COMPARING SKINFOLD EQUATIONS FOR FEMALE ATHLETES USING THE BOD POD AS THE CRITERION

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ABSTRACT

The primary purpose of this investigation was to compare percent body fat (%BF) determined using skinfold regression equations for female athletes to %BF measured using the BOD POD (Life Measurement, Inc., Concord, CA) as the criterion measure. Valid skinfold equations for female collegiate athletes allow individuals to accurately and easily determine players' %BF in a field setting. The accurate determination of body fat in female athletes enables pre- and post-season assessments as well as allows for potential diagnoses of symptoms involved in the female athlete triad (Fornetti et al., 1999; Nattiv & Lynch, 1994; Warner et al., 2004). The BOD POD has been shown to be a valid source of measurement of body composition in female athletes when compared to underwater (hydrostatic) weighing (UWW) and dual-energy x-ray absorptiometry (DEXA). Participants in this study were 75 female collegiate athletes at a Division III University between the ages of 18-24 years. Each participant was tested in the BOD POD and had four skinfold sites measured. Criterion-related concurrent validity and intraclass reliability were tested before testing began to ensure the investigator was valid and reliable at taking skinfold measurements. Three previously developed skinfold equations for females were used to calculate %BF: The first equation (SF-UWW) utilized UWW as the criterion, the second equation (SF-DEXA) was developed using DEXA as the criterion, while the third equation (SF-Gen) was a general skinfold equation that has been recommended for women ages 18-55 years using UWW as the criterion. A one–way analysis of variance (ANOVA) was performed with repeated measures on the four body composition techniques. Tukey's HSD *post hoc* analysis was used to compare the means for each technique. Cohen's *d* was used to calculate effect size for mean differences. No significant differences were found between the BOD POD and any of the skinfold measurements. However, significant differences were found with SF-DEXA having a lower

%BF than SF-UWW and SF-Gen. In conclusion, it was found that the three skinfold equations used in this study compared with the criterion measure, BOD POD.

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CHAPTER I

INTRODUCTION

Body composition testing is important for athletes as an indication of their fitness and health (Warner, Fornetti, Jallo, & Pivarnik, 2004). The most common methods used to predict percent body fat (%BF) are two-compartment methods that divide the body into fat mass (FM) and fat free mass (FFM) (Warner et al., 2004). When using body composition measurements one can monitor preseason and postseason changes and also track unhealthy weight loss or gain as indicators of poor health or eating disorders (Warner et al., 2004; Fornetti, Pivarnik, Foley, & Fiechtner, 1999). The monitoring of body fat is especially important in female athletes because of their increased risk for developing symptoms of the female athlete triad (Fornetti et al., 1999; Nattiv & Lynch, 1994). This triad consists of disordered eating, amenorrhea and osteoporosis. Early identification of these potentially serious disorders is crucial for an athlete because these can lead to harmful diseases or injury. Monitoring is especially important in athletes where leanness and low body fat/weight are advantageous, for example, in sports like gymnastics and figure skating (Fornetti et al., 1999; Nattiv & Lynch, 1994).

There are many methods available for testing body composition. The 'best' way to measure body composition depends on the end sought and the practical possibilities for measurement (Keys & Brozek, 1953). In athletics, tests for predicting %BF must be valid, reliable and readily accessible for coaches or athletic trainers to use on multiple athletes in a short amount of time (Ballard, Fafara, & Vukovich, 2004).

Hydrostatic (underwater) weighing (UWW) has long been considered the "gold standard" in body composition testing [American College of Sports Medicine (ACSM), 2005]. UWW has been used in multiple investgations either being compared to another form of body composition measurement or being used as a criterion measure (Fogelholm & Lichtenbelt, 1997). Despite its widespread use, UWW has many limitations such as its expensive equipment, complicated procedure, time-consuming measurement, and the nessecity of submersing the head under the water (ACSM, 2000).

Dual-energy x-ray absorptiometry (DEXA) is another form of body composition testing. DEXA has been deemed a potential replacement of UWW as the gold standard because of its capability of testing multiple body compartments compared to UWW's two-compartments (Fogelholm & Lichtenbelt, 1997; Kohrt, 1998). There are also limitations to using this method including that both the equipment and testing is expensive and is found mainly in clinical settings, and there is a lack of agreement between available DEXA software versions (Fields, Goran, & McCrory, 2002; Fornetti et al., 1999; Wagner & Heyward, 1999).

Air-displacement plethysmography (ADP) is a newer method available for testing body composition using the commercially available product called the BOD POD (Life Measurement, Inc., Concord, CA). This method is a two-compartment model like UWW, but it removes many of the limitations associated with UWW testing such as submersing the head under water, time to complete the procedure, and the need for an experienced technician. One of the major disadvantages to using this method is the expensive cost of the equipment, but overall it is deemed advantageous for use when compared to UWW and DEXA (Wagner & Heyward, 1999).

UWW, DEXA and ADP are accurate methods of testing body composition but are not routinely available for testing in a field setting due to the large equipment size and lack of portability. Measuring skinfolds is a practical and accessible way of testing body composition in a field setting. There are also disadvantages to using this method that include different caliper types and tester reliability (Brodie, Moscrip, & Hutcheon, 1997). Skinfold measurements are a good estimate of body composition when used in an equation appropriate for the population being assessed (Wilmore & Costill, 2004; Plowman & Smith, 1997). Skinfold models have previously been validated using UWW and DEXA as the criterion measure (Warner et al., 2004), but to date no research is available using the BOD POD as the criterion measure.

Purpose

The primary purpose of this investigation was to compare %BF as estimated from three skinfold regression equations for female athletes against %BF as measured by the BOD POD.

Significance

Valid skinfold equations for female collegiate athletes allow individuals such as coaches and athletic trainers to accurately and easily determine players' %BF in field settings. The accurate determination of body fat in female athletes will enable pre- and post-season assessments associated with increases or decreases in body fat. Potential diagnoses of symptoms involved in the female athlete triad can also be monitored with decreases in body fat. The BOD POD has not been used as a criterion measure to validate skinfold regression equations.

Hypotheses

The following null hypotheses will be tested:

H1: There will be no difference between the female athlete skinfold equation using UWW as the criterion and the BOD POD.

H2: There will be no difference between the female athlete skinfold equation using DEXA as the criterion and the BOD POD.

H3: There will be no difference between the generalized skinfold equation for women and the BOD POD.

H4: There will be no difference between the each of the skinfold equations.

Definitions

- *Air-displacement plethysmography.* Two-compartment densitometric body composition technique that is measured through a commercially available product known by the trade name BOD POD (Dempster & Aitkens, 1995).
- *Body composition*. Body's chief functional constituents: water, fat, protein and minerals (Siri, 1956).
- *Body density*. Ratio of body mass to body volume.
- *Dual-energy x-ray absorptiometry*. Three-compartment method of assessing body composition. Body composition using this method is determined by measuring the attenuation of the x-ray beam over the body on a pixel-per-pixel basis (Curtin et al., 1997; Slosman et al., 1992).
- *Fat free mass*. The total amount of body mass that is not fat mass and is divided into water, mineral and protein.
- *Fat mass*. The total amount of body mass that is not fat free mass.
- *Four-compartment models*. Body composition measured by fat mass and fat free mass then accounting for the variability in fat free mass by measuring total body water and bone mineral (Mazess, Bardon, Bisek, & Hanson, 1990).

- *Hydrostatic (underwater) weighing*. A method to estimate body density by dividing body weight out of water by weight in water (Fornetti et al., 1999).
- *Percent body fat*. Proportion of the body that is fat mass.
- *Residual volume*. Residual volume is the volume of air remaining in the lungs at the end of a maximal expiration (Brozek & Henschel, 1961).
- *Skinfold thickness*. The double thickness of the skin and the adipose tissue between the parallel layers of skin (Plowman & Smith, 1997).
- *Three-compartment models*. Dividing the body into fat mass, water and fat free dry solid (Siri, 1961); Dividing the body into fat, mineral and protein plus water (Lohman, 1986).
- *Two-compartment models*. Considering that the body is composed of fat and the fat free remainder (Keys & Brozek, 1953).

CHAPTER II

REVIEW OF LITERATURE

The purpose of this investigation was to compare percent body fat (%BF) as estimated from three skinfold regression equations for female athletes against %BF as measured by the BOD POD. The review of literature is comprised of four sections; basic body composition principles, body composition techniques, comparison of techniques, and importance to female athletes.

Basic Body Composition Principles

Two-, Three-, and Four-Compartment Models

Measuring body composition directly can be done through the chemical analysis of animal or human cadavers (Kempster, 1986). Keys and Brozek (1953) stated that direct analyses are possible only in very rare instances, but can provide the final calibration data for indirect analyses. There are more practical, indirect methods of estimating body composition. These indirect methods involve models that divide the body into different compartments. The model that most scientists have adopted (Wilmore & Costill, 2004) and is most often used in a sport setting is the 2-compartment model (Warner et al., 2004). According to Keys and Brozek (1953), the 2-compartment model is the simplest approximation of body density (D_b). This is completed by considering that the body is composed of fat, which is a constant density but a highly variable proportion of the whole body, and the fat free remainder. Fat free mass (FFM) is all of the body's nonfat tissue. This includes bone, muscle, organs and connective tissue. Fat mass (FM) is the percentage of total body mass that is composed of fat (Wilmore & Costill, 2004).

The 2-compartment model is based on the assumption that FM and FFM have constant densities of 0.9007 and 1.1 g/cc, respectively, at a temperature of 36º C and that the three major components of FFM (water 72%, mineral 7% and protein 21%) are constant in all individuals as derived from the direct assessment of human cadavers (Siri, 1961). Two-compartment models can be measured via hydrostatic (underwater) weighing (UWW), air-displacement plethysmography (ADP), skinfolds and circumference (Kempster, 1986).

The 2-compartment model can be changed into a 3-compartment model by dividing one part into two. These models claim their validity by combining D_b and total body water (TBW) instead of just measuring D_b like two-compartment models (Withers, Lafogia, Heymsfield, Wang & Pillans, 1996). For example, there are two different models that break the body down into three compartments. Siri (1961) divides the 3-compartment model into FM, water, and fat free dry solid. Siri identified that the largest source of error in the two-compartment model is the variation in FFM hydration, therefore, he divided this into water and fat free dry solid. This model assumes the density of FM is 0.9007 g/cc, water is 0.9937 g/cc and fat free dry solid is 1.569 g/cc at a temperature of 36 º C. Siri's (1961) three-compartment equation is:

$$\%BF = (211.5/ D_b) - 78.0 * [\text{weight (kg)/body mass (kg)}] - 134.8$$

Lohman (1986) used the same framework as Siri by dividing his three-compartment model into fat, mineral, and protein plus water. The assumption of fat density at 0.9007 g/cc, mineral at 3.037 g/cc, and protein plus water at 1.0486 g/cc exists in this model. This model has an advantage over two-compartment models because it accounts for biological variability in bone mass which comprises ~5.6% of FFM. Lohman's three-compartment equation is:

$$\%BF = (638.6/ D_b) + 396.1m - 609.0$$

where m = mineral (g/cc) as a fraction of body mass. Three-compartment models can be measured via dual-energy x-ray absorptiometry (DEXA). When comparing three-compartment equations, Withers et al. (1996) reported that the Siri equation (1961) appears to be more logical than Lohman (1986) because it accounts for biological variability in total body water (TBW). Water significantly impacts FFM having the lowest density but comprising the largest fraction of any other components (Withers et al., 1996).

Four-compartment models allow for the extension of the three-compartment models by controlling the inter-individual variability in more than one of the four FFM components (Withers et al., 1996). A four-compartment model, as described by Mazess, Bardon, Bisek and Hanson (1990), measures D_b (FM and FFM) and then accounts for variability in FFM by measuring TBW and bone mineral. This model takes the masses and volumes for bone mineral and water and subtracts them from the mass and volume of the whole body. The remainder of the body is partitioned into FM and non-bone (soft tissue) mineral (Withers et al., 1996). This model is shown in Withers et al. (1996).

$$\%BF = (251.3/D_b) - 73.9\,(\text{weight (kg)}/\text{body mass (kg)}) + 94.7\,\text{bone mineral (gram/kg)} - 179.0$$

Four-compartment models can be measured by assessing total body potassium or *in vivo* neutron activation but are very difficult to perform and are not practical methods of body composition assessment (Kempster, 1986).

Body Composition Uses

Assessment of body composition is an important aspect in health and fitness for a wide variety of populations (Vescovi, Zimmerman, Miller, Hildebrandt, Hammer, & Fernhall, 2001). Uses for body composition measurements involve the assessment of body fat, fat distribution, muscle mass, and bone mass (Webster & Barr, 1992). Professionals can use body composition to assess weight gain and fat distribution. An appropriate dietary program for weight loss, gain, or management can be prescribed according to one's body composition measurements.

Body composition can be monitored by studying its effects on disease and genetics and the impact these items have on the human body (Brodie et al., 1998). Athletic trainers may use body composition measurements for monitoring and managing their athletes' fitness and health. Certain sports may require leanness for optimal performance such as gymnastics, while other sports such as wrestling may require a certain weight standard for competition (Ballard et al., 2004; Webster & Barr, 1992). The assessment of body composition may be used to monitor preseason and postseason changes such as muscle and fat gain or loss in athletes (Warner et al., 2004).

Body composition has also been linked to health conditions making it a very important measurement. Some of these health conditions include cardiovascular disease, diabetes, certain types of cancers, osteoporosis and osteoarthritis (Wagner & Heyward, 1999). Assessment of weight gain/loss, monitoring disease, and monitoring preseason and postseason changes in make body composition a very important component in a healthy athlete.

Body Composition Techniques

Hydrostatic (Underwater) Weighing

Densitometry, the concept of measuring density, is an important concept in determining body composition. This concept suggests that water, fat, protein and minerals have distinctly different densities (Siri, 1961). D_b can be measured by dividing one's mass by volume. The density of body fat is less than other components of the body. Therefore, the larger proportion of fat a person has, the lower their density of the whole body (Keys & Brozek, 1953).

One method of measuring D_b is by hydrostatic (underwater) weighing (UWW). For a long time UWW has been described as the "gold standard" for assessing body composition because for many years researchers have compared other methods to UWW as a criterion. Chemically determined D_b agrees within 0.6% of D_b measured with UWW (Heyward & Wagner, 2004). This technique is based on Archimedes' principle stating that a body immersed in water is buoyed up by a counterforce equal to the weight of the water displaced (Keys & Brozek, 1953). This concept is used to estimate a person's body volume. UWW uses a two-compartment model that divides the body into FM and FFM (Warner et al., 2004; ACSM, 2005).

Many factors contribute to measuring D_b using UWW. The density of the water, which is dependent on temperature, must be taken into account in order to determine D_b (Brozek & Henschel, 1961). Measurement of residual lung volume is needed to accurately calculate D_b using UWW. Residual volume is the volume of air remaining in the lungs at the end of a maximal expiration (Brozek & Henschel, 1961). Residual lung volume can be measured on land in a seated position similar to the position experienced underwater where the subject is asked to maximally exhale to the point of residual volume (Vescovi et al., 2001). A person's body volume is estimated by weighing a person on land, and then totally submersed underwater. D_b can then be estimated using the previous information in the following equation (Brozek & Henschel, 1961):

$$D_b = \frac{\text{Weight in air}}{\left(\frac{\text{Weight in air} - \text{Weight in water}}{\text{Density of water}}\right) - \text{Residual Volume}}$$

This equation takes the difference between a person's land weight and underwater weight and then corrects for changes in the density of the water (which is dependent on temperature) and one's residual volume (Keys & Brozek, 1953).

Percent body fat is estimated by an equation that converts D_b to %BF. The equation of Siri is often used to convert D_b to a body fat estimate (Siri, 1956):

$$\%BF = 4.950/\text{body density} - 4.50$$

This equation is based on a chemical analysis performed on five Caucasian human cadavers. The analysis of the cadavers led to the assumption that FFM is at a constant hydration level of 1.100 (Siri, 1956). This assumption means that the density of each tissue that is composed of FFM is known and constant, and each type of tissue represents a constant proportion of the FFM (Wilmore & Costill, 2004). This equation also assumes that the density of fat is 0.900 (Brozek & Henschel, 1961). Another equation that calculates body fat from D_b is Brozek (1953). This equation is similar to Siri (1956) except it uses the constants of 0.9007 for the density of fat and 1.100 for the density of FFM making the equation (Brozek, Grande, Anderson & Keys, 1963):

$$\%BF = 4.971/BD - 4.519$$

Dual-Energy X-ray Absorptiometry

Dual-Energy X-ray Absorptiometry (DEXA) is another form of body composition measurement. This method is primarily found in clinical settings (Fornetti et al., 1999). In contrast to UWW, DEXA is a three compartment model that measures FM, FFM and bone mineral (Ballard et al., 2004; Warner et al., 2004). Body composition using this method is determined by measuring the attenuation of the x-ray beam over the body on a pixel-per-pixel basis (Curtin, Morabia, Pichard & Slosman, 1997; Slosman, Casez, Pichard, Rochat, Fery, Rizzoli, Bonjour, Morabia & Donath, 1992). DEXA measurements made with a total body scanner using the DPX model (Lunar Radiation Corp, Madison, WI) produce a series of transverse scans from head to toe of a subject at 1 cm intervals and an energizing voltage of 40 to 70 kV. Around 20,000-22,000 pixels are involved in a typical scan. Of those pixels, ~40-45% contains bone and soft tissue and 55-60% contain soft tissue alone (Mazess et al., 1990). Each pixel is determined to be either bone or soft tissue and then separated into those pixels that are only soft tissue and those that are both soft tissue and bone (Fornetti et al., 1999).

The first set of equations are used to find soft tissue and bone where B = bone, T = soft tissue, μ = the attenuation coefficient and LR = the log of the ratio of the intensity of the attenuated beam ($LR_{40} = \ln(I_{40}=I_{40})$ and $LR_{70} = \ln(I_{70}=I_{70})$) (Sutcliffe, 1996).

$$\text{Soft tissue} = (\mu_{B40}\, LR_{70} - \mu_{B70}\, LR_{40}) / (\mu_{B70}\, \mu_{T40} - \mu_{T70}\, \mu_{B40})$$

$$\text{Bone} = (\mu_{T40}\, LR_{70} - \mu_{T70}\, LR_{40}) / (\mu_{T70}\, \mu_{B40} - \mu_{B70}\, \mu_{T40})$$

%BF is determined from the ratio of attenuation of the lower energy to the higher energy of the beam (Slosman et al., 1992). This second set of equations separate lean tissue from fat where F = fat and L = lean tissue (Sutcliffe, 1996).

$$\text{Lean tissue} = (\mu_{F40}\, LR_{70} - \mu_{F70}\, LR_{40}) / (\mu_{F70}\, \mu_{L40} - \mu_{L70}\, \mu_{F40})$$

$$\text{Fat tissue} = (\mu_{L40}\, LR_{70} - \mu_{L70}\, LR_{40}) / (\mu_{L70}\, \mu_{F40} - \mu_{F70}\, \mu_{L40})$$

Analysis can be done on the whole body or specific body parts such as the trunk, arms and legs (Curtin et al., 1997).

Air-Displacement Plethysmography

Air-Displacement Plethysmography (ADP) is another two-compartment densitometric body composition technique that is measured through a commercially available product known by the trade name BOD POD (Life Measurement, Inc., Concord, CA). This system was not available for routine use until around the mid-1990s making it a fairly new form of measurement (Fields et al., 2002).

The BOD POD is a dual-chambered system that determines body volume provided by the application of gas laws within the chambers (McCrory, Gomez, Bernauer, & Mole, 1995). This is done through a movable diaphragm with a volume perturbing element that is located on the wall separating the two chambers. The volume of each chamber is equal in magnitude but opposite in sign (Wagner & Heyward, 1999). So when volume goes up in one chamber, it goes down in the opposite chamber. A measured volume is taken without a subject and then repeated with the subject in the front chamber. An air circulation system is used between the two chambers to maintain equivalency of gas composition in the two chambers and the constancy of Poisson's y (explained below) in the pressure-volume relationship (Dempster & Aitkens, 1995).

Body volume is determined by subtracting the subject chamber volume from the empty chamber volume (McCrory et al., 1995). The air inside the chamber is indirectly measured according to the principles of Boyle's law stating that at a constant temperature (isothermal conditions) volume (V) and pressure (P) are inversely related. This equation is derived as (Dempster & Aitkens, 1994):

$$P_1 * V_1 = P_2 * V_2$$

$$\text{therefore: } P_1/P_2 = V_2/V_1$$

Adiabatic conditions are the opposite of isothermal and take into account that the temperature of air does not remain constant as volume changes. Poisson's Law uses the equation to describe these adiabatic conditions:

$$P_1/P_2 = (V_2/V_1)\text{^}y$$

"^y" is the ratio of specific heat of the gas at constant pressure to that at constant volume. This value for air is 1.4 and 1.3 for triatomic gases such as CO_2 and H_2O (Daniels & Alberty, 1967). Air that is perturbed under adiabatic conditions have changes 40% greater than under isothermal conditions making the changes in gases under these two conditions important to account for (Dempster & Aitkens, 1997). D_b is calculated based on the measurement of volume. This equation uses the principles of densitometry (Keys & Brozek, 1953):

$$D_b = \text{mass/volume}$$

Once D_b is known, the relative percentages of FM and FFM are determined using this equation by Siri (1961) (Dempster & Aitkens, 1995):

$$\%BF = 4.95/\ D_b - 4.50$$

In order to measure body volume accurately, Dempster and Aitkens (1995) recommend that the effects of clothing, hair, skin surface area and lung volume must be eliminated or accounted for. Clothing can be dealt with by wearing minimal amounts of clothing such as a bathing suit. A swim cap can be worn to compress hair and eliminate trapped air. Surface area artifact can produce a negative volume caused by the isothermal effects related to the skin surface area. To account for the negative volume, the BOD POD automatically computes this artifact by using the Dubois formula to estimate body surface area (BSA):

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

BSA is then multiplied by a constant *k* that describes the negative volume produced by that area (Dempster & Aitkens, 1995):

$$\text{Surface Area Artifact} = k(\text{l/cm}^2) * \text{BSA (cm}^2\text{)}$$

Skinfolds

A skinfold is the double thickness of the skin and the adipose tissue between the parallel layers of skin (Plowman & Smith, 1997). Skinfold models are developed by taking measurements at three or more sites. A fold of subcutaneous fat is measured by a special pincher caliper that exerts a constant tension of 10 g/mm^2 (McArdle et al., 1994). Jackson and Pollock (1985) use a Lange caliper (Cambridge Scientific Industries, Cambridge, Maryland) because other calipers have shown to yield high readings. The sums of the values measured by the skinfolds are then used to obtain estimates of D_b, relative body fat or FFM (Wilmore & Costill, 2004). Jackson and Pollock (1985) recommend that three different sums of three skinfolds be taken. The median value of each site is then used for calculations. Skinfold sites should be measured in succession so a complete data set is taken before repeating the measurements for the second and third time (Norton, Whittingham, Carter, Kerr, Gore & Marfell-Jones, 1996).

Different skinfold sites can be used for women to measure body density. Three and seven site formulas are most often used (Jackson & Pollock, 1985). The sum of three and seven site skinfolds are highly correlated demonstrating that different combinations of the sum of skinfolds can be used without much of a loss of accuracy. The sum of three skinfolds is used more often than the sum of seven because of time and feasibility (Jackson & Pollock, 1985). For women the seven sites are the chest, axilla, tricep, subscapular, abdomen, suprailium and thigh skinfolds. The three site formula measures the tricep, suprailium and thigh (Jackson & Pollock, 1985).

Estimating body fat using skinfold thickness measurements is based on the concept that subcutaneous fat reflects the fat content in the body. Even though it matters very little which side of the body a measurement is taken from, measurements are always taken on the right side irrespective of the subject's preferred side (Martorell, Mendoza, Mueller & Pawson, 1988; Norton et al., 1996).

D_b is calculated by regression equations developed from the measurements of certain skinfold thickness sites on the body of a subset of a certain population (Erselcan, Candan, Saruhan, & Ayca, 2000). Skinfolds should not be taken after training or competition, sauna, swimming or showering, since exercise, warm water and heat produce increased blood flow in the skin that can increase skinfold thickness (Norton et al., 1996). This is especially important in athletes due to the increased likelihood that an athlete will be training or competing.

Comparison of Techniques

Hydrostatic (Underwater) Weighing

Since UWW is considered the 'gold standard' in body composition, most publications compare it to one or several other methods (Fogelholm & Lichtenbelt, 1997). A literature analysis by Fogelholm & Lichtenbelt (1997) reported 54 studies that compared one or several methods of body composition to UWW. Although UWW has been widely used among researchers, there are limitations to using this technique. First, an experienced technician is required for the administration of UWW (Vescovi et al., 2001). This technique also requires expensive equipment and is time-consuming to perform. Subjects may also experience difficulty or anxiety when submersing their head underwater providing limitations to results (American College of Sport Medicine, 2000). The maximal exhalation that is required while submerged underwater may produce difficulty for certain populations such as the elderly, children and individuals afraid of the water.

Heyward and Wagner (2004) stated that even though UWW is known as the "gold standard" measurement it relies on several assumptions and is therefore not error free. One assumption that potentially affects the elderly, children and athletes is the fixed density of FFM involved in UWW equations. This assumption involves the proportions of minerals, water and proteins being constant (Fogelholm & Lichtenbelt, 1997; Fornetti et al., 1999). The research that was done by Brozek to develop the fixed densities was only completed on male Caucasians making these densities only applicable in male Caucasian populations (Brozek et al., 1963).

Research has shown that people who complete resistance training have a higher density of FFM than used in standard equations such as the Siri equation. This is problematic in athletes leading to an underestimation of FFM and an overestimation of FM (Wilmore & Costill, 2004). Also, in female athletes the variability of fixed proportions may be more prevalent not only because of training but also menstrual cycles leading to inaccurate assessments of %BF because menstruation leads to fluid retention. Therefore UWW may not be the best criterion measure when developing prediction models for female athletes using various "field" techniques (Fornetti et al., 1999). These limitations may hinder or make it impossible to administer UWW and get consistent, accurate results on certain populations, including female athletes (Vescovi et al., 2001).

Dual-Energy X-ray Absorptiometry

Because DEXA uses a three compartment model, some researchers have deemed DEXA as a potential candidate in replacing UWW as the next reference method of measuring body composition (Fogelholm & Lichtenbelt, 1997; Kohrt, 1998). This is due to the fact that FFM is measured and not considered uniform across populations like in UWW. DEXA also takes away any potential anxiety involved with full body submersion in water (Kohrt, 1998).

One limitation to using DEXA is the length of time taken to perform each test. Depending on the size of the area tested and the size of the patient, the scanning time averages 12-18 minutes (Slosman et al., 1992), which is about 10 minutes longer than the BOD POD. Different machines, modes and software versions available for DEXA have shown to produce inter-device variability which leads to potential limitations. Technical expertise is also required with DEXA to run the test and analyze results (Fields et al., 2002; Wagner & Heyward, 1999). The instrumentation to perform DEXA is very expensive, found mostly in clinical settings and is not readily available to trainers, coaches or even most medical staff making it an unlikely method for assessing body composition in collegiate athletes (Fornetti et al., 1999).

Air-Displacement Plethysmography

The BOD POD has many advantages when compared to other body composition methods. This method takes less time (<5 minutes) compared to previous methods. DEXA take longer than 10 minutes and UWW can take approximately a half hour. Compared to UWW, the BOD POD is more comfortable because it uses air instead of water. The BOD POD can be used with very little training because of its automated system making it easier to administer than UWW and DEXA. Unlike DEXA, which uses radioactive x-ray equipment, the BOD POD is non-invasive. The BOD POD also can accommodate various subjects making it useful for a wide variety of populations (e.g., children, obese, elderly, and disabled persons) (Ballard et al., 2004; Fields et al., 2002; Utter, Goss, Swan, Harris, Robertson, & Trone, 2003; Wagner & Heyward, 1999). In a review comparing the BOD POD to other reference methods, it ranked at or near the top in categories such as time, cost, maintenance, ability to accommodate people with limitations, and ease of use (Fields et al., 2002). One of the major disadvantages to using the BOD POD is cost but since there is little technical training needed for administration, it is more practical than UWW and DEXA (Wagner & Heyward, 1999).

The BOD POD has been found to be comparable to both UWW and DEXA in multiple studies. In a review by Fields et al. (2002), multiple studies were reviewed producing an average study means of agreement between the BOD POD and UWW within 1% body fat and 1% agreement between the BOD POD and DEXA. The range of variance between the BOD POD and UWW is 0.76 to 0.96, and the ranges of SEEs were from 1.8% to 2.3%. The range of variance between the BOD POD and DEXA was between 0.78 and 0.91, and the ranges of SEEs were from 2.4% to 3.5%BF.

In a study of female collegiate athletes, Ballard et al. (2004) found the BOD POD to be a reliable and valid predictor of body composition when referenced to DEXA. No significant differences between the two methods in measuring %BF (r = 0.94; SEE = 2.11) or FFM (r = 0.94; SEE = 1.228) were found. In a study comparing UWW and the BOD POD by Utter et al. (2003) there were no significant differences found in D_b, %BF or FFM in a heterogeneous collegiate wrestling population in both euhydrated (Weight (kg)=76.7±13.1; %BF=12.4±4.8) and dehydrated (Weight (kg)=74.7±12.9; %BF=12.2±4.5) states. Another study comparing UWW and the BOD POD found no differences in D_b or %BF in adult men and women aged 18-52 years (r=0.88; SEE=3.6) (Vescovi et al., 2001).

Skinfolds

UWW, DEXA and ADP are accurate methods of testing body fat but are expensive laboratory techniques and require a certain amount of training to administer (Utter et al., 2003; Kohrt, W., 1998; Vescovi et al., 2001). These pieces of equipment are also not portable and would be time consuming when testing multiple athletes. Skinfold thicknesses are measured with a skinfold caliper. Advantages to using this method include that it is a noninvasive measure that is fairly pain-free. Skinfold calipers are fairly inexpensive, easy to maintain, and simple and convenient to use. This method can also be used in a field or laboratory setting because the calipers are portable. Although some training is required in order to properly take skinfold measurements, they do not require extensive training for use. There are also limitations to this method that include different caliper types, skill level of the tester, and tester reliability (Brodie et al., 1997).

Skinfold models have previously been validated using UWW and DEXA as the criterion measure (Warner et al., 2004). Skinfold measurements are a good estimate of body composition when used in an equation appropriate for the population being assessed (Pollock & Jackson, 1984; Wilmore & Costill, 2004; Plowman & Smith, 1997). Jackson (1984) felt that unique populations, such as athletes, should use population specific equations.

Brozek (1961) suggested that the validity of prediction equations is limited by age and sex. Aging is associated with changes in fat distribution and bone density. Pollock and Jackson (1984) reported that bone density increases up to age 20 and decreases after age 50. Pollock, Laughridge, Coleman, Linnerud, and Jackson (1975) found that when predicting D_b in women body fat tends to shift with age to the thoracic-trunk regions. The authors therefore felt that accounting for the changes in fat distribution would increase the predictability of D_b in this age group. Siri (1956) also reports of the decrease in the proportion of total body water with age. This behavior is attributable to differences in fat storage with age. For these reasons it is important to produce a population specific equation appropriate for the population being tested.

Population specific equations can predict fatness fairly accurately when testing subjects of similar age, gender, state of training and race (McArdle et al., 1994). These equations are developed from relatively small, homogenous samples leading to the application of the equation being only for that small subsample (Jackson & Pollock, 1985). All of the above purposes of measuring skinfolds are important when testing female athletes.

Importance to Female Athletes

Although the use of skinfolds to predict body fat is widespread, there are few prediction models that are specifically validated for female athletes (Warner et al., 2004). Current research has not yet used the BOD POD as the criterion measure to develop a skinfold regression equation for female collegiate athletes. A recent study by Ballard et al. (2004) has found the BOD POD to be a reliable and valid measure of body fat in female collegiate athletes making it a logical criterion measure.

Population-specific equations are very important when predicting body fat using skinfolds. Equations that are general to the population may be inaccurate because of changes in fat distribution that comes with age. Female athletes are one population where very few prediction models to assess body fat have been developed (Warner et al., 2004). Brodie et al. (1997) stated that in order to provide valid estimates of body composition it is essential that equations represent the study sample being used.

Although very few population specific equations have been developed for female athletes, no skinfold equations have been validated using the BOD POD as the criterion measure. Jackson et al. (1980) developed multiple equations for women using UWW as the criterion method. The equation that has been recommended for female athletes is:

$$D_b = 1.0960950 - 0.0006952\,(X) + 0.0000011\,(X)^2 - 0.0000714\,(\text{age})$$

where X is the sum of tricep, abdomen, suprailium and thigh skinfolds in mm ($r = 0.849$; SEE = 0.0084). The cross-validation of this equation produced an $r = .813$, SEE = 3.8, and SD = 25.0 ± 5.9. This equation has been recommended by multiple authors for female athletes (Wagner & Heyward, 2004; Sinning & Wilson, 1984; Lohman, 1988; Wells, 1991). Sinning and Wilson (1984) found when tested on 79 female collegiate athletes an $r = 0.795$ and SEE = 3.27.

More recently, researchers developed a skinfold equation to predict fat free mass in collegiate female athletes using DEXA as the criterion measure (Warner et al., 2004):

$$FFM = 8.51 + (0.809 * \text{mass}) - (0.179 * \text{abdominal skinfold}) - (0.225 * \text{thigh skinfold})$$

Warner et al. (2004) found when tested on 101 female collegiate athletes an $r = 0.98$ and SEE = 1.1.

Generalized skinfold equations are also available for women. These equations take into account a population that varies in age and body composition (Jackson et al., 1980). One such equation was developed and recommended for women by Jackson et al. (1980) because of its feasibility and cross-validation statistics:

$$D_b = 1.0994921 - 0.0009929\,(X) + 0.0000023\,(X)^2 - 0.0001392\,(\text{age})$$

where X is the sum of the tricep, thigh and suprilium skinfolds in mm. The development and cross-validation of this equation was completed on women between the ages of 18 and 55 years and produced an $r = .820$, SEE = 3.7 and a SD = 25.1 ± 5.8. Various other recommendations have been given for this equation (Wagner & Heyward, 1999; Daniel, Sizer & Latman, 2005, Heyward & Wagner, 2004).

CHAPTER III

METHODS

The primary purpose of this investigation was to compare percent body fat (%BF) as estimated from three skinfold regression equations for female athletes against %BF as measured by the BOD POD. In this chapter, the methods are explained as follows: participants, research design, equipment used, procedures, and statistical analysis.

Participants

The participants for this study were female collegiate athletes recruited from a National Collegiate Athletic Association (NCAA) Division III university in Northwest Ohio. Inclusion criteria included participation in a female collegiate sport and being between the ages of 18 and 24 years. These athletes were recruited through contact with various intercollegiate coaches. The participants were athletes involved in teams including basketball, soccer, softball, swimming and volleyball. The procedures as well as the potential benefits and risks were explained before obtaining written informed consent from each participant. Each subject was provided a list of pretest procedures (Appendix A). The project was approved by both of the universities' Institutional Review Boards for use of human subjects before the data was collected. Subject characteristics are shown in Table 1.

A one-way analysis of variance (ANOVA) was performed on each of the different subject characteristics. A statistically significant difference ($p < 0.05$) was found for height with the basketball team being significantly shorter than the soccer team. A tall post player was absent from the basketball team's data collection, and due to the small sample size, the exclusion of this player may account for this finding. There were no other significant differences between groups.

Table 1

Subject Characteristics (Mean ± SD)

	Basketball (n=17)	Soccer (n=18)	Softball (n=15)	Swimming (n=17)	Volleyball (n=8)	Total (n=75)
Age (Years)	19.2 ± 1.3	18.9 ± 1.4	19.7 ± 1.2	19.2 ± 1.2	19.6 ± 0.9	19.3 ± 1.2
Height (cm)	162.6 ± 8.9*	169.6 ± 4.3*	168.8 ± 6.1	165.5 ± 6.6	167.6 ± 4.3	166.7 ± 6.8
Weight (kg)	69.6 ± 12.6	70.9 ± 10.1	68.3 ± 6.5	64.4 ± 8.2	70.2 ± 5.48	68.5 ± 9.4
BMI (kg/m^2)	26.3 ± 4.5	24.7 ± 4.1	23.9 ± 1.9	23.5 ± 2.8	25.0 ± 1.9	24.7 ± 3.5

* = $p < 0.05$; Basketball < Soccer

Equipment Used

BOD POD

The BOD POD (Life Measurement, Inc, Concord, CA) is an instrument that measures body volume by air-displacement plethysmography. As described in Dempster and Aitkens (1995), the BOD POD is a molded fiberglass structure containing two chambers with a common wall separating the two. Subjects sit in the front chamber that is closed by a series of electromagnets during data collection. The rear chamber holds the instrumentation for the BOD POD including pressure transducers, electronics, breathing circuit, valves, and an air circulation system. Mounted between the two chambers is a volume-perturbing element in the form of a moving diaphragm that ensures the two chambers are equal in magnitude but opposite in sign. Using the gas laws of Boyle and Poisson, reference chamber air volume is determined by the pressure fluctuations that occur as a result of the volume perturbations.

D_b is calculated from the BOD POD based on the measurement of volume, which uses the principles of densitometry (Keys & Brozek, 1953):

$$D_b = \text{mass/volume}$$

D_b is then converted to %BF using this equation by Siri (1961):

$$\%BF = 4.95/\ D_b - 4.50$$

Skinfolds

Skinfold measurements were taken with Lange skinfold calipers (Cambridge Scientific Industries, Cambridge, Maryland) at four sites: tricep, supriliac, abdomen and thigh. Lange skinfold calipers are used because these close to a constant tension as opposed to plastic calipers.

Procedures

Percent Body Fat as Determined Using the BOD POD

Each subject was instructed to wear a swimsuit and a swim cap to compress air in the hair. Before the subject entered the BOD POD, the subject was asked to void. The electronic scale was calibrated by the BOD POD computer system by clearing the scale then measuring with 20kg weights on the scale prior to any testing. Height was measured to the nearest centimeter and body weight (kg) was measured on the calibrated scale. For the BOD POD, a two-point calibration was performed at baseline using a 50-1iter calibrated cylinder in an empty chamber for 20 seconds. The subject then entered the chamber and sat down breathing normally for 20 seconds. This was the initial test for body volume. At the end of the first test a second identical test was performed to verify consistency. The door was opened and shut between trials. The data was accepted if the two measurements agreed within 150 ml. If the two measurements were different by more than 150 ml then a third test was performed. After a subject's data was in agreement within 150 ml, she could then exit the BOD POD.

Included in the BOD POD system is the additional predicted measurement of average thoracic gas volume. McCrory et al. (1998) found that, on average, predicted thoracic gas volume did not differ significantly from the measured volume in 18-56 year old men and women. Failure to account for thoracic gas volume when using BOD POD software will result in the overestimation of D_b (McCrory et al., 1998). Predicted measurements of thoracic gas volume were used in data analysis.

Data appeared immediately on the computer screen containing %BF, FM, FFM and thoracic gas volume. The entire process took around three to four minutes. These procedures were performed as recommended by Life Measurement Instruments, the manufacturers of the BOD POD.

Skinfolds Measurement Procedures

The four skinfold sites were measured three times on the right side of the body to the nearest 0.5 mm; the median value was used for analysis (Martorell et al., 1988). Each skinfold was grasped firmly with the thumb and index finger holding the caliper perpendicular to the fold approximately one centimeter away from the thumb and finger (Jackson & Pollock, 1985). The definition of measurement sites are as explained by Jackson and Pollock (1985). Briefly, the tricep measurement is a vertical fold on the posterior midline of the upper arm halfway between the acromion and olecranon process with the elbow extended and relaxed. The suprailiac site is a diagonal fold above the crest of the ilium at an imaginary spot where a line would come down from the anterior axillary line. The abdomen site is a vertical fold directly to the right of the umbilicus. The thigh measurement is a vertical fold on the anterior aspect of the thigh midway between the hip and knee joints. The measurements were taken in rotating order. Three measurements were taken from each site.

Data from the skinfold measurements were utilized in three different skinfold equations. The first and third skinfold equations were converted from body density (D_b) to %BF via the equation of Siri (1961). The three different skinfold equations used for this study were:

1) The first equation (Jackson et al., 1980) was developed using UWW as the criterion method and has been recommended for female athletes (SF-UWW):

$$D_b = 1.0960950 - 0.0006952\ (X) + 0.0000011\ (X)^2 - 0.0000714\ (\text{age})$$

where X is the sum of tricep, abdomen, suprailium and thigh skinfolds in mm.

2) The second equation was developed from female athletes using DEXA as the criterion measure (Warner et al., 2004)(SF-DEXA):

$$\text{FFM} = 8.51 + (0.809 * \text{mass}) - (0.179 * \text{abdominal skinfold}) - (0.225 * \text{thigh skinfold})$$

3) The third equation was developed using UWW and is recommended for women between the ages of 18 and 55 years (Jackson et al., 1980)(SF-Gen):

$$D_b = 1.0994921 - 0.0009929\ (X) + 0.0000023\ (X)^2 - 0.0001392\ (\text{age})$$

where X is the sum of the tricep, thigh and suprilium skinfolds in mm.

Criterion-related concurrent validity was measured by comparing the tester's skinfold measurements to an Exercise Physiologist (Ph.D.) with more than 15 years of experience with skinfold measurements. The validity coefficients between testers for each skinfold measurement were above r = 0.80, which is recommended in order to substitute the tester for the experienced technician (Safrit, 1986): triceps, r = 0.9585; suprailiac, r = 0.9411; abdomen, r = 0.9453; thigh, r = 0.9610.

Intraclass reliability was tested for the three trials on all four skinfold sites by calculating a mean square value representing the sum of changes in the mean and error (Vincent, 1995). This was done to measure the repeatability or consistency of the tester's ability to take skinfold measurements. All of the trials were highly correlated: triceps, R = 0.9916; suprailiac, R = 0.9917; abdomen, R = 0.9927; thigh, R = 0.9942. The coefficient of variation was computed for each subject's skinfold results by dividing the standard deviation by the mean and multiplying by 100 (Duffy & Jacobsen, 2001). The mean coefficient of variation for each site reflects a small variability relative to the mean for each subject: triceps = 4.33%; suprailiac = 5.74%; abdomen = 3.98%; thigh = 3.41%.

Statistical Analysis

All pretest data were analyzed using StatView for Macintosh (Abacus Concepts, Inc., Berkeley, CA). Criterion-related concurrent validity and intraclass reliability were tested before actual testing began to ensure that the investigator could obtain valid and reliable data when taking skinfold measurements.

Data were analyzed using SPSS 14.0 for Windows (SPSS Inc., Chicago, IL). A one – way analysis of variance (ANOVA) was performed with repeated measures on the four body composition techniques. The four assessment techniques were: 1) a female athlete skinfold equation (SF-UWW) using UWW as the criterion, 2) a female athlete skinfold equation (SF-DEXA) using DEXA as the criterion, 3) a generalized skinfold equation (SF-Gen) for women, 4) the BOD POD. The independent variable was body fat assessment technique with the four levels of techniques and the dependent variable was estimated %BF. Tukey's HSD *post hoc* analysis was used to compare the means for each technique, and Cohen's *d* was used to calculate effect size for mean differences (Cohen, 1987). All statistical analyses were evaluated at an alpha of 0.05.

Sample Size Determination

G-Power analysis was used to determine a target sample size. Using the following parameters of a large effect size (Cohen's d) of 0.80, a power of 0.80, an alpha level of 0.05 and four groups, an estimated sample size of 76 was computed for this study (Erdfelder, Faul & Buchner, 1996).

CHAPTER IV

RESULTS

The primary purpose of this investigation was to compare percent body fat (%BF) as estimated from three skinfold regression equations (SF-UWW, SF-DEXA, SF-Gen) for female athletes against %BF as measured by the BOD POD. In this chapter the results are given.

Comparison of Skinfold Measurements to the BOD POD

The study consisted of 75 female athletes from a National Collegiate Athletic Association (NCAA) Division III University: basketball (n=17), softball (n=15), soccer (n=18), swimming (n=17), and volleyball (n=8). Body composition results (mean ± SD) are presented in Table 2.

Table 2

%BF Results (Mean ± SD)

	Basketball (n=17)	Soccer (n=18)	Softball (n=15)	Swimming (n=17)	Volleyball (n=8)	Total (n=75)
SF-UWW	25.07 ± 5.47	25.71 ± 5.54	25.82 ± 4.51	25.16 ± 5.32	26.89 ± 3.97	25.59 ± 5.03
SF-DEXA	23.48 ± 3.05	23.94 ± 4.41	21.78 ± 3.69	23.51 ± 2.72	21.3 ± 2.57	23.03 ± 3.50
SF-Gen	25.53 ± 3.96	25.33 ± 5.15	25.41 ± 5.74	25.77 ± 5.21	21.79 ± 4.92	25.11 ± 5.02
BOD POD	23.52 ± 4.44	24.83 ± 6.97	24.2 ± 6.01	26.02 ± 8.24	22.16 ± 5.55	24.39 ± 6.42

A one-way analysis of variance (ANOVA) with repeated measures was performed on the four different body composition techniques. Mauchly's Test of Sphericity was significant which indicated that the assumption of sphericity was violated. The Greenhouse-Geisser method was used to correct the degrees of freedom in order to determine statistical significance. Based on the statistical analysis, a significant main effect was observed for the body composition techniques ($F_{(3,222)} = 5.79$, $p < 0.01$, $\eta^2 = 0.07$). Eta^2 (η^2) is the ratio of the variance due to treatment and the total variance (Vincent, 1995). This means that only 7% of the total variance can be attributed to the body composition techniques. A Tukey's HSD *post hoc* analysis showed no significant differences between the BOD POD and any of the skinfold equation estimates.

The magnitude of these differences (Cohen's *d*) were small (see Table 3). Cohen (1987) defines a small effect as 0.2, a moderate effect as 0.5, and a large effect as 0.8. *Post hoc* analysis did show that significant differences were, however, found between the skinfold equation estimates SF-UWW vs. SF-DEXA, and SF-DEXA vs. SF-Gen. The magnitude of these differences was moderate and is shown in Table 3.

Table 3

Effect Sizes for Skinfold Techniques (Cohen's *d*)

	SF-DEXA	SF-Gen	BOD POD
SF-UWW	0.58*	0.096	0.21
SF-DEXA	-------	0.48*	0.26
SF-Gen	-------	-------	0.13

$p < 0.05$

Comparison of Percent Body Fat Techniques by Sport

A secondary analysis was conducted using a factorial ANOVA design with the different groups as the between-subjects effects and the different techniques as the within-subjects effects. As expected, based on the primary analysis, a significant effect for technique was revealed ($F_{(3,210)} = 6.36$, $p < .001$, $\eta^2 = 0.08$). No statistically significant effects were found for groups

($F_{(4,70)} = 0.49$, $p > 0.05$) or the interaction between groups and techniques ($F_{(12,210)} = 0.94$, $p > 0.05$).

CHAPTER V

DISCUSSION

The primary purpose of this investigation was to compare percent body fat (%BF) as estimated from three skinfold regression equations (SF-UWW, SF-DEXA, SF-Gen) for female athletes against %BF as measured by the BOD POD. In this chapter, the following items will be discussed: BOD POD vs. Skinfold Techniques, Skinfold Equation Estimates, Skinfold Estimates in Volleyball Players, Limitations, Future Research, and Conclusion.

Percent Body Fat Determined from the BOD POD vs. Skinfold Techniques

Based on the results, the null hypothesis was not rejected for this study as there were no significant differences between the BOD POD and each of the three skinfold equations. Previous research has shown that the BOD POD is comparable to both dual-energy x-ray absorptiometry (DEXA) (Fields et al., 2002; Ballard et al., 2004) and hydrostatic (underwater) weighing (UWW) (Fields et al., 2002; Utter et al., 2003; Vescovi et al., 2001). Although these measures have been found comparable, researchers have shown that when comparing the BOD POD to other reference methods, it is ranked at or near the top of the list in categories such as time, cost, maintenance, ability to accommodate people with limitations, and ease of use (Fields et al., 2002). Because the BOD POD is comparable with the techniques used as the criterion measures in SF-UWW, SF-DEXA and SF-Gen, this may explain why there were no significant differences between the BOD POD and each of the skinfold estimates.

Although no skinfold regression equation has been developed for female athletes using the BOD POD as the criterion, the three previously developed equations used in this study are comparable to the BOD POD. Therefore, it is suggested that they can be used for female athletes.

Comparison Between Skinfold Equation Estimates

Statistically significant differences were found between SF-DEXA vs. SF-UWW, and SF-Gen (Table 3). This difference showed DEXA estimating a low %BF compared to the other two equations. Statistically significant differences were not found between SF-UWW and SF-Gen (Table 3). The differences may be due to the use of different criterion measures and the principles on which these are based.

Researchers have reported DEXA and UWW to be highly correlated with each other ($r = 0.95$; $p < 0.01$) but the use of different compartmental models could contribute to the differences between skinfold methods. This is shown in the significant differences between SF-DEXA vs. SF-UWW and SF-Gen. Many scientists believe that DEXA could potentially replace UWW as the "gold standard" in body composition testing because it accounts for three body compartments (fat mass, fat free mass, and bone mineral) while UWW only accounts for two compartments (fat mass and fat free mass) (Fogelholm & Lichtenbelt, 1997; Kohrt, 1998). One of the main differences between two- and three-compartment models is that the three-compartment model accounts for of the variability in FFM where two-compartment models assume a fixed density of FFM (Siri, 1961). In this investigation, the variability in %BF estimates across the different sports was smaller for SF-DEXA in comparison to the variability for SF-UWW and SF-Gen.

The measurement of bone mineral density (BMD) is one way that DEXA accounts for the variability in FFM. Overall, female athletes typically have higher BMD than nonactive females (Warner et al., 2004). The differences in UWW and DEXA become relevant when testing a population such as athletes whose BMD may be altered by the specific nature of their sport (Ballard et al., 2004). Sports such as basketball and volleyball load the bone more than a sport such as swimming. Creighton, Morgan, Boardley, and Brolinson (2001) found that women who participated in high or medium impact sports, such as basketball, volleyball, soccer and track, had a higher BMD and bone formation values than women who participated in nonimpact sports, such as swimming. Duncan, Blimkie, and Kemp (2002) found that female track athletes had greater site-specific BMD than female swimmers. In contrast to the results found in this study, Hall, Houtkooper, and Myers (1992) found by directly measuring %BF that UWW underestimated %BF in lean individuals when compared to DEXA ($p < 0.05$). They contribute this finding to the measurement of FFM (e.g., BMD) that deviates from the assumptions of the two-compartment model used in UWW.

In this investigation, although SF-DEXA was shown to be statistically lower than SF-UWW and SF-Gen, the difference is within 2.56% BF. Even though this difference is statistically significant, it may not be practically significant because it falls within the standard error of the estimate (SEE) produced when developing the skinfold equations (SEE: SF-UWW = 3.8%, SF-DEXA = 1.1% and SF-Gen = 3.7%) used for this study. This difference can also be attributed to the actual measurement error present when using skinfold equations of about 2-3%BF (Heyward & Wagner, 2004).

Percent Body Fat Comparisons in Female Athletes

It is important to use caution when comparing %BF values between athletes because there are many different levels of competition and training (Heyward & Wagner, 2004). Heyward and Wagner (2004) presented a table of the average body fat in male and female athletes, and the results of this study fall close or within the average range. The mean results are shown in Table 4:

Table 4

Mean %BF for Each Sport

	Basketball	Softball	Soccer	Swimming	Volleyball
Mean %BF	24.4%	24.95%	24.3%	25.12%	23.04%

The table presented in Heyward and Wagner (2004) did not provide an average body fat for soccer but did for the other female athlete sports: 1) Basketball = 20 – 27%, 2) Softball = 22%, 3) Swimming = 14 – 24%, and 4) Volleyball = 16-25% (Heyward & Wagner, 2004). The study used to create the SF-DEXA equation found %BF for Division I female athletes in soccer and softball to be 18.2 – 24.5% and 18.2 – 24.2%, respectively (Warner et al., 2004). Basketball was not included in the Warner et al. (2004) study but swimming and volleyball were in a combined group with ice skating and hockey together because of the low sample number for each group. The group's %BF range was 18.8 – 24.0%.

It is important to recognize healthy ranges of %BF for female athletes. If individual reference methods, such as UWW, the BOD POD, or DEXA, are available then those methods should be used to estimate %BF. These methods produce a smaller error of about 1-2 kg when compared to measuring body composition with skinfolds which produces an error of around 2-4 kg (Heyward & Wagner, 2004). Although UWW, DEXA and the BOD POD may be more accurate methods of measuring body fat when compared to skinfolds, they are expensive laboratory techniques and are not available at many universities to test athletes (Utter et al., 2003; Kohrt, W., 1998; Vescovi et al., 2001). Therefore, the accessibility and portability of skinfold calipers make it an important body composition measurement tool which can give excellent estimates when skinfolds are taken by a trained technician.

Limitations

There are possible limitations to this study. All subjects were asked to adhere to the same prestesing instructions prior to skinfold and BOD POD testing. However, if an individual did not following pretesting instructions, then that may have had an effect on the results. Although this information is not known, it is still a potential limitation. For example, an individual that participated in exercise or other events that elevate metabolism before being measured in the BOD POD could experience breathing patterns that were not normal (Fields et al., 2001). Gas in the stomach or intestine can lead to an overestimation of %BF in the BOD POD (Fields et al., 2001). The subject's %BF could have been overestimated if the subject did not void or consumed a carbonated beverage before being tested in the BOD POD. Another possible limitation is the fact that many members of the swim team wore one piece swim suits which made it harder to grasp the abdomen and suprailiac skinfolds. Additionally, all athletes tested were Caucasian individuals which limits the generalizability of the results of this study to other races.

Future Research

Although McCrory et al. (1995) suggests that using predicted lung volumes instead of directly measuring thoracic lung volumes is a valid form of measurement for the BOD POD, using this prediction could be a limitation. This study did not measure thoracic lung volumes because of the cost associated with testing such a large sample size. Future research should examine these effects directly measuring thoracic lung volumes in the BOD POD on female athletes.

Having completed testing procedures at a NCAA Division III level of sporting athletics, a wide variety of sports were not available for testing. In testing NCAA Division I athletes, Warner et al. (2004) used multiple sports (N = 101) to develop a skinfold model using DEXA as the criterion including crew, cross-country, track and field, field hockey, ice skating and hockey that were in addition to the athletes used for this study. Future research should be done using athletes from a wider variety of sports. Since there was such a low sample size for volleyball players, further examination should be done on female collegiate volleyball athletes with these skinfold equations to determine if any significant differences exist between volleyball players and groups of athletes from different sports.

Conclusion

In conclusion, it was found that the three skinfold equations used in this study were comparable with the criterion measure, BOD POD. In addition, the skinfold equation using DEXA as the criterion proved to be significantly lower than the two skinfold equations that used UWW as the criterion measure. Since the BOD POD is not readily available for testing at every athletic facility, using the recommended skinfold equations are adequate to estimate body fat in college aged female athletes.

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APPENDIX A:

PRETEST INSTRUCTIONS

Before your body composition testing, please follow these instructions:

1. Wear spandex (swimsuit) underneath shorts and a t-shirt.
2. Do not wear any jewelry.
3. Do not ingest food, alcohol, or caffeine 2-3 hours prior to testing.
4. Do not use tobacco products within three hours of testing.
5. Do not exercise prior to your body composition testing.
6. Please inform the researchers immediately if you do not feel well at any time during the testing session.
7. Please bring your completed questionnaire.
8. Please be able to note the date of your last menstruation.
9. Use the restroom before testing.
10. Again, if you have any questions or concerns regarding the data collection or your tasks, please ask the researcher immediately.

APPENDIX B:

INFORMED CONSENT

BGSU®

BOWLING GREEN STATE UNIVERSITY

Kinesiology Division
School of Human Movement, Sport, and Leisure Studies

INFORMED CONSENT STATEMENT

Investigator: Jenny Fruth **Phone:** (419)438-1510

Project Title: Comparing Skinfold Equations for Female Athletes Using the BOD POD As the Criterion

You are invited to participate in a master's thesis study for Bowling Green State University that involves measuring body composition using skinfolds and the BOD POD. I will be comparing previously developed skinfold equations to the BOD POD.

Your participation will last approximately one half hour. You may ask questions at any time during your visit. If at any time during the study you would like to stop participating, you may do so. You are not required to complete the study.

Purpose: The primary purpose of this study is to compare two methods of assessing percent body fat in female collegiate athletes using the BOD POD as the criterion.

Procedure: The research procedures will consist of your voluntary involvement. You will be asked to complete a brief questionnaire regarding weight training and menstrual history. Your height will be taken on a stadiometer to the nearest cm. You will then be weighed on a scale in your spandex suit. A spandex swim cap will then be put over your hair with all hair tucked in. You will then enter the BOD POD for measurement. The BOD POD is an egg-shaped structure with an enclosed chamber where you can sit comfortably. Once seated inside the BOD POD with hands relaxed and feet on the floor, the door will be shut. During this time you should not laugh or talk and should have minimal movement. You will hear the sound of air moving between the two chambers like a soft vacuum. After the first measurement the door will be opened and shut and a second measurement will be taken. If at any time during the testing you feel any anxiety from being in a closed space, a "STOP" button is located in the BOD POD for you to push and the test will automatically be stopped. After the BOD POD measurement the skinfold measurements will take place in the same room. Measurements will be taken three times in rotating order from the tricep, supriliac, abdomen and thigh. A fold of skin will be grasped firmly between my thumb and index finger. The calipers will then be placed 1 cm below and a measurement will be taken. After the measurement is taken the calipers will be released.

Risks: Before participating in the study, you should be aware of the possibility of adverse effects while measuring body fat. While participating in this study, the anticipated risks are no greater than those experienced in every day activities. Potential acute pain and/or bruising may occur during the skinfold measuring procedure. The only potential risk during the BOD POD measurement is the anxiety of being in closed spaces. To minimize this risk, you will be familiarized with this piece of equipment before testing.

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EXPIRES 12/14/07

Benefits: You will gain knowledge of your percent body fat and experience two different techniques for body composition measurement.

Confidentiality: Information received during testing will only be revealed to you and the investigators of this study. Your identity will remain anonymous as you will be provided with a subject number. Individual data will be combined and used with other subject data for analyses.

Voluntary Participation: Your participation in this study is completely voluntary. You may stop participation at any point. You are free to withdraw from answering any questions without penalty or explanation.

Contact Information: If you have any questions or comments feel free to contact Jenny Fruth at 419-438-1510 or by e-mail at jennyf@bgsu.edu, or Dr. Amy Morgan at 419-372-0596 or by e-mail at amorgan@bgsu.edu. If you have any questions or comments about the conduct of this study or your rights as a participant in this study, you may contact the Chair, Human Subjects Review Board, Bowling Green State University, 419-372-7716 or e-mail at hsrb@bgsu.edu.

Authorization: I have read this document and the study has been explained to me. I have had all of my questions answered. I volunteer to participate in this study.

I know that I will receive a copy of this letter.

__________________________________ ____________

Participant's Signature Date