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Comparison of hydrostatic weighing and plethysmography techniques for the development of skinfold prediction equations for children

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COMPARISON OF HYDROSTATIC WEIGHING AND PLETHYSMOGRAPHY TECHNIQUES FOR THE DEVELOPMENT OF SKINFOLD PREDICTION EQUATIONS FOR CHILDREN

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ABSTRACT

Regression equations between skinfold (SKF) measurements and air displacement plethysmography (ADP) were determined 6 to 18 year old athletes (80 males / 34 females) using Pearson r correlation coefficients. Triceps and mid-calf SKF and percent body fat (%BF) by ADP were measured during an Athletic Ability Assessment at The HIT Center (Huntington, WV). A high relationship was found between SKF and %BF by ADP (males; $r^2 = .76$, females; $r^2 = .74$, all; $r^2 = .77$). Data from the subjects were compared with similar correlations determined between SKF and %BF by hydrostatic weighing (HW) from another study (Slaugter et al., 1988). SKF showed a higher correlation with %BF by ADP than by HW (ADP, $r^2 = .77$ and HW, $r^2 = .72$). Therefore, the SKF regression equation based on % BF by ADP may be more accurate than the equation calculated in children for %BF by HW.

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CHAPTER I

Introduction

Body composition for children is an important assessment tool for many reasons. Obesity in adults and children is a major health problem in the United States. It is related to increased risk of coronary heart disease, diabetes, hypertension, cancer, and many other health problems (Kuczumarski, Flegal, Campbell, & Johnson, 1994). Interest in body composition for children is increasing due to the rising incidence of obesity during childhood (Lockner, Heyward, Baumgartner, & Jenkins, 2000).

Analyzing body composition in children is important for a variety of reasons. One aim of health care professionals is to decrease the prevalence of obesity (Dewit, Fuller, Fewtrell, Elia, & Wells, 2000). Therefore, accurate assessments of body composition are essential so that differences in adiposity can be adequately monitored. Another important reason for studying body composition is for understanding the relationship it has to athletic performance. Body composition for children has been shown to be correlated with athletic performance (Clark, Kuta, Sullivan, Bedford, Penner, & Studesville, 1993; Hergenroeder, Brown, & Klish, 1993). As children increase their adiposity, weight bearing physical work becomes more difficult. Therefore, reducing adiposity will improve athletic performance independent of health related benefits. The measurement of body fat provides useful information for athletes to help them monitor their performance improvements as it relates to changes in body composition.

There are several different methods that can be used to assess body composition. Historically, exercise scientists have considered hydrostatic weighing (HW) to be the gold standard for body composition assessment. HW, as originally outlined by Behnke, Feen and Welham in 1942, used Archimedes' principle to determine the body volume by measuring the difference between weight in air from weight in water. This method estimates body composition, particularly fat mass and fat-free mass. Although it is accurate, there are a number of assumptions with this technique. Since this technique requires submersion of the subject underwater, the fear of water may cause inaccurate results in many cases. More specifically, an accurate measurement of residual volume is dependent on complete exhalation while underwater. Another problem with this technique is that it requires multiple measurements in order to achieve reproducible results. The number of trials required is usually dependent on the subjects' ability to perform maneuvers without reserving air in their lungs while totally submerged underwater. Finally, HW is also not practical for field assessments. Thus, HW has proven to be difficult, especially for children since they often have a fear of the water.

Body composition is also determined from anthropometric measures such as body mass index, waist to hip circumference, and skinfold (SKF) measurement. The SKF method is especially useful for predicting body fatness in a variety of settings such as health clubs, fitness facilities, as well as clinical settings. One benefit of this method is that it is easy to do. The measurement instrument (skinfold caliper) is inexpensive, and it can be performed anywhere. Therefore, many studies using SKF technique have already been done (Lohman, 1981; Lohman, 1986; Weststrate & Deurenberg, 1989). Most SKF regression equations are developed using HW as the criterion variable.

Finally, air displacement plethysmography (ADP), was developed for assessing body composition using the densitometric method that estimates the fat and fat-free mass similar to HW. A recently developed device used for this technique is called the BOD POD body composition System (Life Measurement Instruments, Concord, CA, U.S.A.). The instrument is highly sophisticated. However, the protocols and procedures used to apply the measurements are extremely simple and reproducible across testers. Moreover, this new technology using plethysmography offers the capability of measuring body density without the fear of water as a compounding variable.

Since HW has difficulties with respect to collecting accurate results, a SKF equation may be less accurate when the regression equation is based on HW. If ADP is more accurate than HW to determine the body composition in children, because it requires no fear of water, then the SKF regression equation based on ADP may be more accurate. Therefore, the purpose of this study is to compare SKF measurements using HW as the criterion variable as apposed to using ADP.

Null Hypothesis

There will be a greater correlation between skinfold measurements using HW as the criterion variable when compared to using air displacement plethysmography.

Statement of the Problem

Hydrostatic weighing for measuring body density used to develop SKF regression equations for predicting the %BF may be less accurate than using ADP as the variable for comparison. Because subjects are required to be submersed underwater, the fear of water can lead to inaccuracies (especially in children) in this assessment owing to residual predictions. Since ADP does not require submersion in water, it is easier and more accommodating for younger subjects than HW (Dewit, Fuller, Fewtrell, Elia, & Wells, 2000). Thus, this technique may reduce subject error. It has been shown that children are much more willing to accept this type of measurement (Dewit et al., 2000). Therefore, a SKF regression equation based on ADP may be more accurate in children than a SKF regression equation based on HW. One other problem with using SKF analysis to predict body density is that it tends to show population specific errors. Multiple regression equations need to be created for each specific population. This work will focus on creating a regression equation for child athletes using ADP (BOD POD).

CHAPTER II

Review of Literature

The following literature review will attempt to describe what role the body composition of child athletes can play in predicting their sports performance. Several examples will describe the process of selecting elite athletes using body composition analyses. Secondly, this review will describe methods for predicting body composition using SKF and ADP assessments.

Body Composition

The significant role of body composition will be reviewed in this first section to better understand the purpose of this study. This discussion examines why body composition assessment is an important tool for analyzing child athletes.

Body composition is used to describe the proportions of tissue types that make up a person's total body weight. The most particular determination is the distribution of lean muscle mass and fat mass. When body composition assessment is applied to an athlete, a high lean mass and lower fat mass is often synonymous with high strength (Benardot, 2002). Oftentimes this characteristic is associated with an athlete's success; however, there is no single ideal body composition for all athletes in all sports.

There are suggested ranges of lean mass and fat mass for some sports. Each athlete in a sport has an individual range that is ideal for him or her.

Successful athletes tend to be within the range for their particular sport. Many athletes try to fit within the range defined for their sport in order to improve their performance. There may also be health and safety reasons for trying to achieve an optimal body composition besides performance alone. An athlete carrying excess weight may be more likely to be injured than an athlete with more optimal body composition (Benardot, 2002). On the other hand, strict diets and over training often lead to severe energy deficits and weight loss that is associated with a lower muscle mass and a relatively higher fat mass. This situation can also lead to a performance reduction (Benardot, 2002).

The assessment of body composition has been an important tool for studying and evaluation of growth, maturation, nutrition and physical performance (Lohman, Boileau, & Massey, 1975). One of the biggest investigations of body composition involves determining fat and lean content of the human body (Lohman, 1981). Adiposity is a serious health concern for both adults and children. Also, excess body fat has been associated with decreasing physical performance for athletes (Collins, Millard-Stafford, Sparling, Snow, Rosskopf, Webb, & Omer, 1999). The analyzing of body composition can provide valuable characteristics either for the status or preparation for competitive athletic participation or the nature of biological variations of differentiating athletes from other groups (Thorland, Johnson, Tharp, Housh, & Cisar, 1984).

An example of how body composition analysis can be used to help an athlete was shown in a study by Clark, et al. in 1993. This study compared the accuracy of body fat determinations and subsequent calculation of minimal weight by dual energy x-ray absorptiometry (DXA), bioelectrical impedance (BIA), near-infrared photospectometry (NIR), and anthropometry in high school wrestlers.

When wrestlers have to lose weight, they may be using undesirable weight-loss practices and competing at excessively low body weight. If an ideal minimal weight could be predicted easily, it could be safer to control a wrestler's body composition. Moreover, coaches could train the wrestlers in a safer and more appropriate manner. Due to its complex nature, measuring minimal weight based on the laboratory standard HW is not appropriate for many schools. When body composition is applied to one population, careful attention is needed to select the methodology. The limitations and errors for each method should be recognized and understood. In this study SKF assessing was used for anthropometric measurements. One of the issues addressed in this study was the question of making weight.

Many wrestlers and coaches will try to get individuals to lose weight. This study attempted to use SKF analysis to predict the minimal weight a wrestler could reach and still be healthy and perform at a high level. The researchers showed that it is possible to make predictions, but with any SKF study there are errors that needed to be addressed.

Another study by Hergenroeder, Brown, and Klish (1993) estimated body composition from SKF, circumference, and total body electrical conductivity and made an equation for free fat mass in accomplished female ballet dancers.

Due to requiring high athletic performance and maintenance of a thin body type, ballet dancers need a self-controlled and strict lifestyle. Balancing adequate energy intake to maintain a high level of performance and good health is important for ballet dancers. It was found in this study that free fat mass of skillful ballet dancers could be estimated from body weight alone. Because elite ballet dancers have lowered subcutaneous fat, which is significantly different from non-elite ballet dancer populations, a specific equation for estimating free fat mass was used. This equation could be used to predict an elite dancer from a population based on weight alone.

As these examples show, estimating body composition for athletes is useful and important in understanding a athletes' body composition related to their performance as well as their health and safety.

Techniques of Body Composition Assessment

Since SKF measurement techniques are not time consuming, complicated, and expensive, it is the preferred way to determine the body composition in most studies (Ellis, 2001; Lohman, 1981). However, when %BF is calculated from SKF analysis, the equation used in most studies is based on data from HW as a reference. Other techniques are employed to calculate body composition and the following review will discuss some alternative tools and techniques.

Many methodologies have been developed to measure a variety of body composition parameters. Because there are limitations and errors in many of the methods used to calculate body composition, more accurate assessments for body composition have been developed. There are two main categories for these methods. These are laboratory methods and field methods.

The laboratory method rather than field method is generally used for reference method. Hydrostatic weighing has been also used as a reference method. Recently, new methods have been developed with improved technology. Air displacement plethysmography, one of a number of new methods, has been studied, but because of technical difficulties, it had not been widely accepted. However, recent studies have shown a new device, the BOD POD, seems to overcome previous problems with ADP. Another technique, Dual-energy X-ray has also been studied. These two new methods have advantages over HW but as with any method there are limitations and errors. (Elia & Ward, 1999; Ellis, 2001; Fields & Goran, 2000; Heyward, 1998; Lockner et al., 2000; Sardinha, Lohman, Teixeira, Guedes & Going,1998; Wagner & Heyward, 1999).

While laboratory reference methods are typically more accurate, they are also more time consuming, inconvenient, and expensive. Field methods are more focused on assessing percent body fat (Wagner & Heyward, 1999). They are applied easily anywhere and are typically inexpensive. Field methods generally determine %BF by using a prediction equation that is made by regression analysis between variables from the field method and scores from reference and criterion variables. The accuracy of a reference method, therefore, is directly related to the accuracy of the predicted field method. Developing a regression equation depends on population, measured method, and reference method used. Therefore, each developed regression equation is made for a specific population. A population can be defined by such variables as age, gender, and activity level (Heyward, 1998; Jackson & Pollock, 1977; Lohman, 1986; Wagner & Heyward, 1999; Weststrate & Deuremberg, 1989). The field methods introduced in this section include bioelectrical impedance, near-infrared photospectometry, skinfold technique, and anthropometric measurements.

Bioelectrical Impedance Analysis

BIA is a field method estimating total body weight and free fat mass using electrical current. Resistance and reactance are measured using one of two single-frequency BIA analyzers. The principle of BIA is that lean tissue contains large amounts of water and electrolytes which are good electrical conductors, while fat and other lipophilic molecules are poor conductors. The advantages of this technique are that it is quick, easy, and it does not require a highly trained technician. BIA can be a good method as long as the hydration of client is controlled, which can be very difficult (Ellis, 2001; Elia & Ward, 1999; Wagner & Heyward, 1999).

Near-infrared Interactance

NIR uses light absorption and reflectance passing through fat and muscle by near infrared spectroscopy. A computerized spectrophotometer with a scanner and probe is placed on a selected body site then is used to estimate body composition. When %BF is estimated from NIR, client data such as sex, body weight, body frame size, height, exercise level are considered. This method has shown a slightly higher error rate that leads to increasing estimates of body fatness values (Wagner & Heyward, 1999). This method is not complicated and it can be performed easily in the field; however, it has not yet been validated for use in humans.

Anthropometric Measurements

Simply measuring body size and proportion can be used to estimate body composition. Some common anthropometric methods are circumference and skeletal breadth as well as height and body weight. Circumferences reflect fat and free fat mass, and skeletal size is directly related to lean body mass. Because these are easy and practical measurements, a study that involves a large number of subjects often uses anthropometric methods. In addition, anthropometric indices from this method are used for health-risk stratification. For example, body mass index (BMI) and waist-to-hip ratio have been used for simple indexes of obesity-related health risk. However, this method is very population specific and it has limitations similar to other field methods (Wagner & Heyward, 1999).

Skinfold Technique

The SKF technique is a popular method in both field and clinical settings to estimate body density or %BF. SKF technique measures subcutaneous fat using inexpensive calipers. More than 100 equations for a variety of populations using SKF and/or other anthropometric techniques have been created since the first valid SKF equation was developed by Bronzek and Keys in 1951 (Ellis, 2001; Lohman, 1981).

The SKF technique is simply applied, but careful attention as well as technicians' training skills are needed to ensure accuracy. The SKF measurement starts by pinching the skin with the thumb and forefinger, and pulling it away from the body slightly, then placing the calipers on the fold. Therefore, SKF thickness means the thickness of two layers of skin and underlying subcutaneous fat (Wagner & Heyward, 1999). Different body sites are used for SKF measurements depending on which equation is used. The sum of several SKF thicknesses is usually used to develop an equation. For example, Jackson and Pollock (1978) estimated SKF equation using a 7-site formula for men. This equation required measurements from chest, midaxillary, triceps, subscapular, abdomen, suprailium, and thigh sites on the body. To get accurate SKF measurements, care should be taken to closely follow the standardized procedures for SKF assessments. Taking measurements requires at least two trials at each site (Heyward, 1998).

There are mainly three sources of error for the SKF measurement. First, the skill of a technician will affect the accuracy and precision of SKF measurements. Another source of error is type of SKF caliper. Different types of calipers can produce different values on the same subject. Lastly, it is difficult to assess the body composition of obese subjects. Because subcutaneous fat is thick, two layers of skin and subcutaneous fat may not be pinched, or the jaws of the caliper may slip off the fold. Therefore, SKF assessment may not be appropriate for measuring BF of extremely obese subjects (Heyward, 1998).

The %BF is predicted by a regression equation based on variables from SKF on total body density. Subcutaneous fat is correlated well with total body fat mass as assessed from densitometry (Weststrate & Deurenberg 1989). The relationship between body density and SKF thickness can change with age, sex, racial background, and athletic ability (Lohman, 1986). Most of the equations are population-specific (Lohman, 1981; Jackson & Pollock, 1977; Weststrate & Deurenberg 1989). Although Lohman (1981) has stated one third of total fat is structured by subcutaneous fat, the amount of subcutaneous fat is the range of 20% to 70% of percent of total fat depending on such biological factors as age, sex, degree of fatness and measurement technique. Therefore, when the body composition for one certain population is determined by using the SKF technique, an equation that was made for this population or a closely related population is used to determine the body composition with the values from the SKF.

Another SKF equation developed by Jackson and Pollock is a well-known formula. The generalized equation was developed on 308 men (age; 18-61 years) and cross-validated on 95 men by Jackson and Pollock (1978). The regression equation was calculated to estimate body density using the sum of 3 sites SKF (chest, abdomen, and thigh) (r=.91, SE=.0077g/cc). This equation shows good relationship with the previous equation that was developed for 7 sites SKF (chest, midaxillary, triceps, subscapular, abdomen, suprailium, and thigh) (r=.90, SE=.0078g/cc). The correlations between predicted and HW body density exceeded .090 with SE about .0077 g/ml.

A similar study was performed for women (249 women ages 18-55 years) by Jackson, Pollock, and Ward (1980). The regression equations were calculated using the same sum of 7 sites (r=.85, SE=.0083g/cc) and the sum of 3 sites (triceps, thigh, and suprailium) (r=.84, SE=.0086g/cc). Correlations between predicted and hydrostatically determined %fat was ranged from .815 to .820 with SE of 3.7 to 4.0% fat. From these results, Jackson and Pollock (1978) stated that age is an important factor that needs to be taken into consideration when determening body composition analysis with SKF.

Using a regression equation from SKF tests on body density for children must be treated differently from SKF tests for adults since a number of studies ascertained that age is an important issue for determining accurate SKF measurement. Lohman (1986) also stated formulas for children are needed because the chemical compositions of body tissues such as water, minerals (such as potassium and calcium), and protein are immature. Several SKF prediction equations for children have been developed for specific populations.

Thorland, Johnson, Tharp, Housh, and Cisar (1984) estimated body density in adolescent athletes. A hundred forty one male (mean age = 17.43 ± 0.95) and 133 female (mean age = 16.51 ± 1.39) were sampled to derive equations using the sum of three or seven SKF measures. SKF sites were used at triceps, scapula, midaxillary, suprailiac, abdominal, thigh, and medial calf. The actual density was measured by HW. High validity coefficients (R = .81 to .82) with low standard error (SE = .0055 to .0056 g/ml^{-1}) in the male sample while the equations for female sample displayed similar results (R = .82 and SE = .0060 g/ml^{-1}).

Slaughter, Lohman, Boileau, Horswill, Stillman, Loan, and Bemben (1988) determined SKF prediction equations for estimation of body fatness in children and youth. Two-site SKF equations using triceps and medial calf for both males and females were developed using body density from HW and multi-component models (bone mineral and body water) including maturation, race, and sex variables in the sample of 310 subjects included four maturation groups of black and white males and females. There were 66 prepubescent children (50 males, X = 9.8ys and 16 females, X = 10.0ys), 59 pubescent children (30 males, X = 12.2ys and 29 females, X = 11.4ys), 107 teen postpubescent children (58 males, X = 15.8ys and 59 females, X = 15.3ys), and 68 adults (36 males, X = 23.1ys and 32 females, X = 22.5ys). Because the resulting differences between maturation groups were small for the triceps and calf combination equation, there was no separate equation for each maturation group. An equation was developed for each gender, however. These are:

$$\text{Males: }\%BF = .735\,(\text{triceps} + \text{calf}) + 1.0 \quad (1)$$

$$\text{Females: }\%BF = .610\,(\text{triceps} + \text{calf}) + 5.1. \quad (2)$$

The skinfold thickness is measured as mm (millimeter). Standard error (SE) for both equations is 4.17. Slaughter et al. (1988) recommend these equations for predicting body fat in children 8 to 18 years of age.

The SKF assessment is widely used for body composition analysis in both clinical and field locations. One of the biggest reasons is that the SKF assessment does not take time for measurement so that it can be applied to a large population relatively quickly. Many studies about SKF assessment have also been performed because body composition analysis using SKF is population-specific. An important point of relevance for this thesis is that these studies have used HW to determine body density and %BF when the regression equation was calculated even though HW has some errors that can tend to be large when assessing children.

Dual-energy X-ray

DXA as a reference method uses an x-ray beam that passes in a posterior to anterior direction through the bone and soft tissue upward to a detector (Wagner & Heyward. 1999). Some studies of body composition in children recently such as Lockner et al. (2000) and Fields and Goran (2000), mention that DXA provides good assessment especially for children because it is a simple procedure and no water submersion is necessary as in HW.

Although the accuracy of DXA for measuring total body bone mineral and bone mineral density is widely accepted, researchers have discussed that there are limitations for assessing the composition of bone-free soft tissue. Also, it is time consuming, expensive, and has the drawback of radiation exposure (Wagner & Heyward, 1999; Lockner et al., 2000; Fields & Goran, 2000).

Hydrostatic Weighing

As a reference method, HW has been used for about 50 years (Elia & Ward, 1999). Albert Behnke (Behnke, Feen & Welham, 1942) used hydrodensitometry based on Archimedes' principle. That is, a body immersed in a fluid is buoyed by a force equal to the weight of the displaced fluid. The body volume is determined by measuring weight in air and weight in water. This volume is used to calculate body density that can be determined by weight divided by volume (density = weight / volume). There was good test-retest reliability found when Ward, Pollock, Jackson, Ayres, and Pape (1978) tested repeated measurements of volumetry (r = .96) and of hydrodensitometry (r = .99). They found that there was also good agreement in accuracies between both methods (r = .96). These consistent and accurate results have made HW the standard for assessing body composition to date (Heyward, 1998; Wagner & Heyward, 1999).

HW measurements require a subject to be totally submersed under water and to exhale completely. The residual lung volume (RV) may be measured by the predicted volume with gender-specific regression equations using age and height, or by gas-dilution techniques such as helium and oxygen, or by the nitrogen washout technique (Morrow, Jackson, Bradley, & Hartung, 1986; Motley, 1957; Wilmore, Vodak, Parr, Girandola, & Billing, 1980). Behnke et al. (1942)

mentioned the greatest error in HW is the determination of RV. If air still remains in the lungs while a subject submerses in water, that remaining air in the lungs gives a more buoyant body and affects the validity of the measurement. Therefore, RV has to be measured or predicted to make sure of an accurate body density assessment (Behnke et al., 1942; Heyward, 1998; Wagner & Heyward, 1999).

Although HW is still referred to as the gold standard reference, there are difficulties and errors including measuring RV which can lead to less accurate data.

Hydrostatic Weighing in Children

To achieve accurate measurements, an expert technician is required and a subject has to be very cooperative; both technician and subject need to have a good understanding of this method to allow for the highest accuracy (Elia & Ward, 1999; Nicholson, McDuffie, Bonat, Russell, Boyce, McCann, Michael, Sebring, Reynolds, & Yanovki, 2001; Wagner et al., 2000; Wagner & Heyward, 1999). HW requires full submersion of subjects underwater and they must completely exhale. This fact means HW may not be appropriate or it may be impossible for some populations such as children, obese, sick patients, elderly, and those who are afraid of water (Dewit, Fuller, Fewtrell, Elia, & Wells 2000; Elia & Ward, 1999; Heyward, 1998; McCrory, Gomez, Bernauer, & Molé, 1995; Nicholson et al., 2001). Dewit et al. (2000) reported one third of the children who attended his study failed in obtaining successful measurements. Moreover, HW is not an appropriate method in all children especially for those as young as 4 years old. Lockner et al. (2000) also stated that estimation of %BF from HW measurement in his study had a prediction error that was large (SE>4.5 %BF). Thus, his study considered HW to not be a good method for determining body composition in children. Another consideration is that HW can be very time consuming (Fields, Wilson, Gladden, Hunter, Pascoe, & Goran, 2001; Lockner et al., 2000; McCrory et al., 1995; Wagner et al., 2000). In addition, each subject generally requires more than one trial to achieve reproducible results. Fields et al. (2001) mentioned six to eight trials during which about 30 minutes was required for each subject. Lockner et al. (2000) stated that each child took about 75 minutes to complete the protocol and some children needed additional coaching for completion of the protocol.

Air Displacement Plethysmography

One other method for measuring body density is air displacement plethysmography (ADP). This is not really a new technique; on the contrary, the method has been available for some time. Problems in the procedure limited the interpretation of the results for this technique study initially (Elia & Ward, 1999). For example, Gnaedinger, Reineke, Pearson, Huss, Wessel, and Montoye in 1963 described that the greatest sources of error in his ADP method were due to the difficulty of controlling temperature, pressure, and humidity.

A new device for ADP overcomes these past problems. The BOD POD has been used as a new ADP system for measuring body volume. This body volume can be used to calculate body density with an additional measurement of body weight (Dempster & Aitkens, 1995).

The BOD POD consists of two, front and rear, fiberglass chambers. A client enters and exits through the door with an acrylic window in the front chamber while the molded seat that a client can sit down upon during the data collection, separates the unit into front and rear chamber. There is an instrumentation panel including pressure transducers, electronics, breathing circuit, valves, and air circulation system in the rear chamber. A movable diaphragm, used to determine volume, is mounted on the separated wall between front and rear chamber. This diaphragm is oscillated by computer control to produce complementary and small volume perturbations in the two chambers. These changes are analyzed to maintain chamber air volume for testing using the application of basic gas laws. The body volume is determined by measuring the difference between the chamber volume with and without the subject (McCrory, Gomez, Bernauer, & Molé, 1995):

$$\text{Body Volume} = \text{Chamber Volume}_{\text{empty}} - \text{Chamber Volume}_{\text{subject inside}}. \quad (3)$$

There are important considerations in mind when human measurements are taken. It is important to understand that skin, hair, clothing, and thoracic gas volume will affect the results of body volume. Gas under isothermal conditions (physiological body temperature) is more compressible than under adiabatic conditions. Air in the chamber is at adiabatic conditions while air close to skin, hair, and clothing will not maintain adiabatic conditions. Moreover, air in the lungs will be kept close to isothermal conditions. The effects of skin, hair, clothing, and lung gas should be accounted for or eliminated when determining accurate body volume (Dempster & Aitkens, 1995, McCrory et al., 1995).

The following studies were performed to determine the effects of clothing, hair, and thoracic gas volume (Vtg) in ADP. One study showed there was no significant difference between measured Vtg (Vtg_{meas}) and predicted Vtg (Vtg_{pred}), and also %BF by using Vtg_{meas} and $Vtg_{pred.}$ Moreover, the difference between measured and predicted RV in HW method was larger than the difference between Vtg_{meas} and Vtg_{pred} in ADP method (McCrory, Molé, Gomez, Dewey, & Bernauer, 1998).

Vescovi, Zimmerman, Miller, and Fernhall (2002) studied the effects of clothing on accuracy and reliability of ADP. Subjects were tested on three different occasions to estimate %BF with ADP. During these tests, clothing variables were measured such as wearing a swimsuit, a hospital gown, and nothing (subjects were nude). These studies showed that test-retest reliability of ADP is not affected by clothing as the same results were obtained for all situations (swimsuit, gown, and nude) over 4 trials. However, the study showed that wearing a hospital gown can influence the accuracy of %BF measurements determined by ADP compared with %BF calculated by HW. The results showed that %BF were underestimated by approximately 9 % compared with the recommended swimsuit as well as the nude subjects. The nude subjects did not significantly differ in the prediction of %BF from those wearing the swimsuit. Thus, there is no benefit of being naked for ADP studies. This is another benefit to this technique as many subjects are uncomfortable while nude.

The effects of skin, hair, and clothing should be eliminated or suppressed as much as possible. When a subject enters the chamber he or she should be wearing the equivalent of a swim cap to compress hair and a bathing suit to minimize clothing. The effect of skin areas is produced automatically by computer as surface area artifact which is estimated using body surface area (Dempster & Aitkens, 1995).

Thoracic gas volume (Vtg) is measured during the test or it can be predicted by calculation. The average thoracic gas volume during tidal breathing is measured while the subject is breathing normally through a tube attached to a port in the front chamber to the breathing circuit held in the rear chamber. The subject performing normal tidal breathing is monitored on the computer screen. Then the airway is occluded with a solenoid-controlled shutter at the mid point of an exhalation. During occlusion, air does not move within the airway, and pressure changes are small. At this point, Vtg can be determined automatically with computer. While air in lung maintains isothermal conditions, the body volume is underestimated by 40 percent of Vtg. Therefore, this is taken into account for the initial body volume when calculating body volume (Dempster & Aitkens, 1995):

$$\text{Body Volume} = \text{Body Volume}_{raw} - \text{Surface Area Artifact} + 40\%_{TG}. \quad (4)$$

Many studies have shown the precision of the measurements taken by ADP for a variety of populations within the last 7 years. Dempster and Aitkens (1995) evaluated and determined the reliability and validity of ADP by measuring a mass of known volume ($r = 1.00$, $SE = 0.004$). McCrory et al. (1995) showed a high reliability and validity of ADP measurement in humans. Twenty six adult females and forty two adult males ranging in ages from 20 to 56 years were subjects tested for validity of ADP. There was no significant difference between %BF of ADP and %BF of HW using a 95 % confidence interval. The regression equation found in this study was $\%Fat_{HW} = 1.86(\pm 0.83) + 0.94\ \%Fat_{BP}$ (± 0.03). SE was 1.81 and r^2 was .93 (numbers in parentheses are SE of the intercept and slope, respectively).

Other studies confirmed these results for adult humans with limitations and errors (Sardinha, Lohman, Teixeira, Guedes, & Going, 1998; Collinss, Millard-Stafford, Sparling, Snow, Rosskopf, Webb, & Omer, 1999; Nuñez, Kovera, Pietrobelli, Heshka, Horlick, Kehayias, Wang, & Heymsfield, 1999; Dewit, Fuller, Fewtrell, Elia, & Wells, 2000; Wagner, Heyward, & Gibson, 2000). These consistent studies concluded ADP is a valid and reliable instrument for measuring human body composition. The results from these studies show that %BF and body density calculated by ADP can be compared to %BF and body density determined by HW.

Studies have been performed to determine the predictive relationships between ADP and other methods for determining body density (Sardinha, Lohman, Teixeira, Guedes, & Going, 1998). One study, Sardinha et al. (1998) compared SKF method and ADP using 62 middle-aged men (the mean age 37.6 ± 2.9 years). Correlation coefficients between SKF method with Jackson and Pollock's 3-site (chest, triceps, and subscapular) and ADP to estimate %BF was .79 (P = .001). ADP was compared with other methods too such as DXA and BMI. ADP performed better than the other methods in general.

While these studies have shown the accuracy of ADP in adults, children were selected for the sample to assess body composition using ADP in the following. Dewit, Fuller, Fewtrell, Elia, and Wells (2000) compared ADP with HW for body composition analysis for children. ADP and HW measurements were applied to 22 children aged 8 – 12 years. The results of this study show ADP was practicable and acceptable to all children while about one third (10/32) of children initially recruited into their study were not successful with HW measurements. The precision was calculated by dividing the SD of differences between duplicate measurements by $\sqrt{2}$. The precision for body composition analysis by ADP was approximately twice as good as that obtained by HW.

One other study compared body density between the ADP and HW, and %BF between ADP and DXA in children (Nuñez, Kovera, Pietrobelli, Heshka, Horlick, Kehayias, Wang, & Heymsfield, 1999). Twenty two females (mean age = 13.1) and 26 males (mean age = 12.5) were used for subject in this study. Mean body density by HW and ADP were not significantly different (P = .58). Two body densities were highly correlated [$B_{d\ HW}$ = 0.239 + 0,774 x ($B_{d\ ADP}$); r = .91, SE = 0.007 g/cm^3, P < 0.001]. A high correlation was seen for %BF between DXA and ADP [%BF $_{DXA}$ = 2.84 + 0.86 x (%BF $_{ADP}$); r= 0.90, SE = 4.05, P < .0001]. Another study that shows similar results (Lockner, Heyward, Baumgartner, and Jenkins, 2000) concluded ADP measurement is both accurate and a practical method for body composition analysis in children even though small differences from other methods were observed.

The accuracy of ADP has been proven in the previous studies, and many other studies have also been performed. However, the study about body composition analysis using ADP has been suggested for further investigation (McCrory et al., 1995; Lockner et al., 2000; Nuñez et al, 1999; Dewit et al, 2000; Sardinha et al., 1998; Collins et al., 1999).

Summary and Conclusion

The body composition analysis is an important tool for athletes and their performance (Hergenroeder, Brown, and Klish, 1992). Excess body fat has been associated with decreasing physical performance for athletes (Collins, Millard-Stafford, Sparling, Snow, Rosskopf, Webb, & Omer, 1999). The body composition analysis has been studied using different methods in a variety of populations. Some of theses methods include HW, SKF, and ADP. These studies show the accuracy of each method, and also make comparisons between methods in specific populations. A new device, the BOD POD, has become the trend for body composition studies. The studies also have shown the accuracy of ADP.

In conclusion, this thesis will attempt to use these techniques and what was outlined in this review to develop a regression equation for determining %BF in adolescent athletes based on SKF analysis and ADP as the reference method.

CHAPTER III

Methods

Informed consent was acquired by all subjects prior to the Athletic Ability Assessment at The HIT (High Intensity Training) Center. Since the subjects were under 18 years of age, parental consent was required.

Subjects

The subjects were 114 healthy children between the age of 6 and 18 years old. All subjects participated as clients in a local performance enhancement center (The HIT Center, Huntington, WV). All subjects and their parents agreed to complete the test. The test protocol was approved by the trainers of the HIT Center when each client took the Athlete Ability Assessment. All subjects were athletes and the distribution of their participation in sports is shown in Table 3 in the results section of this thesis. The average weight was 62.88 kg ± 19.83 and the average height was 164.55 cm ± 16.84. The details of their physical characteristics and body composition are shown on Table 1 and 2 in the results section of this thesis.

Procedures and Instrumentation

All data were collected when subjects took an Athlete Ability Assessment at The HIT Center. Each subject completed a SKF measuring. SKF measurements were taken at the triceps and mid calf sites on all subjects. Then, ADP (BOD POD) test was used to determine body composition. Subjects changed their clothes to a swim cap and a bathing suit because of the impact of hair and clothing on the BOD POD measuring. Before the BOD POD assessment, the BOD POD instrument was calibrated for consistancy with the testing environment. Demographic data were entered into the BOD POD software. The subject was weighted then entered the BOD POD to measure volume. One testing time was 50 seconds, and each subject was tested repeatedly until reproducible results were obtained as determined by a 150 ml level of tolerance. Repeating the entire test process from the beginning was needed if data were not reproducible (Dempster & Aitkens, 1995). Average for thoracic gas (Vtg) volume was predicted based on a regression equation predicting functional residual capacity (FRC) and lung volume (V_R) for sex, age and height. Vtg was calculated as:

$$Vtg = FRC + 0.5\ V_{T.} \quad (1)$$

where V_T is the tidal volume. FRC and V_R were predicted from these formulas developed by Crapo, Morris, Clayton, and Nixon (1982):

$$\text{Women \& Men: } FRC = 0.0472\ Ht + 0.0090\ A - 5.290, \quad (2)$$

$$\text{Women: } V_R = 0.1970\ Ht + 0.0201\ A - 2.421 \quad (3)$$

$$\text{Men: } V_R = 0.2160\ Ht + 0.0207\ A - 2.840 \quad (4)$$

FRC and V_R are in liters, Ht is height in centimeters, and A is age in years (Elia & Ward, 1999; McCrory, Molé, Gomez, Dewey, & Bernauer, 1998).

Design and Analysis

This study was designed to determine the relationship between %BF measured by air displacement plethysmography (ADP) and skinfold measurement (SKF). This relationship was determined by Pearson r correlation coefficient and the equation for the line of best fit was plotted. A scatter plot was constructed using the ∑SKF on the x-axis and %BF ADP on the y- axis. This was compared with the relationship between ∑SKF and %BF measured by HW in Slaughter et al., 1988.

In their study, SE and r^2 are shown for the sum of triceps and calf plus design variables in 3 categories such as prepubescent, pubescent and postpubescent. Design variables also included maturation, sex and race. From the Slaughter et al. study, the average of the three categories r^2 was 71.67 and SE was 4.17. Average data are used in this study because this thesis work did not separate subjects into three distinct categories. In addition, it should be noted that the equations in this study did not adjust for maturation, race and sex.

CHAPTER IV

Results

Descriptive Characteristics

Eighty males and 34 females served as subjects for this investigation. The mean age was 13.74 ranging from 6 to 18 years. Physical characteristics of the subjects are presented on Table 1. Sports that subjects took part in are presented on Table 3. The %BF measured by ADP for males and females were 21.6 and 19.6, respectively. Using SKF technique described by Slaughter et al. (1988), %BF for males (22.74% ± 8.41) and females (21.25% ± 8.34) were slightly higher than previously measured %BF using ADP (see Table 2.).

Table 1.

Physical Characterisitcs of Subjects

Variable	Total (N = 114)			Males (N = 80)					Females (N = 34)				
	Mean		SD	Mean		SD	Minimum	Maximum	Mean		SD	Minimum	Maximun
Age(yr)	13.74	±	2.86	13.72	±	3.19	6.00	18.00	13.79	±	1.87	11.00	18.00
Weight(kg)	62.88	±	19.83	64.08	±	22.02	25.00	118.64	60.02	±	13.08	35.91	94.36
Height(cm)	164.55	±	16.84	165.63	±	19.23	119.38	200.66	161.95	±	8.54	142.24	180.34

Table 2.

Body Composition of Subjects

	Total (N = 114)			Males (N = 80)					Females (N = 34)				
Variable	**Mean**		**SD**	**Mean**		**SD**	**Minimum**	**Maximum**	**Mean**		**SD**	**Minimum**	**Maximum**
Skinfolds													
Triceps	15.09	±	6.25	14.06	±	6.07	4.00	32.00	17.54	±	6.07	7.00	31.00
Mid calf	14.59	±	6.56	13.49	±	6.17	0.00	29.00	17.19	±	6.79	6.00	35.00
Sum	29.67	±	12.08	27.56	±	11.35	8.00	52.00	34.72	±	12.41	13.00	63.00
%BF Skinfold	22.74	±	8.41	21.25	±	8.34	7.00	39.00	26.28	±	7.57	13.03	43.53
%BF BOD POD	21.60	±	9.73	19.26	±	9.32	4.00	39.00	27.19	±	8.44	9.40	43.00

* Male: 0.735 (triceps + calf) + 1.0

Female: 0.610 (triceps + calf) + 5.1 (Slaughter et al. 1988)

Table 3.

Sports of Subjects

Sports	Males
Baseball	40
Basketball	18
Soccer	5
Football	9
Tennis	3
Softball	1
Golf	1
t-ball	1
Not mention	2
Total	80

Sports	Females
Softball	10
Ice Skating	6
Basketball	5
Cheerleading	3
Golf	2
Tennis	2
Gymnastics	1
Soccer	1
Track & Field	1
Dance	1
Cross Country	1
Not Mention	1
Total	34

Relationship between percent body fat by ADP and Sum of SKF

The relationship between %BF determined by ADP and ∑SKF was established by Pearson r correlation coefficient. The relationship between %BF by BOD POD and ∑SKF in 80 males was highly correlated as shown in Figure 1. Linear regression analysis produced an r^2 = .76 (Regression Coefficients = .7178 and Intercept = .5196). The relationship between %BF by BOD POD and ∑SKF in 34 females is also highly correlated as shown in Figure 2. Linear regression analysis produced an r^2 = .74 (Regression Coefficients = .5858 and Intercept = 6.8495). When combining males and females into one group, the relationship between %BF by BOD POD and SKF is r^2 = .77, yielding a regression coefficient of 0.7062 and an intercept of 0.6486 (see Figure 3).

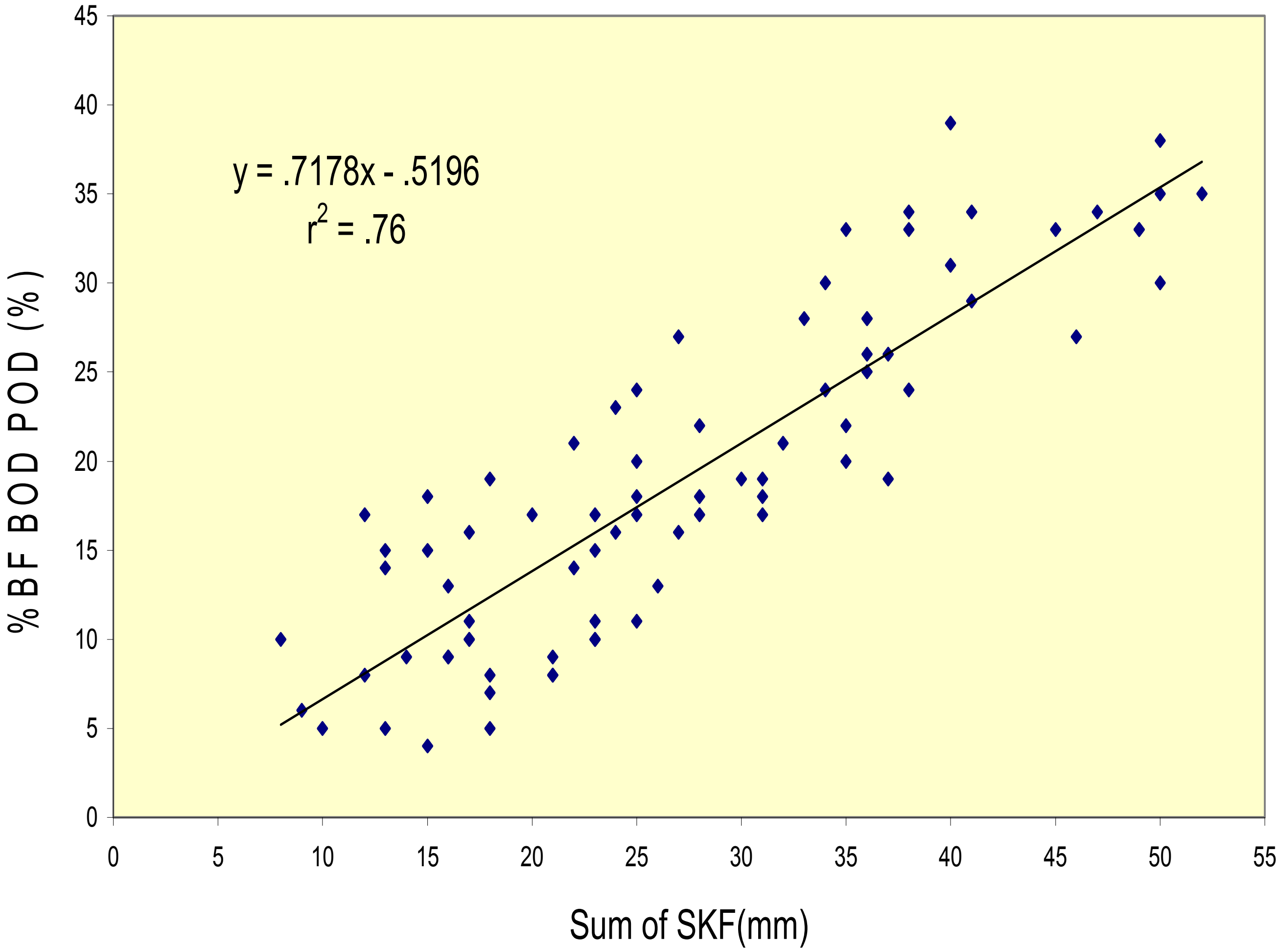

Figure 1. Relationship Between Percent Body Fat by BOD POD and Sum of Skinfolds in Males

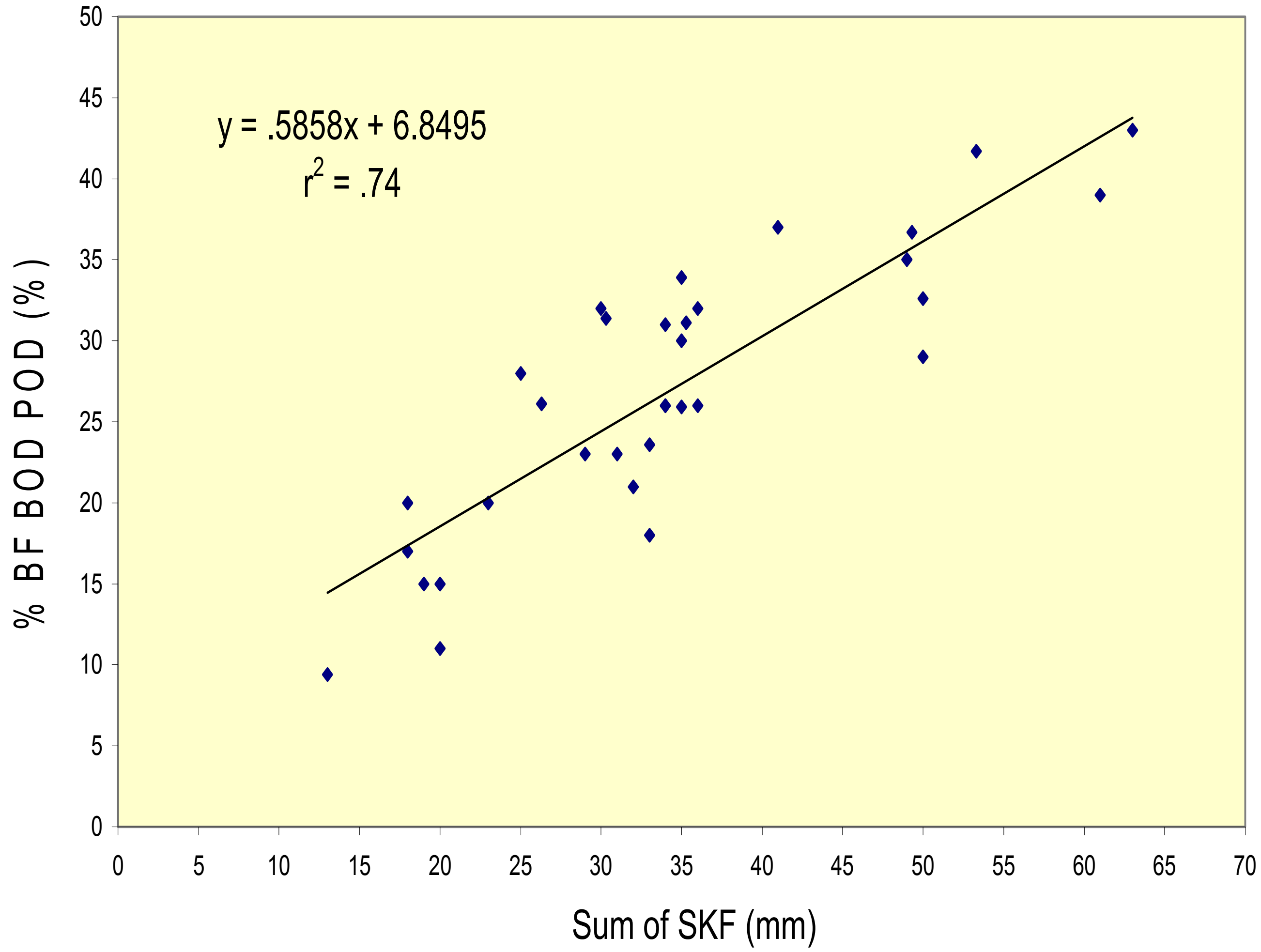

Figure 2. Relationship Between Percent Body Fat by BOD POD and Sum of Skinfolds in Females

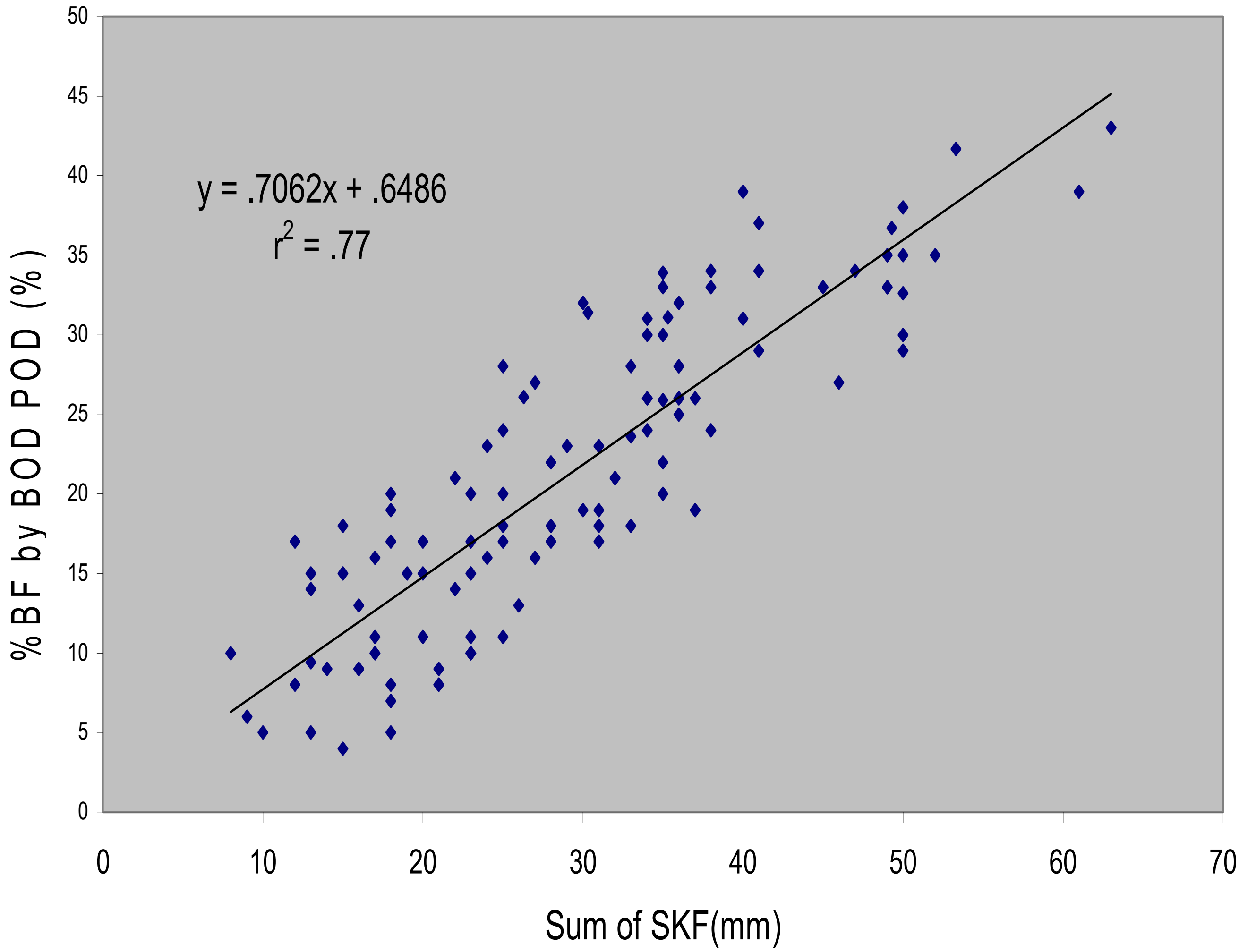

Figure 3. Relationship Between Percent Body Fat by BOD POD and Sum of Skinfolds

Comparison of HW and ADP

The current study did not perform hydrostatic weighing studies, therefore body composition data are compared to a previous study by Slaughter et al. (1988). The previous study showed a correlation coefficient between %BF based on HW and SKF measurements. Because their study showed the relationship between %BF based on HW and SKF measurement in 3 maturation categories, it is necessary to take an average value of 3 maturation categories to compare to ADP values determined by the current study. The average of the 3 maturations groups yielded an r^2 of .72. The relationship between %BF based on ADP and SKF measurements in this study was highly correlated ($r^2 = 0.77$). Figure 4 demonstrates that in the current study, the relationship between ADP and SKF measurement shows a higher correlation than the relationship between HW and SKF measurement (ADP, $r^2 = .77$ and HW, $r^2 = .72$). In addition, the relationship between HW and SKF measurements in prepubescent children is even lower ($r^2 = .62$) in the Slaughter study than the value determined for the average of the three maturation groups. If only the prepubescent data from Slaughter study is compared with the correlation of the current study, the difference is greater (Slaughter, $r^2 = .62$ and current, $r^2 = .77$).

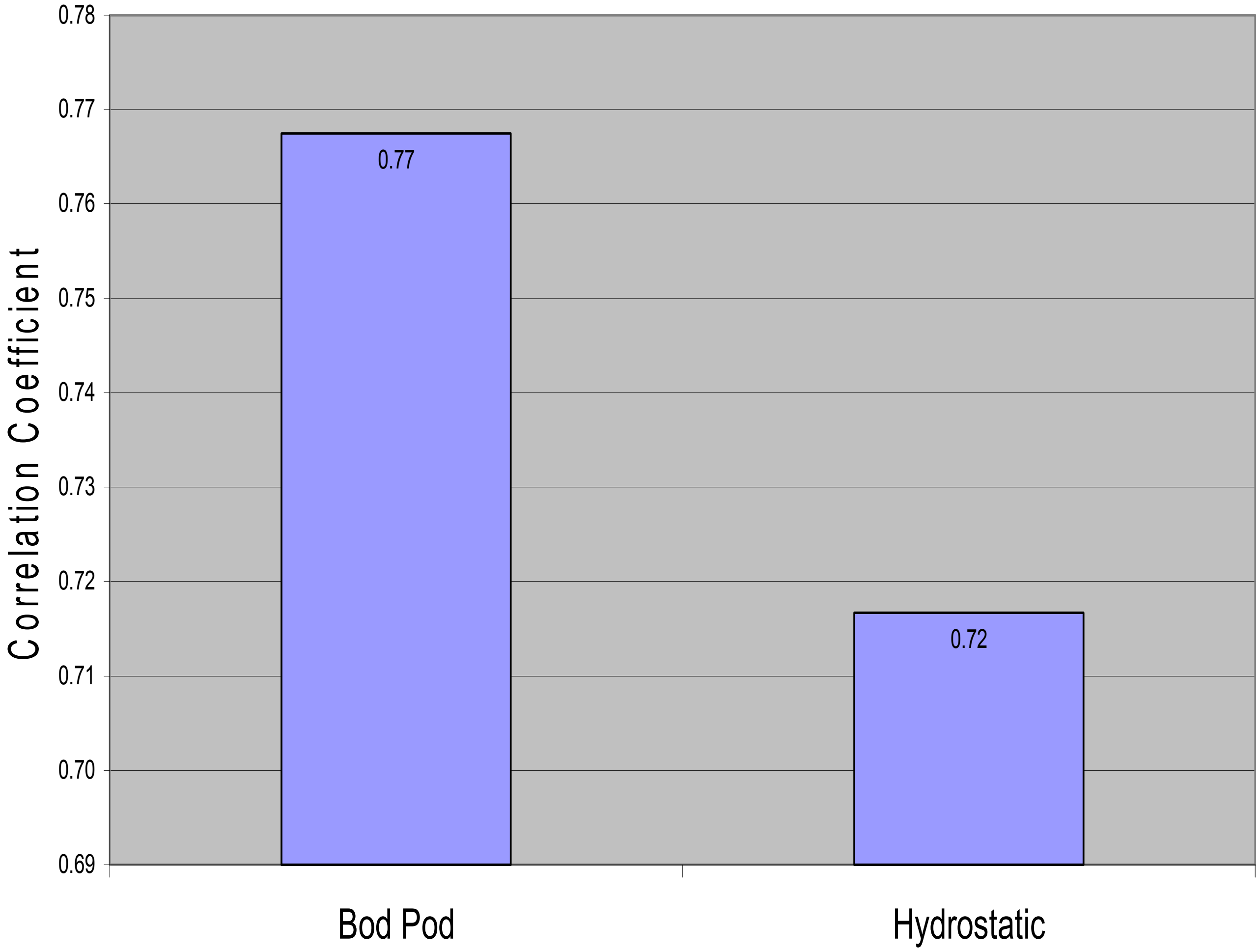

Figure 4. Comparison Between Bod Pod and Hydrostatic Weighing with Skinfold Measurements

CHAPTER V

Discussion

This study examined the relationship between percent of body fat (%BF) from air displacement plethysmography (ADP) and skinfold (SKF) measurement in 114 children aged 6 to 18. Regression equations were created and the correlation between %BF from SKF measurements and ADP using BODPOD were also determined. This equation was compared to the relationship reported between HW and SKF by Slaughter et al. (1988). The purpose of this study was to determine a SKF regression equation for children based on ADP.

The results from the sum of SKF and %BF using ADP yielded a high correlation between them based on regression analysis. These regression equations are as follows;

$$\text{Males: } y = .7178x - .5196 \ (r^2 = .76), \quad (1)$$

$$\text{Females: } y = .5858x + 6.8495 \ (r^2 = .74), \quad (2)$$

$$\text{Both: } y = .7062x + .6486 \ (r^2 = .77). \quad (3)$$

X is sum of triceps and mid calf SKF and y is %BF.

One limitation of the study is that the range of age in this study is 6 to 18 years. Because SKF results are closely related with changes in age and maturation (Lohman, 1986; Slaugher, Lohman, Boileau, Loan, Horswill, &Wilmore, 1984), an equation for smaller ranges of age should be created. This can be done in future studies as more data are collected from more subjects. In addition, as more data are collected, the importance of age grouping can be further elucidated.

One other limitation to this study was the small total number of females (n = 34). As stated before, a larger sample of females is needed to create regression equations for females. This can also lead to further information regarding differences between males and females.

A similar study by Sardinha et al. (Sardinha, Lohman, Teixeira, Guedes, & Going, 1998) has shown the predictive relationships between the ADP and SKF using 62 middle-aged men (the mean age 37.6 ± 2.9 years). Correlation coefficients between SKF with Jackson and Pollock's 3-site (chest, triceps, and subscapular) and ADP to estimate %BF was .79 (r^2 = .62). The characteristics of subjects are obviously different, so this current study and the Sardinha study cannot be compared directly. However, both studies compared relationship between ADP and SKF.

The finding of this study is that between sum of SKF and %BF by ADP yields a higher correlation coefficient (r^2 = .77, SE = 4.71) than between sum of SKF and %BF by HW (r^2 = .72, SE = 4.17) from Slaughter's study (1988). The Slaughter study (1988) showed a correlation between HW and SKF measurements in prepubescent children (r^2 = .62, SE = 4.5). When this correlation was compared with the correlation between SKF and %BF by ADP (r^2 = .77, SE = 4.71) in this current study, the difference between these correlations is even greater. Therefore, ADP correlation with SKF may be more accurate than %BF determined by using HW.

The null hypothesis that there will be a greater correlation between skinfold measurements using HW as the criterion variable when compared to using air displacement plethysmography needs to be rejected. There is a strong relationship between the body composition of 6 – 18 years children when comparing SKF measurements and ADP.

Considering the increase in children obesity in recent years ((Lockner, Heyward, Baumgartner, & Jenkins, 2000), it is paramount to develop more accurate prediction equations for body composition in children. The reason for the improvement in predictability with ADP may be attributed to the differences in the technique requirements. That is, unlike HW, ADP eliminates the fear of water. Through years of experience using underwater weighing on the childhood population, exercise physiologists have been plagued with methodological problems that are directly related to the fear of water. These problems usually result in inaccuracies related to the prediction of residual volume (RV). Varying amounts of exhaled air by a child that is uncomfortable in water leave the investigator helpless in determining body composition parameters. Some studies are especially noted by higher incomplete results reported in child measurements in HW (Dewit, Fuller, Fewtrell, Elia, & Wells 2000). The ADP method predicts RV using regression analysis in the same manner as HW. However, during the actual measurement, the child is breathing normally while sitting comfortably in a pressure chamber. Thus, reproducible results are easily obtained.

The BOD POD has been widely used recently. About 200 facilities are operating in The United States that use the BOD POD to assess body composition. The present study selected children as a special population that can benefit from the new ADP technology. It follows that other special populations may enjoy the same advantage. For example, there are many people with disease states or conditions that preclude them from climbing in large tanks of water and exhaling maximally. With the ADP method, the patient sits in the apparatus as if he is sitting in a chair at home. This allows for reproducible results. Our data suggest that skinfold equations for patients with various degrees of disability should be developed using ADP technology.

Conclusion

Data from the present study allows the rejection of the null hypothesis. A higher correlation was found between skinfold measurements and air displacement plethysmography when compared with using hydrostatic weighing as the criterion variable. This suggests that new equations need to be development using ADP technology. Special populations such as children and adults with disabilities may benefit greatly as more accurate prediction equations are developed. We, therefore, recommend that studies similar to the present study be conducted in these various populations.

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