Obesity has increased exponentially within the last three decades and is now widely recognized as one of today’s leading health threats due to it being a risk factor for diseases such as type 2 diabetes, cardiovascular disease, and hypertension. In recent years, there have been advances in technology such as bioelectrical impedance analysis (BIA), dual-energy X-ray absorptiometry (DEXA), and air-displacement plethysmography that have been used to categorize individuals into percent fat categories. However, there are still concerns with the validity of these devices.

PURPOSE: The purpose of this study was to analyze the validity of the InBody 520, BodPod, and Hologic DEXA against hydrostatic weighing.

METHODS: 32 male and 30 female subjects performed body composition testing using the InBody 520, BodPod, Hologic DEXA, and hydrostatic weighing.

RESULTS: The constant error values and mean values for percent body fat were the highest among the DEXA compared to the InBody and BodPod. The InBody showed a non-significant relationship ($p=0.11$, $p=0.47$, and $p=0.26$) between constant error values and percent body fat values for hydrostatic weighing for females, males, and all subjects respectively. The BodPod showed a significant negative relationship ($p=0.04$ and $p<0.01$) between constant error values and percent body fat from hydrostatic weighing but a non-significant negative relationship ($p=0.16$) for males. The DEXA showed a significant positive relationship ($p<0.01$ and $p=0.05$) between constant error and percent body fat for hydrostatic weighing for males and
all subjects respectively. CONCLUSION: The BodPod underestimated individuals with less fat mass and overestimated individuals with more fat mass. The Hologic DEXA consistently overestimated percent fat in all individuals.

*Keywords:* Hologic, dual-energy X-ray absorptiometry (DEXA), InBody, BodPod, body compositio
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VALIDITY OF WHOLE AND REGIONAL BODY COMPOSITION TESTING DEVICES

BY

RACHEL TAUBER

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Thesis Director:
Peter J. Chomentowski III
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CHAPTER 1

INTRODUCTION

Obesity has increasingly become more of an epidemic within the last three decades, especially within the United States. According to the World Health Organization (WHO, 2000), obesity is a disease defined by excess body fat to the extent health is impaired (Wang & Beydoun, 2007). Excess adiposity is now widely recognized as one of the leading health threats and as a major risk factor for type 2 diabetes, cardiovascular disease, and hypertension (Caballero, 2007; Romero-Corral et al., 2008). BMI is based on the observation that body weight is proportional to the square of the height in adults with normal body frames (Romero-Corral et al., 2008). Obesity and overweight are indicated by having a BMI greater than 30 kg/m² and 25 kg/m² respectively (Caballero, 2007; WHO, 2000). The prevalence of obesity has steadily increased over the past three decades, and evidence suggests obesity is likely to remain on the rise (Wang, Beydoun, Liang, Caballero & Kumanyika, 2008). The prevalence of obesity in U.S. adults increased from 15% in the 1976-1980 time period to 33.8% for 2007 to 2008 (Flegal, Carroll, Ogden & Curtin, 2010; Ogden et al., 2006). If the data included overweight individuals, the prevalence would increase to 68%. As a result, more than two thirds of the United States adult population is either overweight or obese (Flegal et al., 2010). In addition, 17% of children are obese, and most children will carry their weight into adulthood (National Center for Health Statistics, 2010; Ogden et al., 2006). While there have been large disparities between population
groups and continuing changes in patterns, there has been a general consensus that the prevalence of overweight and obesity also rose in every age, gender, and ethnic category (Wang et al., 2008).

Overall, there has been a faster increase in obesity in women than in men (rate of 0.91 vs 0.65), with African American women having the highest increase in prevalence among all ethnicities (0.878; Wang et al., 2008). Non-Hispanic African Americans had the highest prevalence for obesity, and minority groups (i.e., non-Hispanic African Americans and Mexican Americans) had a higher combined prevalence for obesity than non-Hispanic Whites by almost 10%. Between 2003 and 2004, the corresponding prevalence of obesity was 76.1% and 75.8 versus 64.2% (Wang & Beydoun, 2007). More than 80% of non-Hispanic African American women aged 40 years and older were overweight and obese, and the prevalence of extreme obesity was twice as much in African American women than Caucasian and Mexican American women (Wang & Beydoun, 2007). While some ethnicities have shown an increase in prevalence, Asian Americans showed a much lower prevalence (5%) than the national average (30%; Wang & Beydoun, 2007).

The total caloric intake is increasing while the total energy expenditure is decreasing. Less than 30% of the US population has an adequate level of physical activity, another 30% is active but does not meet the daily recommendations, and the remainder are sedentary (Cabellero, 2007). The availability of electronic devices in the home has promoted a sedentary lifestyle, particularly among children (Pi-Sunyer, 2002). Transportation has also played a role in sedentary lifestyle, which has led to lower energy expenditure. Urban planning promotes car use, commends long commutes, and restricts the opportunities for walking, which also lead to sedentary lifestyle (Cabellero, 2007). Limited and/or unsafe public spaces for recreational
physical activity and for children to walk to school have also led to lower energy expenditure (Caballero, 2007). There has been a dramatic decline in the proportion of children who walk or bike to school, and the average US teenager spends over 30 hours per week watching television (Caballero, 2007). Budget constraints and pressure to meet academic performance in school has also lead to a limited amount of physical activity in schools (Caballero, 2007).

Since obesity is on the rise, it is important to have valid and reliable tools to assess growth and body composition (Jensky-Squires et al., 2008). It is essential to develop safe and accurate tools to assess body composition as well as devices that are affordable (Jensky-Squires et al., 2008). Body composition analysis is important for understanding proportional changes in fat and lean mass for healthy individuals as well as individuals with various health condition (Jensky-Squires et al., 2008). One of the main objectives of obesity management is to reduce fat mass and to preserve fat-free mass during weight loss in order to maintain the physical capacities and energy expenditure of obese subjects (Lazzer et al., 2008).

BMI is the most common way to measure body composition, but BMI has limited diagnostic performance due to its inability to discriminate between fat and lean mass (Okorodudu et al., 2010; Romero-Corral et al., 2008). Another method is bioelectrical impedance analysis (BIA), but the accuracy and precision of the BIA method is often influenced by instrumentation, subject factors, technician skill, environmental factors, and the prediction equation used to estimate fat-free mass (Kushner, 1992; Lohman, 1989; Van Loan, 1990). The BodPod has been validated against hydrostatic weighing, but factors that influence estimation of body volume and the use of predicted rather than measured lung volumes may affect the accuracy (COSMED USA, n.d.). Recently, the dual-energy X-ray absorptiometry (DEXA) scanner has emerged as a valid measurement, but the type of scanner may affect the results. For
example, the Hologic scanner yielded higher total body fat results than a different manufacturer of the DEXA, GE-Lunar, in both men and women (Plank, 2005). Due to the high variability among the BodPod, the DEXA, and the InBody, there was a need to compare the accuracy of these devices to hydrostatic weighing, which has been considered to be the gold standard for multiple decades (Jensky-Squires et al., 2008). The purpose of this study was to analyze the validity of the InBody 520, BodPod, and Hologic DEXA against hydrostatic weighing. It was hypothesized that the DEXA would be statistically different than the BIA and the BodPod compared to hydrostatic weighing based on paired-sample $t$ tests and constant error (CE). In addition, it was hypothesized that the BodPod and InBody 520 would be the most similar to hydrostatic weighing.
CHAPTER 2

REVIEW OF THE LITERATURE

Obesity and Morbidity

The increase in prevalence of obesity has led to an increase in morbidity and mortality. Obesity and extreme obesity are associated with an increase rate of death from all causes, particularly from cardiovascular disease (Adams et al., 2007; Flegal, Graubard, Williamson & Gail, 2005; Mokdad, Marks, Stroup, Gerberding, 2005). In the United States, estimates of annual excess deaths due to obesity range from 112,000 to 365,000. Weight-related cardio-metabolic risks have increased at an accelerated rate, diabetes mellitus rose from 1.5% to 6%, and metabolic syndrome increased from 27% to 56% in men (Gregg et al., 2005).

Type 2 diabetes and insulin resistance are strongly associated with obesity, with almost 80% of cases being weight related (Colditz, Willett, Rotnitzky & Mason, 1995). Insulin signaling is defective with obesity and is associated with other post receptor binding defects in insulin action including impaired generation of second messengers, diminished glucose transport, and abnormalities in some critical enzymatic steps involved in glucose metabolism (Pi-Sunyer, 2002). The increased levels of free fatty acids found in obese individuals also contributes to the defects in glucose metabolism and storage due to increased mobilization and oxidation in the muscle and liver (Pi-Sunyer, 2002). Insulin resistance is characterized by a reduced ability to
take up glucose at a given insulin concentration (Barnard, Roberts, Varon, & Berger, 1998). In response to the resistance, the pancreas secretes more insulin to promote blood glucose uptake (Barnard et al., 1998). High levels of insulin can increase the sympathetic nervous system which leads to elevation of epinephrine and norepinephrine levels, which can increase heart rate, stroke volume, and blood pressure and can interfere with insulin release and glucose uptake at the tissues (Tepperman & Tepperman, 1987).

The amount of fat in the body is regulated as part of energy homeostasis, which is a process in which energy intake is matched to energy expenditure and the size of the body energy stores (Woods & Seeley, 2002). Insulin and leptin are two hormones that control energy balance. The primary role of leptin specifically is to provide the central nervous system with a signal of energy stores in the body to enable the brain to adjust as necessary to balance intake and expenditure (Enriori, Evans, Sinnayah & Cowley, 2006). Pancreatic insulin secretion and leptin, which is secreted from white fat mass, are both directly proportional to the size of the fat mass. Administration of either hormone into the brain relays a signal in which the brain assumes that more fat has accumulated in the body (Woods & Seeley, 2002). As a result, reducing the amount of insulin or leptin in the brain causes increased food intake, decreased energy expenditure, and increased weight gain leading to a person feeling underweight (Woods & Seeley, 2002). Activation of central leptin receptors increases the activity of the sympathetic nervous system with stimulates energy expenditure in adipose tissue (Enriori et al., 2006). Lack of leptin or leptin receptors leads to obesity (Woods & Seeley, 2002).

Hypertension or other cardiovascular diseases, respiratory illnesses such as asthma, chronic obstructive pulmonary disease (COPD), and sleep apnea are also increased with individuals who are obese (Poulain et al., 2006). A larger body mass increases circulatory
demand, including elevation in the cardiac output and systemic vascular resistance (Arciero & Nandil, 2004). The increased size of the chest and abdomen in obese individuals alters respiratory patterns that lead to ventilation-perfusion mismatches and predisposes the individual to hypoxia and carbon dioxide retention that can then lead to sudden cardiac death from ventricular arrhythmias (Arciero & Nandil, 2004). Obesity also promotes increased plasma lipid peroxidation, which is a free-radical-generating process. Free radicals are involved in multiple human pathologies including cancer, hypertension, and atherosclerosis (Amirkhizi, Siassi, Minaie, Djalali, Rahimi & Chamari, 2007). Obesity increases the mechanical and metabolic work on the myocardium, which leads to greater myocardial oxygen consumption and lipid peroxidation production (Amirkhizi et al., 2007). Obesity can also cause lipid peroxidation by progressive and cumulative cell injury resulting from pressure from the large body mass (Amirkhizi et al., 2007).

Fat tissue accumulation impairs ventilatory function, and an increase in BMI is often associated with a reduction in forced expiratory volume in one-second, forced vital capacity, total lung capacity, and mainly functional residual capacity (Poulain et al., 2006). Obesity increases the ventilatory work due to a reduction in chest wall compliance and respiratory muscle strength which can lead to an imbalance between the demand on the respiratory muscles and their capacity to generate tension (Poulain et al., 2006). Abdominal and thoracic fat are likely to have direct effects on the downward movement of the diaphragm and chest wall compliance (Salmone, King & Berend, 2010). Therefore, a reduction in the downward movement of the diaphragm is likely to decrease total lung capacity by limiting the room for lung expansion (Salmone, King & Berend, 2010). Obesity is also a risk factor for sleep apnea. Increased fat tissue deposition in the pharyngeal region and reduced operating lung volumes in obesity act
together to reduce upper airway caliber, modify airway configuration, and increase their collapsibility, leading to closures during sleep (Poulain et al., 2006).

Gastroesophageal disease and nonalcoholic fatty liver disease is linearly related to obesity (Angulo, 2002). A large amount of fat mass has a significant positive relationship with cholesterol production. The increased presence of cholesterol in bile is likely the cause of gallbladder disease (Arciero & Nindl, 2004; Bray, 1987). Lastly, obesity is also associated with complications of pregnancy, menstrual irregularities, hirsutism, stress incontinence, and psychological disorders (Calle, Thun, Petrelli, Rodriguez & Heath, 1999; National Institutes of Health, 1998; Rabkin, Mathewson & Hsu, 1977; Rim & White, 1979).

An increase in disease also leads towards an increase in medical costs. Medical expenses due to obesity and being overweight increased to 9.1% of the total US medical expenditures in 1998 and has only increased since then (Wang et al., 2008). It has been projected that by 2030, the health care costs attributable to obesity and overweight could range from $860 to $956 billion, which would account for 15.8 to 17.6% of total healthcare costs or 1 in every 6 dollars (Wang et al., 2008).

Body Composition

Body composition is defined as the measurement of body tissues such as muscle mass, soft tissue, body fat, water composition, and bone mineral density. Body mass can be viewed as different levels that range from the atomic level to molecular, cellular, tissue-organ, and finally to whole body (Wang, Pierson & Heymsfield, 1992). In a two-compartment model, body composition is broken down into fat mass and fat-free mass. Body fat percent is the percentage of the total body mass that is composed of fat. Fat-free mass simply refers to all body tissue that
is not fat, including bone, muscle, organs, and connective tissue. Body fat percentage can be broken down into categories that classify an individual as underweight, normal weight, overweight, and obese. An individual is considered obese if total body fat percent is greater than 25% for males and 35% for females (Kenney, Wilmore & Costill, 2015).

Fat mass can further be broken down into essential and storage fat. Essential fat consists of the fat in the heart, lungs, liver, spleen, kidneys, intestines, muscles, and within the central nervous system. It is the minimum amount of fat needed in the body for normal physiological functioning. An ideal percentage of essential fat for a man is 3% and 12% for a woman (Behnke & Wilmore, 1974). Storage fat includes fat primarily in adipose tissue and can include the visceral fatty tissues that protect the organs within the thoracic and abdominal cavities and the larger adipose tissue volume deposited under the skin’s surface. Females generally have more fat than males and such fat serves as important biological functions for childbearing and other hormone-related functions. Hormones such as estrogen and lipoprotein lipase play a critical role in body mass. Estrogen influences body growth by broadening the pelvis, stimulating breast development, and increasing fat deposition in the hips and thighs (Tichy & Mallasanos, 1976). Lipoproteins are transporters that carry cholesterol and triglycerides through the bloodstream to fat storage depots, and lipoprotein lipase activity is very high in the hips and thighs of women. There is low lipolytic activity from hormone-sensitive lipase, which makes it difficult for women to lose fat in the hip and thigh region (Vella, Kravitz & Kravitz, 2002). Men also generally have more muscle mass than women that is associated with an increased total body water composition, protein content and mineral body content compared to females (Cohn et al., 1980).

Aging also plays a role in gender and body composition. Body size and composition are similar in boys and girls during early childhood, but during late childhood, girls begin to
accumulate more fat than boys. Boys begin to increase their fat-free mass at a much higher rate than girls during adolescence (Wang, 2002). These body composition differences between the sexes occur primarily because of endocrine changes with development. At full maturity, not only do males have more muscle mass, but the distribution of the muscle mass differs from that in women (Rogol, Roemmich & Clark, 2002).

History of Body Composition

Body composition can date back to 400 B.C. to the ancient Greeks. The ancient Greeks originally believed that humans were comprised of fire, air, water, and earth. The Greeks thought that these elements could be hot, cold, dry, or moist. When food was ingested, these elements would be converted into four body humors: blood, phlegm, yellow bile, and black bile (Schultz, 2002). Modern body composition can be traced back to the 1st century; however, many conceptual frameworks were not practical or accurate (Wang, Wang & Heymsfield, 1999). Important and accurate advances started to develop in the early 20th century. In 1921, J. Matiegka developed the anthropometric model to estimate total body muscle mass, and metabolic concepts started to be developed in the 1930s (Wang et al., 1999).

In the early 1940s, Albert Behnke introduced hydrostatic weighing using Archimedes - principle and the two-compartment model (Behnke, Feen & Welham, 1942). Archimedes principle and the hydrostatic weighing technique revolutionized body composition since they provided a simple and practical method for investigators to estimate fat mass and fat-free mass in humans (Behnke et al., 1942). According to Heymsfield et al. (2005), the Archimedes principle states, “A body immersed in a fluid is acted on by a buoyance force, which is evidenced by a
‘loss’ of weight equal to the weight of the displaced fluid” (p. 19). Buskirk (1961) proposed the use of a constant correction of 100mL to approximate the volume of gas in the gastrointestinal tract. Therefore, the equation used for hydrostatic weighing from Archimedes principle is:

\[ D_b = \frac{W_a}{D_w} \frac{W_a}{(Rv+0.100)} \] (1)

The two-component model, which divides body composition into fat mass and fat-free mass, can then be divided into more compartments. The fat compartment consists of extractable lipids, and the fat-free mass can be broken down into water, protein, and mineral components (Siri, 1961). Siri (1956) proposed that the following equation could be used to calculate percent body fat from body density:

\[ \% \text{ fat} = \frac{457}{\text{Body Density}} - 414.2 \] (2)

The Brozek equation is similar to the Siri equation, and is another commonly used equation to calculate percent body fat (Brozek, Grande, Anderson & Keys, 1963). The equation is as follows:

\[ \% \text{ fat} = \frac{495}{\text{Body Density}} - 450 \] (3)

To ensure accuracy, the two equations that use this two-compartment model require the following assumptions to be met: 1) the density of fat is 0.901 g/cc, 2) the density of the fat-free mass is 1.10 g/cc, 3) the densities of fat and the fat-free components are the same for all individuals, 4) the densities of the tissues comprising the fat-free mass are constant within an individual and their proportional contribution to the lean component remains constant, and 5) the individual being measured differs from the reference body only in the amount of fat. The fat-free mass of the reference body is assumed to be 73.8% water, 19.4% protein, and 6.8% mineral (Brozek et al., 1963; Siri, 1961). Differences in fat-free mass density are found according to
differences in age, gender, ethnicity, body fat percentages, and physical activity levels, which cause these assumptions to not be met; therefore, different equations have been established to allow these criteria to be met (Baumgartner, Heymsfield, Lichtman, Wang & Pierson, 1991; Wang, Heymsfield, Aulet, Thornton & Pierson, 1989; Williams et al., 1993). Schutte et al. (1984) determined an equation that could be used for African American men to correct for ethnicity differences:

$$\% \text{ fat} = \frac{437.4}{\text{Body Density}} - 392.8$$

Ortiz et al. (1992) also determined an equation that could be used specifically for African American females to correct for ethnicity and gender differences:

$$\% \text{ fat} = \frac{483.2}{\text{Body Density}} - 436.9$$

In 1961, W.E. Siri introduced the three-compartment model, and the first BIA was introduced as well (Siri, 1961). The three-compartment model suggests fat mass, fat-free mass, and total body water are the three components that comprise body composition based on body mass and body volume (Siri, 1961). This method can be related to differences in hydration, and it assumes that the ratio of protein to mineral is constant (Siri, 1961). The four-compartment model was later created to expand on the three-compartment model. The four-compartment model measures fat mass, total body water, bone mineral, and residual. Multicompartment models allowed for a smaller error rate than the two-compartment model; however, there are still a handful of assumptions that need to be met, such as 1) the density of water is 0.9937 g/cm$^3$, 2) the density of protein is 1.34 g/cm$^3$, 3) the density of soft tissue is 3.317 g/cm$^3$, 4) fat is 0.9007 g/cm$^3$, 5) bone mineral is 2.982 g/cm$^3$, and 6) glycogen is 1.52 g/cm$^3$ (Heymsfield et al., 2005).

Many other important techniques were developed since then, such as dual-energy X-ray absorptiometry, which can be dated back to the early 1970s. Over the next few decades,
computed axial tomography (CT) and magnetic resonance imaging (MRI) techniques were developed. Air-displacement plethysmography also emerged as a reliable measurement of body composition (Foster, Hutchinson, Mallard & Fuller, 1984; Hounsfield, 1973; Mazess, Cameron, & Sorenson, 1970; Tokunaga, Matsuzawa, Ishikawa & Tarui, 1983).

**Body Composition Devices**

BMI is the most common method used to diagnose obesity and has been used extensively in epidemiological studies and in clinical practice due to its simplicity. However, the BMI has limited diagnostic performance due to its inability to discriminate between fat and lean mass (Okorodudu et al., 2010; Romero-Corral et al., 2008). The sensitivity to diagnose obesity by BMI is relatively low since it misses more than half of people with body fat percent defined as obese (Romero-Corral et al., 2008). BMI may also misclassify those with high muscle mass into overweight or obese (Völgyi et al., 2008). Therefore, there is a need to find alternatives to diagnose obesity and percent body fat.

BIA is a commonly used method for estimating body composition by measuring the impedance or resistance to small electrical current as it travels through the body’s water pool (Lee & Gallagher, 2008). An estimate of total body water is acquired from which total body fat-free mass is calculated using the assumption that 73% of the body’s fat-free mass is water (Lee & Gallagher, 2008). Total body water weight is then split into intracellular water and extracellular water compartments, which is useful to describe fluid shifts and fluid balance and to explore variations in levels of hydration (Lee & Gallagher, 2008). Other assumptions include 1) the human body is shaped like a perfect cylinder with a uniform length and cross-sectional area.
and, 2) at a fixed signal frequency, the impedance to current flow through the body is directly related to the length of the conductor (height) and inversely related to the cross-sectional area (Kushner, 1992). Impedance is a function of resistance and reactance where:

\[ Z = \sqrt{R^2 + X_c^2} \]  

(4)

Resistance (R) is a measure of pure opposition to current flow throughout the body; reactance (X_c) is the opposition to current flow caused by capacitance produced by the cell membrane (Kushner, 1992).

The advantages of BIA include portability and ease of use, relatively low cost, minimal participant participation required, and safety. The validity of BIA, however, has been shown to be inaccurate and remains a significant issue (Lee & Gallagher, 2008; Lukaski, Bolonchuk, Hall & Siders, 1986). The disproportionality of the body in terms of its size, shape, and composition between limbs and trunk affect impedance measurements. In severely obese subjects, there is a greater proportion of body mass and body water accounted for by the trunk. The hydration of fat-free mass is greater in obese subjects, and the extracellular water and intracellular water ratio is larger in obese patients. Therefore, the ability to predict fatness in severely obese subjects remains a problem (Tagliabue et al., 2001). BIA is also influenced by sex, age, disease state, race or ethnicity, and level of fatness in which total body water weight and relative extracellular water weight are greater in obese individuals compared with normal-weight individuals (Lee & Gallagher, 2008). BIA also relies on the differing behavior of biological tissues in response to an applied electrical current since the total impedance incorporates both resistance and capacitance components (Völgyi et al., 2008).

The accuracy and precision of the BIA method are also affected by instrumentation, subject factors, technician skill, environmental factors, and prediction equation used to estimate
fat-free mass (Kushner, 1992; Lohman, 1989; Van Loan, 1990). The standard error of estimate
(SEE) is estimated to be ~3% body fat if the reference method is error free. However, this is
extremely unlikely, so as a result, part of the total prediction error (20% to 50%) is associated
with the BIA method and the equations can be attributed to error in the reference method
(Lohman, 1992). Therefore, the SEE is closer to 5-6% of body fat (Jackson, Pollock, Graves &
Mahar, 1988). Subject factors such as eating, drinking, dehydrating, and exercising alter the
individual’s hydration state, thereby affecting total body resistance and estimate of fat-free mass
(Jackson et al., 1988).

Traditionally, assessing body composition relied upon the principle of hydrostatic
weighing, which was considered the “gold standard” (Jensky-Squires et al., 2008). A subject’s
body mass in air is assessed usually within 50g. The body volume in water is estimated, and the
body volume equals loss of weight in water with the appropriate temperature correction for
water’s density. The water temperature provides the correction factor to determine water density
at the weighing temperature (Tanaka, Girard, Davis, Peuto & Bignell, 2001). Body volume
calculation requires subtracting the buoyancy effect of the residual lung volume measured
immediately before, during, or following the hydrostatic weighing. Failing to account for the
residual lung volume underestimates the whole-body density because the lungs’ air volume
contributes to buoyancy. Residual lung volume decreases slightly in water compared to air and is
due to the water’s compressive force against the thoracic cavity (Hsfeh, Kline, Porcari & Katch,
1985). Hydrostatic weighing follows two assumptions: 1) the density of each tissue constituting
the fat-free mass is known and remains constant and 2) each tissue type represents a constant
proportion of the fat-free mass (Siri, 1961).
While hydrostatic weighing is considered the gold standard, there are a few limitations for the measurement. Subjects are submerged in water by either sitting, kneeling, or prone after maximal expiration and multiple trials are required to eliminate error variability. Hydrostatic weighing requires a tank, which is not always available, and it requires time and practice. In addition, some individuals are not comfortable in the water (Volpe, Melanson & Kline, 2010).

Air-displacement plethysmography is an alternative to hydrostatic weighing. Air-displacement plethysmography is suitable for young children, the elderly, and other special populations since complete submersion of water is very difficult. Air-displacement plethysmography uses pressure-volume relationships to estimate volume and density. Boyle’s law describes the pressure-volume relationship at constant temperature:

\[ \frac{P_1}{P_2} = \frac{V_2}{V_1} \]  \(5\)

P1 and V1 represent one paired condition of pressure and volume, and P2 and V2 represent a second equation (Faires, 1962). The quality of air compressed under isothermal conditions will decrease its volume in proportion to the increasing pressure (Faires, 1962). In contrast, under adiabatic conditions the temperature of air does not remain constant as its volume changes and the molecules gain or lose kinetic energy. Poisson’s law shows the relationship between pressure and volume under adiabatic conditions:

\[ \frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^{\gamma} \]  \(6\)

\(\gamma\) is the ratio of specific heat of the gas at constant pressure to that at constant temperature (Sly, Lanteri & Bates, 1990). For small changes in volume relative to total volume air, under isothermal condition changes its pressure by 40% less than it would under adiabatic conditions (Dempster & Aitkens, 1995). Failure to correct for this difference introduces significant volume measurement errors (~2.5%; Gradinger et al., 1963). The BodPod estimates body volume by
application of Poisson’s law and has improved precision and accuracy compared with past 
techniques (Demerath et al., 2002; Dempster & Aitkens, 1995; Fields, Goran & McCrory, 2002; 

There has been validation of hydrostatic weighing and air plethysmography. Due to the 
biological variability in the fat-free mass in a given population, the SEE for body fat for 
hydrostatic weighing is estimated to be within 1-2% body fat (Lohman & Going, 2006). Most of 
the studies in adults with hydrostatic weighing have been conducted in young to middle-aged 
adults, and the subjects’ BMI have varied between 17 to 40 kg\textper m^2. The average differences 
between the BodPod and hydrostatic weighing ranged from -4% to 1.9% fat. However, the larger 
percentage differences may have been due to differences among small sample sizes (Collins et 
al. 1999; Dewit, Fuller, Fewtrell, Elia & Wells, 2000; Fields, Hunter & Gorman, 2000; Iwaoka 
et al., 1998). In some studies with multiple ethnicities represented, ethnicity did not contribute 
significantly to differences between the methods (McCrory et al., 1998; Nunez et al., 1999). 
Among studies reporting multiple correlation coefficients, R ranged from 0.78 to 0.94 and SEE 
ranged from 1.8 to 2.3% fat in the excellent range (Lohman, 1992).

Since the same equation is used to convert density from BodPod and hydrostatic 
weighing to percent fat, differences between the methods must be attributable to factors that 
influence estimation of body volume, including clothing; moisture on the body, in the hair, and 
on the swimsuit; metabolism; and the use of predicted rather than measured lung volumes. Other 
factors that may explain differences between the two devices are subject sex, subject size, and 
errors in residual volume and lung volume (Demerath et al., 2002). Reliability was high for 
percentage body fat and body density in adults and is considered a valid measurement method in 
the healthy elderly (Lee & Gallagher, 2008).
The DEXA has emerged as a dependable method to measure body composition. DEXA systems provide whole-body and regional estimates of three main components: bone mineral, bone-free fat-free mass, and fat mass (Lee & Gallagher, 2008). The DEXA technique is accepted as a noninvasive measurement method that can be applied to everyone at all ages. The radiation exposure ranges from 0.04 to 0.86 mrem, which is equivalent to between 1 and 10% of a chest x-ray (Lee & Gallagher, 2008). There are multiple advantages to using the DEXA. The DEXA includes accuracy and reproducibility and provides assessment of regional body composition and nutritional status in disease states and growth disorders (Lee & Gallagher, 2008). While there are many advantages to the DEXA, there are also some disadvantages, including a small amount of radiation, the scanning bed or stretcher has an upper weight limit, and the whole-body field of view cannot accommodate very large persons (Lee & Gallagher, 2008). This may be an issue for measuring individuals who are severely obese.

The DEXA has several assumptions, including 1) the assumed constant attenuation of fat and bone mineral content, 2) minimal effects of hydration on lean tissue estimates, 3) lack of an effect of variations in regional thickness on soft-tissue estimates, and 4) the fat content of the area being analyzed is comparable with the fat content of the unanalyzed area (Lee & Gallagher, 2008). Errors in the estimation of fat mass, lean, and bone in both regional and whole-body values are a limitation associated with these assumptions (Lee & Gallagher, 2008).

There are three manufacturers of DEXA scanners currently available: Hologic, GE-Lunar, and Norland (Plank, 2005). Recently, manufacturers introduced fan-beam technology in which faster scanning speeds and higher resolutions were offered; however, magnification and projection effects at the boundaries of the beam may compromise accuracy in these machines (Plank, 2005). Hologic developed the QDR-2000 and GE-Lunar developed Expert, and both of
those machines are fan-beam machines (Plank, 2005). When comparing the two, the Hologic scanner yielded higher total body fat results than the GE-Lunar scanners in both men and women (Plank, 2005). Fat in the arms and legs was significantly greater when measured by the Hologic QDR-2000 and the GE-Lunar DPX-L, and the Hologic DEXA reported lower trunk fat values (Bairos, Dawson-Hughes & Roubenoff, 2003). In another study, the Hologic machine generated markedly higher values for the fat content of the arms, the legs and total body, but significantly lower values of the trunk (Yang, Zhu & Paton, 2004).

The results of studies comparing body composition measurements by DEXA and BodPod in adults are generally similar to studies in which hydrostatic weighing was the criterion method. Theoretically, the regression line relating the values from the two methods should have a slope equal to 1.0. The SEE should be between 2 and 3% body fat. Lastly, the error between methods must remain uncorrelated by the mean value (Altman & Bland, 1983). Multiple studies have shown an agreement in mean values, and the percent fat ranged from 1% to 3% in pencil-beam DEXA scanners (Evans, Saunders, Spano, Arngrimsson, Lewis & Cureton 1999; Kohrt, 1998; Lohman, Harris, Teixeira & Weiss, 2000; Withers et al., 1998).
CHAPTER 3

METHODOLOGY

Participants

Thirty-two males and thirty female participants were recruited to participate in the study via verbal proposal to Kinesiology and Physical Education classes at Northern Illinois University and flyers posted in various locations throughout the university. The subjects ages ranged from 18-29 years old. Females were instructed that they needed to pass a pregnancy test, and failure to pass a pregnancy test would result in dismissal from the study. Any female subject who failed to pass a pregnancy test would be excluded from participating due to the mild radiation from the DEXA and the electrical current from the InBody device. Other exclusion criteria included anyone with metal implants in the body, a weight larger than 350 pounds, anyone younger than 18 years old or older than 29 years old, and any type of respiratory illness.

Procedures

Participants were recruited to participate in the study via a speech to Kinesiology and Physical Education classes at Northern Illinois University and flyers posted in various locations throughout the university campus (Appendix A). Upon interest, the principle investigator (PI)
scheduled a time for subjects to meet with the PI and completed an informed consent (Appendix B) and an initial screening questionnaire (Appendix C). The initial screening questionnaire asked the participant basic demographic questions such as age, gender, did they currently have any metal implants in their body or a pacemaker. Height was measured to the nearest centimeter using a wall-mounted stadiometer and weight was measured to the nearest tenth of a kilogram once on the InBody 520. The subject’s BMI was determined by dividing weight in kilograms by height in meters squared. The subjects who met all inclusion criteria and qualified for participation in the study were scheduled a time to come back for testing (at least 24 hours later) and instructed on proper guidelines to follow for the day prior to and the day of testing to ensure accurate results.

All subjects were given a document explaining what they are to refrain from 24 hours before and instructions for the day of testing (Appendix E). All subjects were to refrain from eating for at least five hours prior to testing but no more than 12 hours, not exercise within eight hours prior to testing, not consume large amounts of liquids within four hours prior to testing, not consume caffeine or other diuretics within three hours prior to testing, not consume alcohol within 12 hours prior to testing, and not shower directly prior to testing. The subject would be asked to return for testing to the body composition lab at least 24 hours after the initial screening meeting.

Upon return for testing, the PI had a questionnaire that the subject had to truthfully answer to ensure they followed all pretesting guidelines (Appendix D). When the subject returned for testing, if female, they were given a pregnancy test to confirm participation in the study. When the pregnancy test came back negative or if the subject is male, both female and male subjects were asked by the PI to confirm that they had followed all pretesting procedures.
from the Pretest Guidelines form. Once confirmed, male subjects were asked to void all contents of their bladder, females already having done so during the pregnancy test. Upon return from the restroom, subjects changed into the clothes they brought if they had not done so already and removed all clothing and jewelry of any kind excluding underwear (unless it contained any type of metal). Subjects were asked again to ensure they were not wearing any metal, including removable piercings or jewelry. Weight was remeasured to the nearest tenth of a kilogram once on the InBody 520 to ensure consistency and accuracy. Height was already measured during the first session.

The subjects stood for 15 minutes prior to beginning the InBody 520 due to proper hemodynamics of blood flow. Standing for 15 minutes prior to the InBody 520 was crucial because the InBody 520 recognizes that the subject is in the standing position and time is needed for all blood and body fluids to properly circulate/pool to where they typically would be while standing due to gravity. Gravity acts upon the body’s venous return system causing blood to accumulate in the lower extremities (Belloni, 1999). The subject was then asked to wipe his or her hands and feet with Virex solution before stepping onto the foot electrodes with heels properly on the heel electrodes and feet rolled forward for proper foot placement. Once the InBody 520 recognized and confirmed the subject’s body weight, the subject’s data was input, including height, gender, age, and an identification number. Once all data was entered properly, the subject was asked to grab hold of the hand electrodes with his or her thumbs in proper placement over the electrodes. The subject was instructed to hold his or her arms straight and away from the body at approximately a 45-degree angle and stand upright with good posture. The subject was then instructed to stand still for the duration of the test, which takes
approximately 90 seconds to complete. Once the test was complete, the subject was instructed to step off the machine.

After completion of the InBody 520, prior to beginning the DEXA scan, the PI entered data into the DEXA computer specific to the subject, such as his or her identification number, age, height, and weight. All of this information was filled out on the Initial Screening Questionnaire, and the InBody 520 already measured his or her body weight. The subject was placed within the scanning rectangle on the DEXA bed by the PI, with proper arm placement, positioned at the subject’s side and slightly pronated with his or her fingers pointed straight. The subject’s toes were pointed up and their feet were held together by a plastic strap to eliminate movement throughout the scan. Once the subject was in position, the subject was instructed to remain as still as possible for the duration of the scan. The whole-body scan took just over 6 minutes to complete.

Once the InBody 520 and the DEXA scan were completed, the PI instructed the subject to change into proper attire for the BodPod test, if he or she had not done so already. For accuracy purposes, women wore wear a sports bra without any wires and spandex or tight shorts. Men wore wear tight fitting shorts or spandex swim trunks. The subjects then put on a swim cap to wear during the test to minimize any discrepancies with the hair. Each test required the PI to recalibrate the BodPod empty. The computer screen walked the PI through a series of instructions to calibrate the BodPod. Once the calibration was completed, the PI entered the subject’s data including the identification number, technician, gender, age, and height. Height was reported in centimeters. The Siri equation was used for Caucasian subjects while the Schutte equation was used for African Americans. Once the data was entered, the PI calibrated the BodPod with the calibration volume. The computer instructed the PI to clear the scale and verify
nothing was on the BodPod. Once the scale was verified, the PI instructed the subject to step on the scale. Once the weight was measured, the PI opened the BodPod door and instructed the subject to step carefully into the BodPod and sit comfortably. The PI verified that the subject was wearing proper attire and instructed the subject on what would happen during the test. The PI explained the button in the BodPod that would cancel the test and ensured that the subjects understood how to use it. The PI explained that when the subject was in the BodPod he or she needed to remain perfectly still and quiet, breathe normally, and not touch the magnets, windows, or walls. The PI told the subject that the test will last for 50 seconds and the test would be repeated once or twice to ensure accuracy. The PI closed the door, pressed “enter” on the computer and allow the test to run. After the first trial was ran, the PI opened the door to tell the subject to remain seated and still, closed the door, and ran another test. If the two tests varied, a third test was prompted. Once the test was done, the subject stepped out of the BodPod. The equation for percent fat that was used was either the Siri equation or the Schutte equation depending on the subject’s ethnicity. The Schutte equation was only used for African American males.

Once the BodPod was complete, the subject was tested using hydrostatic weighing. The PI ensured that the hydrostatic weighing tank was properly calibrated. If there was a large time frame in between testing (~2 hours) or if a large amount of water was displaced, the PI recalibrated the tank to ensure accuracy. The PI entered all of the information of the subject into the computer. The Siri equation was used for Caucasian subjects while the Schutte equation was used for African Americans. The lung volume was estimated using a specific formula depending on gender (Quanjer, 1983). For males it was:

\[
\text{Residual volume} = 0.033 \times \text{Height (inches)} + 0.022 \times \text{Age (years)} - 1.232
\]  

(6)
For females it was:

\[ \text{Residual volume} = 0.046 \times \text{Height (inches)} + 0.016 \times \text{Age (years)} - 2.003 \] (7)

The PI instructed the subject to walk up the steps, get into the hydrostatic weighing tank, and crouch down in the water. The subject then sat down on the weighing platform. The PI instructed the subject to submerge himself or herself in the water to get his or hair wet. Next, the PI instructed the subject to wipe the air bubbles off of his or her hair, arms, torso, and legs. The PI then instructed the subject to put his or her feet on the platform and cross ankles with knees slightly apart. The PI then explain the immersion process to the subject. The instructed “Grasp both handles and stay firmly seated on the weighing platform and take a breath.” The subject was then instructed to exhale slowly and continue to exhale as the subject went underwater and, “after expelling as much air as possible, hold still for a few seconds before coming up.” The PI started recording weighing data as soon as the subject began to go underwater, and the PI stopped recording data as soon as the subject came back up for air. The PI analyzed the graph of weight and saved the trial while the subject caught his or her breath. The PI repeated the process at least three times or until the results became consistent (Tesch, 2013). All consistent trials were required to be within a tenth of a kilogram after the subject expelled all of his or her air. The equation for percent fat that was used was either the Siri equation or the Schutte equation depending on ethnicity. The Schutte equation was only used for African American males.
Statistical Analysis

A one-way repeated-measure analysis of variance (ANOVA) was used to determine mean differences in percent body fat from the InBody 250, BodPod, Hologic DEXA, and hydrostatic weighing. Follow-up paired-sample t tests with Bonferroni correction (0.05/6=0.0083) were used when appropriate. Bland-Altman plots were generated to look at the relationship between CE and percent body fat with the hydrostatic weighing. Linear regression analyses were used to determine the relationships for percent body fat from the InBody, BodPod, and DEXA versus hydrostatic weighing. An alpha of \( p < 0.05 \) was used for all ANOVAs and regression analyzes.
CHAPTER 4

RESULTS

Table 1 presents the validation results comparing all methods (BodPod, InBody, and DEXA) to the criterion method, hydrostatic weighing for females, males, and all subjects. For females (n=30), the average percent fat ranged from 29.1% to 36.9%. For males (n=32), the average percent fat ranged from 17.1% to 25.5%. For all subjects (n=62), the average percent fat ranged from 23.3% to 31.0% in all. All three sample populations, the DEXA values reported significantly higher percent body fat values than the InBody, BodPod, & hydrostatic weighing values. There were no significant mean differences, however, among InBody, BodPod, and hydrostatic weighing values. All linear regression lines had a positive slope with a positive intercept with, except the DEXA values, which had negative values for females, males, and all subjects. All regressions were significant (p<0.05). All correlations were high in the positive direction. For females, the CE ranged from -7.76 to -0.57 percent body fat. For males, the CE ranged from -7.64 to 0.05 percent body fat. For all subjects, the CE ranged from -7.7 to 0.07 percent body fat. For all three samples, the CE was the highest among the DEXA values (Table 1). The SEE for all methods ranged from 2.5 to 3.5 percent body fat. The total error (TE) for all three methods ranged from 3.2 to 8.3 percent body fat with the highest values resulting from the DEXA (Table 1).

Figures 1-3 present the CE of DEXA, BodPod, and InBody against hydrostatic weighing percent fat values respectively for females. Figure 2 displays a significant correlation (p <0.05)
between CE and percent fat using the BodPod while Figures 1 and 3 report a non-significant relationship. Figures 4-6 represent the CE of the DEXA, BodPod, and InBody against hydrostatic weighing percent fat values respectively for males. Figures 4 and 5 show a non-significant relationship for the BodPod and the InBody, whereas Figure 6 shows a significant ($p < 0.05$) relationship for the DEXA. Figures 7-9 present the CE of DEXA, BodPod, and InBody against hydrostatic weighing percent fat values respectively for all subjects. Figures 7 and 9 show a significance for the DEXA and the BodPod. Figure 8 displays a non-significant correlation.

**Table 1.** Validity of percentage of body fat values estimated from BodPod, InBody, and DEXA compared to hydrostatic weighing (n=62).

<table>
<thead>
<tr>
<th>Gender</th>
<th>Method</th>
<th>% fat (±SD)</th>
<th>Slope</th>
<th>Intercept</th>
<th>CE</th>
<th>r</th>
<th>SEE</th>
<th>TE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female (n=30)</td>
<td>BodPod</td>
<td>29.8 ± 9.9</td>
<td>0.79</td>
<td>5.468</td>
<td>-0.66</td>
<td>0.96</td>
<td>2.5</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>InBody</td>
<td>29.7 ± 10.4</td>
<td>0.73</td>
<td>7.607</td>
<td>-0.57</td>
<td>0.92</td>
<td>3.4</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>DEXA</td>
<td>36.9 ± 8.2</td>
<td>0.94</td>
<td>-5.530</td>
<td>-7.76</td>
<td>0.93</td>
<td>3.1</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>HW</td>
<td>29.1 ± 8.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male (n=32)</td>
<td>BodPod</td>
<td>17.1 ± 7.7</td>
<td>0.74</td>
<td>5.237</td>
<td>0.76</td>
<td>0.91</td>
<td>2.6</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>InBody</td>
<td>17.8 ± 6.7</td>
<td>0.78</td>
<td>3.982</td>
<td>0.05</td>
<td>0.85</td>
<td>3.3</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>DEXA</td>
<td>25.5 ± 5.4</td>
<td>1.03</td>
<td>-8.294</td>
<td>-7.64</td>
<td>0.89</td>
<td>2.9</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>HW</td>
<td>17.9 ± 6.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All (n=62)</td>
<td>BodPod</td>
<td>23.3 ± 10.8</td>
<td>0.81</td>
<td>4.439</td>
<td>0.07</td>
<td>0.96</td>
<td>2.6</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>InBody</td>
<td>23.6 ± 10.5</td>
<td>0.81</td>
<td>4.273</td>
<td>-0.25</td>
<td>0.93</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>DEXA</td>
<td>31.0 ± 8.9</td>
<td>0.98</td>
<td>-6.954</td>
<td>-7.70</td>
<td>0.95</td>
<td>3.0</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>HW</td>
<td>23.3 ± 9.2</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

*CE=Constant error (actual value-predicted value): actual value is hydrostatic weighing, and predicted value is the equipment being evaluated against hydrostatic weighing

*SEE=Standard error of estimate: average amount of error in predicting the percent body fat from the equipment being evaluated

*TE=Total error: the square root of the sum of constant errors squared divided by the sample size
Figure 1. The relationship between the constant error (hydrostatic weighing - DEXA) and the hydrostatic weighing percent body fat reference value for females (n=30).
Figure 2. The relationship between the constant error (hydrostatic weighing - BodPod) and the hydrostatic weighing percent body fat reference value for females (n=30).

Figure 3. The relationship between the constant error (hydrostatic weighing - InBody) and the hydrostatic weighing percent body fat reference value for females (n=30).
Figure 4. The relationship between the constant error (hydrostatic weighing - BodPod) and the hydrostatic weighing percent body fat reference value for males (n=32).

Figure 5. The relationship between the constant error (hydrostatic weighing - InBody) and the hydrostatic weighing percent body fat reference value for males (n=32).
Figure 6. The relationship between the constant error (hydrostatic weighing - DEXA) and the hydrostatic weighing percent body fat reference value for males (n=32).

Figure 7. The relationship between the constant error (hydrostatic weighing - BodPod) and the hydrostatic weighing percent body fat reference value for all subjects (n=62).
Figure 8. The relationship between the constant error (hydrostatic weighing - InBody) and the hydrostatic weighing percent body fat reference value for all subjects (n=62).

Figure 9. The relationship between the constant error (hydrostatic weighing - DEXA) and the hydrostatic weighing percent body fat reference value for all subjects (n=62).
CHAPTER 5

DISCUSSION

Obesity has been on the rise within the last few decades. Obesity is also widely recognized as one of today’s leading health threats and is a risk factor for type 2 diabetes, cardiovascular disease, and hypertension (Cabellero, 2007). For the last 30 years, obesity has been primarily diagnosed using BMI (Romero-Corral et al., 2008). However, it has a limited diagnostic performance due to its inability to discriminate between fat and fat-free mass (Okorodudu et al., 2010). Therefore, it is crucial to find alternative valid measures to assess body composition. In recent years BIA, DEXA, and the BodPod have become popular due to the fact they are all invasive techniques compared to hydrostatic weighing. Although they are becoming more accepted, there are still concerns about their validity compared to hydrostatic weighing (Lee & Gallagher, 2008; Plank, 2005). Therefore, the purpose of this current study was to determine the validity of the InBody, BodPod, and Hologic DEXA against hydrostatic weighing.

InBody 520

The InBody 520 reported a mean percent fat within 1% of hydrostatic weighing values for females, males, and all subjects. This finding is inconsistent with the findings of Lazzer et al. (2008), who found that the InBody underestimated percent fat mass. One-way repeated-measures ANOVA showed differences in means to be statistically significant ($p < 0.05$). However, pairwise
comparisons indicated only a statistical significance with the DEXA. This finding is consistent with Lazzer et al. (2008), who found that the DEXA cannot be used interchangeably with the other devices. There was a non-significant relationship with the InBody compared to the BodPod and hydrostatic weighing. The SEE ranged from 3.3-3.5 percent body fat with all three sample sizes. Figure 3 and Figure 8 indicate a non-significant ($p = 0.11$ and $p = 0.26$) negative relationship between percent fat and the constant error for females and both genders. This is consistent with Jensky-Squires et al. (2008) who showed a negative relationship between the CE of the InBody and hydrostatic weighing. The InBody slightly overestimated the percent body fat for females. Figure 5 indicates that there is a mean of 0.05 for a constant error with a non-significant relationship. All of these indicate that there is not a strong correlation with constant error and the reference values. This is consistent with the findings of Biaggi et al. (1999), who indicted that there was a positive but non-significant correlation between hydrostatic weighing and bioelectrical impedance. Activity levels, body types, and hydration status could ultimately play a role in the differences between genders and both genders combined (Jensky-Squires et al., 2008). The InBody relies on the response of tissues to an applied electrical current. The InBody 520 is a multifrequency BIA which uses low- and high- frequency electric currents (Völgyi et al. 2008).

BodPod

The CE ranged from -0.66 to 0.76 percent body fat for all three sample sizes. For females, there was a statistically significant negative relationship ($p = .04$). This indicates that as the percent fat increased, the CE was more likely to overestimate percent fat. For the leaner females, there was an underestimation of percent fat. For males, there was also a negative
relationship. However, it was non-significant \( (p = .16) \). This is consistent with the findings of Collins et al. (1999) and Iwoaka et al. (1998). These studies indicated that there was a non-significant relationship between CE and percent fat in males. Overall, there was a negative relationship that is statistically significant \( (p < 0.01) \). This indicates that there is an overall relationship that the leaner the individuals are, the more likely the BodPod will underestimate percent fat, and the more fat the individual has, the BodPod will overestimate percent fat. This contradicts the findings of Biaggi et al. (1999), Levenhagen et al. (1999), and Millard-Stafford et al. (2001). These studies indicate that there is an upward trend between the percent fat and CE for both genders.

The linear regression displayed slopes that ranged from 0.74 to 0.81 for all three populations, consistent with the findings of Iwoaka et al. (1998) in which the slope was 0.78 for males. The slope of the current study (0.81) was similar with Millard-Stafford et al. (2001) for both genders (0.76 and 0.77 respectively). The SEE ranged from 2.5-2.6 percent body fat, which is consistent with Collins et al. (1999), Fields et al. 2000, and Fields et al. (2001).

Any differences between hydrostatic weighing and BodPod may be due to the differences in measured body mass (Fields, Goran & McCrory, 2002). In the current study, the body mass from the InBody was used for the hydrostatic weighing rather than the BodPod mass. While the current study didn’t investigate specific gender differences, the minimal differences seen between the significance of the CE of males compared to females and both genders may be a result of the excess body hair. Excess body hair may decrease body volume by increasing the isothermal air near the surface of the body. As a result, body volume may be underestimated (Fields, Goran & McCrory, 2002). Fasting conditions may also play a role in the current investigation’s results. The subjects were required to refrain from eating 5 hours prior to testing.
but no more than 12 hours. Gas in the stomach or the intestine that is not accounted for leads to an underestimate of body density and an overestimate of percent fat with hydrostatic weighing. Air-displacement plethysmography at least partially accounts for gas in the intestine (Fields, Goran & McCrory, 2002). Therefore, it was crucial that the guidelines of fasting were followed.

**DEXA**

All three sample sizes indicated a negative mean CE between -7.76 to -7.64 percent body fat. When comparing these values to hydrostatic weighing, it indicates that there was a non-significant positive relationship for females, a significant positive relationship with males, and a significant positive finding overall for all subjects. Overall, there is an overestimation of fat mass for all three samples. These findings are consistent with Silva et al. (2006), who indicated an overestimation of percent fat. Likewise, Santos et al. (2010) observed an overestimation of percent fat when using the Hologic 4500A DEXA. Lewis and Cure (2000) found that percent body fat from the DEXA displayed more deviation from the criterion method than any other techniques, including two-compartment models. The findings in the current study contradict the findings of Moon et al. (2009), which indicate a negative trend of percent body fat. The large CE may suggest a bias to overestimate percent body fat by more than 7.7% body fat. This finding contradicts the findings of Schoeller et al. (2005), which indicate that the Hologic DEXA QDR 4500A consistently underestimated fat mass compared to the criterion method (underwater weighing). This also contradicts Tylavsky et al. (2002), who stated that the Hologic QDR 4500A overestimates fat-free mass compared with other criterion methods.
There are multiple reasons why there is inconsistency amongst DEXA devices. The first source of error could be attributed to the software used to analyze the scan and the DEXA scatter itself (Moon et al., 2009). Software versions and different manufacturers are shown to give considerably different soft tissue assessments of the same individual. GE Lunar and Hologic are shown to give major differences in measurements of total body and regional body fat in HIV patients and in body fat distribution (Yang, Zhu & Paton, 2004). Another source of error could be the inability of the DEXA to measure soft tissue overlying the bone, considering DEXAs have the assumption that the soft tissue next to the bone has the same tissue composition as the soft tissue over the bone (Moon et al., 2009). Estimates for soft tissue in regions next to the trunk, arms, and head may decrease precision (Brownbill & Ilich, 2005).

Limitations and Applications

There were a few limitations within the study. The first was that lung volume was estimated for both the BodPod and the hydrostatic weighing. Measured lung volumes could have resulted in a higher accuracy; however, due to the time constraints and the equipment feasibility, measured lung volume was not quantified for each subject. A second limitation was the variation in body weight between the InBody and the BodPod. The BodPod-measured body weight was constantly slightly lower than the InBody weight, which may have led to the BodPod percent fat to be slightly different than the actual percent. The BodPod scale calibration was performed daily during testing using the predetermined calibration weights supplied from the manufacturer. The InBody calibrated itself during the warm-up processes. However, there is no calibration with a predetermined weight. The PI also had to rely on the honesty of the subjects while completing
the follow-up questionnaire for adherence to the pretest guidelines. This may have affected the accuracy of the equipment since many of the guidelines had to do with hydration and manufacturer recommendations. Hydration levels could play a large role in accuracy, especially with the InBody and DEXA because those machines take total body water weight into consideration. The BodPod and InBody also have specific guidelines for fasting prior to testing (Biospace, Inc., 2011; COSMED USA, n.d.). Hence, subject failure to comply with these guidelines could alter the validity of the results without the PI knowing.

The majority of the participants were Caucasian with only a few participants being of an African American or Asian American ethnicity. Therefore, the sample size for this study was not robust in terms of ethnic diversity. Future studies could include focusing on finding a sample with multiple ethnicities rather than a majority of the participants being Caucasian. African American men and women have relatively greater skeletal muscle mass, bone mineral mass, and bone density than Whites, so it could have been beneficial to have more subjects who are African American (Cohn et al., 1977; Nelson, Feingold, Bolin & Parfitt, 1991; Ortiz et al., 1992; Schutte et al., 1984). Conducting research with more African Americans could be extremely beneficial for African American females since the relative mineral content in the fat-free mass of younger (7.8%) and middle-aged (7.5%) African American women is higher than Caucasians (7.3% and 6.7% respectively), and the bone density is significantly greater for African American women than White women (1.18 to 1.25 g/cm² compared with 1.16 g/cm²; Deck-Cote & Adams, 1993; Ortiz et al., 1992). It would also allow the ability to look at the validity among the differences in equations used such as the Siri equation, Schutte equation, Brozek equation, and the Ortiz equation since it has been found that the Siri equation underestimates the average body fat of African American women and men by 2% to 3% (Ortiz et al., 1992; Schutte et al., 1984).
Lastly, recruiting based on specific BMI or percent fat categories could be beneficial to examining the accuracy of the BodPod, DEXA, and InBody compared to hydrostatic weighing to determine if there is a more accurate measure with certain body composition testing devices for specific body types. The average percent fat for females in this current investigation was around 29% for females, and the average for males was around 17%. Testing more athletes with a lower percent body fat or testing individuals who are considered obese would be beneficial to determine if there is a difference in fat mass versus fat-free mass, mineral content, total body water weight, etc., within different populations among one or more of the devices used.
REFERENCES


COSMED USA, Inc. (n.d.). *Quick reference guide*. Concord, CA.


APPENDIX A

RECRUITMENT FLYER

Validity of Whole and Regional Body Composition Testing Devices

Are you interested in body composition?
Are you a male or female within the ages of 18 to 29 years old without any metal implants?

Participants will be tested on InBody 520, DXA, BodpPod, and Hydrostatic Weighing
Approximately 1.5 hours of your time will be required over 2 visits
*** DXA scan does expose participant to minimal amounts of radiation***
**Negative pregnancy test will be required for females**

For more information, please contact:
Rachel Tauber (a graduate student in the department of Kinesiology and Physical Education at NIU):
Rtauber1@niu.edu
Hello,

My name is Rachel Tauber and I am a graduate student in the KNPE Exercise Physiology program here at Northern Illinois University. I am currently recruiting both males and females within the ages of 18 and 29 years old to participate in my thesis titled “Validity of Whole and Regional Body Composition Testing Devices”. The study will take place over two sessions and will take approximately 1.5 hours of your time. The first meeting will be to go over the informed consent and initial screening to ensure eligibility in the study. In order to be included in this study, you have to be between 18 and 29 years old, females not being pregnant, not having any metal implants, and weigh less than 350 pounds. Testing will consist of a Bioelectrical Impedance Analysis (BIA) device, Dual Energy X-Ray Absorptiometry (DEXA) scanner, hydrostatic weighing, and the BodPod. Some of the downsides of the study includes a minimal amount of radiation from the DEXA and submerging yourself completely in water. This is extremely beneficial for those of you who want to go to into the clinical side of our field. It is also costs a lot of money outside of this study to do all of these devices, so you’ll be able to do it for free. If you are interested in participating in this study or would like any further information, please contact me at rtauber1@niu.edu.
APPENDIX C

INFORMED CONSENT

Department of Kinesiology and Physical Education

Informed-Consent Form to Act as a Participant in a Research Study

Title: Validity of Whole and Regional Body Composition Testing Devices

I agree to participate in the research project titled “Validity of Whole and Regional Body Composition Testing Devices” being conducted by Dr. Peter J. Chomentowski 3rd, an Assistant Professor in the department of Kinesiology and Physical Education at Northern Illinois University. I have been informed that the purpose of this investigation is to compare body composition measurements such as total body fat percentage, appendicular lean mass, appendicular fat mass, trunk adiposity, visceral fat, total lean mass, and total fat mass taken from InBody 520™, BODPOD, Hydrostatic weighing and Hologic Horizon Dual Energy X-ray (DXA) scanner.

I understand that I am eligible for this study because I am within the ages of 18 and 29, if female, I can verify negative pregnancy by taking a pregnancy test on the day of testing, I have no metal implants, and I am less than 550 pounds.

I understand that if I agree to participate in this investigation and I am eligible to participate, I will be asked to do the following: 1) complete an informed consent form, 2) complete an initial screening questionnaire prior to any participation, 3) allow the Principal Investigator to evaluate my height, weight, and body composition via InBody 520™, BODPOD, hydrostatic weighing, and the DXA.

I understand that my participation will be over the course of 2 days, the first day will consist of the initial screening questionnaire, informed consent, and explanation of guidelines to follow for testing, and the second day will consist of all testing including the InBody 520™, BODPOD, Hydrostatic weighing, and the DXA. I am aware that I will be given a specific time to arrive at the Advanced Testing Laboratory in Anderson Hall. The total time of my participation will last approximately 60 minutes. I understand what is involved with my participation in the experiment as explained verbally to me by the Principal Investigator.

I am aware that my participation is voluntary and I may withdraw at any time without penalty or prejudice. I understand that if I have additional questions or concerns regarding this project, I may contact Dr. Chomentowski (815-753-9190). I am aware that if I have further concerns or need more information regarding my rights as a research participant, I may contact the Office of Research Compliance at Northern Illinois University at (815) 753-8588.

I understand there are foreseeable risks to me if I agree to participate in the study, including any adverse effects caused by exposure to radiation.

A DXA is a type of X-ray used to measure bone strength and content, as well as body composition. During the DXA test, X-rays of your body will be taken to measure how much body fat and lean muscle tissue (non-fat tissue) are present. I will be lying flat on a table during the test, while the machine takes pictures of different areas of the body. The test itself will last approximately 6 minutes; however, I will be lying down for a total of 15 minutes while I am positioned for the test.

X-rays will be used during this research study to measure body composition from the DXA. The cumulative radiation exposure from this test is approximately 1.5 mrem, which is a very minimal amount of radiation. For comparison, natural daily background radiation exposes humans to approximately .7 mrem per day, a flight in a commercial airplane across the continental United States has a radiation exposure of approximately four to six mrem and traditional X-rays can range anywhere from 25 mrem up to 270 mrem.
A bioelectrical impedance analyzer is a device that uses a small electrical current to predict body fat percentages based on the resistance of current flow through different components of the body such as total body water (TBW) and fat free mass (FFM). The InBody 520™ is done with the subject standing upright, stepping on two foot electrodes and holding on to two handles with two thumb electrodes. The InBody 520™ takes approximately 90 seconds to complete. There are no risks associated from the very minimal electrical current omitted during the testing.

The BOD POD is an Air Displacement Plethysmograph device (ADP) that uses whole body densitometry to determine body composition (fat vs. lean). BOD POD is based on relationship between pressure and volume thus the BOD POD produces very small volume changes inside the chamber and measures the pressure response to these small volume changes. You will be asked to sit in a pressurized chamber for a total of 2.5 minutes (each test 45 seconds) and the door will be opened after every test to ensure your safety. There are no risks associated from the minimal pressure change in the chamber during testing.

Hydrostatic weighing is the process of measuring your buoyant counter force equal to the weight of the water which is displaced. You will be asked to sit on a scale in the tank, expel all the air from your lungs (residual volume always remains in your lungs), sink a few inches and sit motionless for a few seconds on the scale in the tank. Your whole body will be submerged (about 3-5 inches below the surface) for approximately 5 to 10 seconds. At this time, your underwater weight will be quantified. You will be asked to perform this measurement three times. There are no risks associated with the minimal exhalation of air volume due to the short nature of the test and residual volume of air remaining in the lungs.

I understand that all information and data collected in this study will be kept confidential by a specific code number, which will be used for identification. In addition, a master list of code numbers will be locked up in a separate location from any data collection information and only available to the researchers. I am voluntarily making the decision to participate in this research study, signified by my signature below.

I understand that my consent to participate in this study does not constitute a waiver of any legal rights or redress I may have as a result of my participation. I acknowledge that I have received a copy of this informed consent form.

I ___________________________ agree to participate in this study.

Print Name

__________________________________  ___________________________
Signature of Participant               Date

__________________________________  ___________________________
Signature of Principal Investigator    Date
APPENDIX D

INITIAL SCREENING QUESTIONNAIRE

INITIAL SCREENING QUESTIONNAIRE

Name: _________________________________________________________________

Age:__________________________ Sex:_______________________________________

Height: ______________________ Weight:____________________________________

Do you have any metal implanted from surgery such as screws, plates, rods, etc? ____________

Do you currently have a pacemaker implanted? ________________________________

Females: Are you currently pregnant? ________________________________________

Do you have any jewelry on your body? If so, are you able and willing to remove it? _________

** Negative pregnancy will be confirmed by pregnancy test day of testing.

Height: ______________________ Weight:_____________________BMI: __________
### APPENDIX E

#### PRETEST GUIDELINE CHECKLIST

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>YES</strong></td>
<td><strong>NO</strong></td>
<td>Did the subject refrain from eating at least five hours prior to testing but not more than 12 hours?</td>
</tr>
<tr>
<td><strong>YES</strong></td>
<td><strong>NO</strong></td>
<td>Did the subject refrain from exercise within eight hours prior to testing?</td>
</tr>
<tr>
<td><strong>YES</strong></td>
<td><strong>NO</strong></td>
<td>Did the subject refrain from consuming large amounts of liquids within four hours prior to testing?</td>
</tr>
<tr>
<td><strong>YES</strong></td>
<td><strong>NO</strong></td>
<td>Did the subject refrain from consuming caffeine or other diuretics within three hours prior to testing?</td>
</tr>
<tr>
<td><strong>YES</strong></td>
<td><strong>NO</strong></td>
<td>Did the subject refrain from consuming alcohol within twelve hours prior to testing?</td>
</tr>
<tr>
<td><strong>YES</strong></td>
<td><strong>NO</strong></td>
<td>Did the subject refrain from showering directly prior to testing?</td>
</tr>
</tbody>
</table>
APPENDIX F

PRETEST GUIDELINES

Pretest Guidelines

- Do NOT eat at least five hours prior to testing but not more than 12 hours.
- Do NOT exercise within eight hours prior to testing.
- Do NOT consume large amounts of liquids within four hours prior to testing.
- Do NOT consume caffeine or other diuretics within three hours prior to testing.
- Do NOT consume alcohol within twelve hours prior to testing.
- Do NOT shower directly prior to testing.

What to bring to the second session:

- Bath towel
- Males: Compression shorts/Tight fitting swim trunks/Boxer-briefs
- Females: One piece swimsuit/spandex & sports bra (no padding)
- **DO NOT BRING:** any loose clothes, yoga pants, loosely fitting swim trunks, boxers, wired bras, etc.
- **Disclaimer:** Failure to follow guidelines & bring proper clothes will result in rescheduling of the second session and/or dismissal from the study.