will be measured by standing next to a scale attached to the wall. The distance around your hips and waist will be measured with a plastic tape measure.

The following guidelines must have been followed prior to any of the testing mentioned above:

»Avoid drinking alcohol for 48 hours before the assessment
»Avoid eating 4 hours before the assessment
»Drink enough fluid to maintain hydration before the assessment
»Avoid exercise 12 hours before the assessment

Once these tests are completed you will be given an electronic pedometer and explained how to properly use it. You will be asked to wear the pedometer all day, every day for 7 days straight. The pedometer should be taken off only to sleep or when in water (swimming, showering, etc.) You will record the time the pedometer was put on in the morning, the time it was taken off at night and specific activities you engaged in during that day (e.g. walking, gardening, etc). We ask that you follow your regular routine during this week. After wearing the pedometer for a full week you may return it by bringing it back to the lab or ask to meet an investigator at a convenient location.

Potential Risks

There are few risks involved in this testing. The DXA scan requires a total-body x-ray with very low-dosage beams, this is the most risk involved with this study. The radiation exposure is roughly equal to that of a round-trip transcontinental plane ride. The DXA is only operated by certified individuals. *If there is any chance you may be pregnant you should not participate in this study.*

If you have problems with being claustrophobic, sitting in the Bod Pod may be uncomfortable for you. However, you will be able to breathe normally and see out though a large clear panel. The amount time you will be sitting in it is small, only 3 minutes.

It is not recommended to participate in some of the tests we will do if you have an implanted defibrillator. It is important to inform the investigators if you have an implanted defibrillator.

Benefits

The benefits given to you will include knowledge of your body fat as well your bone density. Both of these values have very important health implications. Another benefit will be the awareness of your current actual physical activity levels. With this knowledge, you will know whether you currently achieve recommended physical activity levels or need to add physical activity. When the study is completed, you will be given an opportunity to discuss your test values with an investigator.

Confidentiality

You will be assigned a number to ensure complete confidentiality of data collected. All information will be strictly confidential and data will be stored in a locked cabinet that is only accessible by the study investigators. In the event that results from this study are published, readers will be unable to discern which values are yours or even know you took part in the study.

Questions

You are free to ask questions at any time during this study. You may contact Rebekah Wilson at (865)974-6040. You may also contact Research Compliance Service of the Office of Research at (865)974-3466 if you have any questions about your rights as a participant. Should something occur during this study that keeps you from completing this study, please inform one of the investigators as soon as possible. You are free to withdraw your consent and discontinue participation at any time without penalty.

Consent

By signing below, I am indicating that I understand and agree to take part in this research study.

______________________________ ____________
Your Signature Date

______________________________ ____________
Researcher's Signature Date

Additional Contact Information

Mailing Address: ________________________

____

E-mail address: ________________________

Phone Number: ________________________

APPENDIX B

HEALTH HISTORY QUESTIONNIARE

Subject ID = ______

Health History Questionnaire

1) Date of Birth: _________ Age: ____ Gender: _______

2) If female, when was your last menstrual cycle? ________________

4) Do you have any artificial joints? __________

   8) Do you have any current medical conditions that significantly impact your health? If so, please describe.

___

   8) Do you have a physical condition that may limit your ability to be physically active?
   If so, please describe.

___

   8) Are you currently taking any medications?
   If so, please list.

___

8) Do you have an artificial defibrillator? Yes No

APPENDIX C

ACTIVITY LOG

Activity Log

Phone: 974-6040

Subject ID:

Month:________________ 2005

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Day of week: ______	Day of week: ______	Day of week: ______	Day of week: ______	Day of week: ______	Day of week: ______	Day of week: ______
Date: ______	Date: ______	Date: ______	Date: ______	Date: ______	Date: ______	Date: ______
Time on: ______	Time on: ______	Time on: ______	Time on: ______	Time on: ______	Time on: ______	Time on: ______
Time off: ______	Time off: ______	Time off: ______	Time off: ______	Time off: ______	Time off: ______	Time off: ______
Brief description of your activities today:	Brief description of your activities today:	Brief description of your activities today:	Brief description of your activities today:	Brief description of your activities today:	Brief description of your activities today:	Brief description of your activities today:

The pedometer should be worn at all times except when swimming, showering, or sleeping.

As soon as you wake up each morning, put the pedometer on your belt or waistband and write down the time that you put the pedometer on.

Before you go to bed each night, remove the pedometer and write down the time you took the pedomter off.

VITA

Rebekah Ann Wilson was born in Melbourne, Florida in 1979. Her love for being physically active started in the 1st grade when she joined her first soccer team. Rebekah was raised in Leesburg, Virginia, and graduated from Loudoun County High School in June 1997. She then went on attend East Tennessee State University, graduating in May 2002 with a Bachelor of Science in Exercise Science. While at ETSU she played for the women's soccer team and was a volunteer for the youth group at her church, Cornerstone Church. After marrying Corey Wilson on March 1st, 2003, the Wilson's moved to Knoxville and Rebekah entered the University of Tennessee in August 2003 to pursue a Master's degree in Exercise Physiology. She worked at Fort Sander Health and Fitness Center as an exercise physiologist and personal trainer while going through the Master's program. Rebekah will graduate in August 2005, receiving a Master of Science degree with an emphasis in Exercise Physiology.