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# Predicted Versus Measured Thoracic Gas Volume For The Bod Pod® Air Displacement Plethysmography System

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PREDICTED VERSUS MEASURED THORACIC GAS VOLUME FOR THE BOD POD® AIR DISPLACEMENT PLETHYSMOGRAPHY SYSTEM

by

Phil Blaney

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# ABSTRACT

Predicted Versus Measured Thoracic Gas Volume for the Bod Pod® Air Displacement Plethysmography System

by

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The purpose of this study was to determine whether there is a significant difference between measured values of thoracic gas volume (MTGV) and predicted values of thoracic gas volume (PTGV) using the Bod Pod®. One hundred and thirteen college freshmen, both males and females, were tested using the Bod Pod® by first measuring thoracic gas volume with the Bod Pod® technique, then by using pre-determined values based on height, weight, and age that predict thoracic gas volume. Results of a paired *t* test showed that measured thoracic gas volume and predicted thoracic gas volume were significantly different. A Pearson's product-moment correlation coefficient was calculated to be $r = .60$ which is significant at the $p \leq .05$ level. A Bland and Altman plot was used to reveal any variability about the mean for individual participants MTGV and PTGV and the averages of each. A Pearson's product-moment correlation coefficient was calculated for the data in the Bland and Altman plot. The correlation was calculated as .56, which is significant at the $p \leq .001$ level. It was

concluded that within the limitations of this study, there is a significant difference between MTGV and PTGV when using the Bod Pod® air displacement plethysmography system.

(69 pages)

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# CHAPTER 1

# INTRODUCTION

Since the mid-seventies, the prevalence of overweight and obesity has increased sharply for both adults and children. Data from two National Health and Nutrition Examination Surveys (NHANES) show that among adults aged 20–74 years, the prevalence of obesity increased from 15.0% (in the 1976–1980 survey) to 32.9% (in the 2003–2004 survey) (National Center for Health Statistics, 2004). Although one of the national health objectives for the year 2010, established by the United States Department of Health and Human Services, is to reduce the prevalence of obesity among adults to less than 15% (USDHHS, CDC, 2006) current data indicate that the situation is worsening. In 2006, only four states had a prevalence of obesity less than 20%. Twenty-two states had prevalence equal or greater than 25%; two of these states (Mississippi & West Virginia) had a prevalence of obesity equal to or greater than 30% (USHHS, CDC). Obesity and overweight are conditions in which the energy reserve, stored in the fatty tissue of humans and other mammals, is increased to a point where it is associated with increased morbidity and mortality. Although obesity is an individual clinical condition, it is increasingly viewed as a serious and growing public health problem.

Overall, there are a variety of factors that play a role in obesity. In the United States, a changing environment has broadened food options and eating habits. Pre-packaged foods, fast food restaurants, and soft drinks are all becoming more and more accessible. While such foods are fast and convenient they also tend to be high in fat, sugar, and calories. Choosing many foods from these areas can contribute to an excessive calorie intake. Some foods are marketed as healthy, low fat, or fat-free, but often contain more calories than the fat containing food they are designed to replace. Portion size has also increased, which results in increased calorie consumption. If the body does not burn off these extra calories consumed from larger portions, fast food, or soft drinks, weight gain will occur (USDHHS, 2000). Studies show that genetics can also play a role in obesity; however, genes do not always predict future health. Genes and behavior may both be needed for a person to be overweight. Although obesity has strong genetic determinants, the genetic composition of the population does not change rapidly. Therefore, the large increase in obesity must reflect major changes in nongenetic factors (Hill & Townbridge, 1998).

Overweight and obese individuals are at increased risk for many diseases and health conditions, including: hypertension (high blood pressure; Rönnback, Hernelahti, Hämäläinen, Groop, & Tikkanen, 2007), osteoarthritis (a degeneration of cartilage and its underlying bone within a joint; Shedd et al., 2007), dyslipidemia (for example, high total cholesterol or high levels of triglycerides; Rönnback et al.), type 2 diabetes (Jonker et al., 2006) coronary heart disease and stroke (Rönnback et al.) respiratory problems, and some cancers (endometrial, breast, & colon; Steindorf et al., 2004).

Overweight and obesity and their associated health problems have a significant economic impact on the U.S. health care system as well (USDHHS, 2001). According to a study of national costs attributed to both overweight (body mass index (BMI) 25–29.9) and obesity (BMI ≥ 30), these conditions accounted for

9.1% of total U.S. medical expenditures in 1998 and may have reached as high as $78.5 billion ($92.6 billion in 2002 dollars) (Finkelstein, Fiebelkorn, & Wang, 2003). Approximately half of these costs were paid by Medicaid and Medicare.

A more recent study focused on state-level estimates of total, Medicare and Medicaid obesity attributable medical expenditures (Finkelstein, Fiebelkorn, & Wang, 2004). State-level estimates range from $87 million (Wyoming) to $7.7 billion (California). Obesity-attributable Medicare estimates range from $15 million (Wyoming) to $1.7 billion (California), and obesity-attributable Medicaid expenditures range from $23 million (Wyoming) to $3.5 billion (New York). The state differences in obesity-attributable expenditures are partly driven by the differences in the size of each state's population.

A large amount of research has been conducted to find causes of this rapidly growing problem and a possible method to combat this growth. In exploring possible solutions, there has been a new emphasis placed on physical activity and exercise. Although our bodies need calories for daily functions, weight gain occurs when calories consumed exceed this need. Physical activity has proven to play a key role in energy balance because it uses up excess calories. Regular physical activity is good for overall health. Physical activity decreases the risk for colon cancer, diabetes, and high blood pressure. It also helps to manage weight; contributes to healthy bones, muscles, and joints; and helps to increase quality of life (Jonker et al., 2006; önnback et.al., 2007; Shedd et al., 2007; Steindorf et al., 2004).Many programs centered on physical activity have been launched aiming to combating the epidemic of obesity in the U.S. In 2002, a bipartisan trio of U.S. senators took a serious swipe at the national obesity epidemic with a wide-ranging but modestly priced proposal that covered everything from nutrition research to physical education classes. The Improved Nutrition and Physical Activity Act sought to spend $256 million in its first year (S. 1172, 2003). Although the federal government annually spends millions of dollars on diabetes research, nutrition programs, and other health initiatives, this was the first broad legislation aimed specifically at America's growing waistline (Severson, 2002). In 2004, the Department of HHS and the Food and Drug Administration (FDA), two major government agencies, also launched programs (USFDA, 2004; USDHHS, 2004).

New exercise and weight management programs are popping up everywhere, each with promised positive results. While each of these programs may or may not work, it’s important to find ways to gauge the progress of each individual as he or she embarks on a new program. Many people use overall weight as an indicator of progress; however, this is not the best indicator. Weight measurements say nothing about distribution, quality or source of the weight (Heyward & Wagner 2004.) For this reason, measurements of body composition are becoming increasingly popular in assessing progress in exercise programs as well as overall health.

There are many methods to assess body composition. Skinfold measurements, hydrodensitometry, bioelectrical impedance, dual energy x-ray absorptiometry (DEXA) and near infrared interactance (NIR) have all been used. For years, hydrodensitometry, using the two-component model, has been considered the gold standard. Recently however, a new system called the Bod Pod®, which utilizes air displacement plethysmography, has been developed to estimate body volume. Rather than using water displacement, air displacement plethysmography uses air displacement measurements to obtain body volume values. These values are used to calculate body density that is then applied to the Siri (1961) (or a population specific) equation to estimate percent body fat. There are many advantages to air displacement plethysmography. First, there is minimal pre test compliance by the person being assessed, and it does not require getting wet. Second, it is easy to operate. Third, the time it takes to conduct a Bod Pod® test is short compared to other methods. Finally, it is well suited for special populations (children, obese, elderly, and disabled persons) that would otherwise have a hard time being assessed. For these reasons air displacement plethysmography is becoming a popular method of assessing body composition.

Air displacement plethysmography was developed using the same 2-component model used by hydrodensitometry and utilizes many of the same assumptions. A key difference between the two methods is that in hydrodensitometry, a correction should be made for residual lung volume of air, while in air displacement plethysmography a correction should be made for thoracic gas volume.

There has been a great deal of research looking at the importance of obtaining an accurate residual volume in hydrodensitometry. When a hydrodensitometry test is performed on an individual, the individual is asked to expel all the air out of his or her lungs before he or she fully submerges into the water. Failure to maximally expel all air out of the lungs will make the individual more buoyant, resulting in a lighter under water weight, lower body density, and higher percent body fat (Heyward & Wagner, 2004). Several residual volumes prediction equations have been developed to try to remedy this problem. These equations however have large prediction errors (SEE = 400-500 ml). When the residual volume is measured, the accuracy of hydrostatic weighing is excellent (≤ 1% body fat), but when residual volume is estimated, the measurement error is greatly decreased (± 2.8 – 3.7% body fat) (Morrow, Jackson, Bradley, & Hartung, 1986). It has been further concluded that there is enough individual variation to indicate the necessity for using the actual measured residual volume when absolute accuracy is essential (Wilmore, 1969).

When measuring body volume using air displacement plethysmography (Bod Pod®), it is just as important to obtain an accurate measurement of thoracic gas volume as residual volume in hydrodensitometry. Any measurement of gas in the thoracic cavity cannot be included in a measurement of body volume. Doing so will invalidate the results. Though faster than other methods, using the Bod Pod® to measure thoracic gas volume can sometimes take a long time to obtain an accurate reading. As a result, manufacturers of the Bod Pod® have established predictive values of thoracic gas volume based on height and age. Because of the simplicity and quickness of using these predictive values, most people prefer to use them; however, there is limited research to determine if these values can yield an accurate account of body composition or if they will produce large prediction errors comparable to the residual volume estimates in hydrodensitometry. The major research that has been conducted was performed by the original researchers of the Bod Pod® (McCrory, Mole, Gomez, Dewey, & Bernauer, 1998). Consequently, it will be important to test whether these predicted values produce an accurate estimate of body composition.

## Hypothesis

Predicted thoracic gas volume values based on height, weight, and age, used to estimate body volume, density, and composition in 18-year old college freshman using the Bod Pod® will not be significantly different than thoracic gas volume values obtained by measuring thoracic gas volume directly using the Bod Pod® measurement technique at the $p \leq .05$ level. Thus, using predicted values of thoracic gas volume will be adequate in obtaining measures of body fat percentage within 2% of values obtained when measuring thoracic gas volume directly.

## Purpose of the study

This study was designed to measure the body composition of 113 college freshmen, both males and females, using the Bod Pod® by first, measuring thoracic gas volume with the Bod Pod® technique, then by using pre-determined values based on height, weight and age that predict thoracic gas volume. This was done to answer the following two questions:

1. Is there a significant difference between measured and predicted values of thoracic gas volume using the Bod Pod®?
2. Does a difference in measured thoracic gas volume vs. predicted thoracic gas volume significantly affect values of body volume, body density, or % body fat?

## Significance

Air displacement plethysmography by use of the Bod Pod® is quickly becoming a popular method for assessing body composition in adults. The proposed study is intended to determine whether using predictions of thoracic gas volume based on height and weight, rather than measuring thoracic gas volume directly with the Bod Pod® technique, are adequate in obtaining an accurate estimate of body composition. If the results of the current study support the hypothesis, those using the Bod Pod® to estimate body composition will have the ability to be confident that using predicted thoracic gas volume values will yield valid estimates of body composition. Furthermore conducting tests using the Bod Pod® will be easier for those being tested, as well as less time consuming and less expensive.

## Definitions

1. Bioelectrical Impedance: A procedure for assessing body composition in which an electrical current is passed through the body. The resistance to current flow through the tissues reflects the relative amount of fat present.
2. Dual energy x-ray absorptiometry (DEXA): Method used in clinical and research settings to estimate bone density and the bone mineral, fat, and mineral-free lean tissue of the body from x-ray attenuation.
3. Hydrodensitometry: Body composition method used to estimate body volume via measurement of weight loss when the body is totally submerged

under the water also referred to as hydrostatic weighing or underwater weighing.

4. Near Infrared Interactance (NIR): Body composition method used to estimate percent body fat or total body density via measurement of the reflectance of near infrared light at the measurement site.
5. Residual Lung Volume: Volume of air remaining in the lungs following a maximal expiration.
6. Specific Heat: The amount of heat required to raise the temperature of one gram of a substance by 1° Celsius.
7. Skinfold: Measure of thickness of two layers of skin and the underlying subcutaneous fat.
8. Thoracic Gas Volume: Volume of air in the lungs and thorax.

# CHAPTER II

# REVIEW OF LITERATURE

## Introduction

There is no question that obesity has become a major health issue in the United States. In 1991, only four of 45 states participating in the Center for Disease Control and Prevention's (CDC) Behavioral Risk Factor Surveillance System had obesity prevalence rates of 15-19%, and none had obesity prevalence rates greater than 20%. By the year 2000, all of the 50 states had obesity prevalence rates of 15% or greater, with 35 of the 50 states having obesity prevalence rates as high as 20% or greater. The prevalence of obese individuals in the U.S. increased to 32.2% in 2006 (Ogden et al., 2006), a 16.8% increase in only six years. In 2006, only four states had a prevalence of obesity less than 20%. Twenty-two states had a prevalence equal or greater than 25%; two of these states (Mississippi and West Virginia) had a prevalence of obesity equal to or greater than 30%. The recent increases in the prevalence of overweight and obesity are reflected across all ages, racial and ethnic groups, and education levels in the U.S. (USDHHS, CDC, 2006).

In 2004, two major U.S. government agencies – the Department of Health and Human Services (HHS) and the Food and Drug Administration (FDA) – launched programs aimed at combating the epidemic of obesity in the U.S. A great deal of research has been conducted to find causes of this rapidly growing problem and a possible method to combat this growth. In exploring possible solutions, there has been a new emphasis placed on the role of physical activity and exercise. New exercise and weight management programs are popping up everywhere, each with promised positive results. While each of these programs may or may not work, it is important to find ways to gauge the progress each individual has as he or she embarks on a new program. Many people use overall weight to mark progress; however, this indicator certainly has limitations. Weight measurements say nothing about distribution, quality, or source of the weight. For this reason, measurements of body composition are becoming increasingly popular in assessing progress in exercise programs as well as overall health.

To completely understand the science of estimating body composition, one must consider the theoretical models underlying the measurements. Information on the composition of the human body is primarily based on the chemical analysis of organs and a limited number of human cadaver analyses (Forbes, Cooper, & Mitchell, 1953; Widdowson, McCane, & Spray, 1951). These studies provided reference data for the development of body composition models that divide the body weight into multiple components. Of these models, the 2-component model is the most widely used to obtain reference measures of body composition (Heyward & Wagner, 2004).

The 2-component model describes the human body as two distinct parts, the fat and the fat-free body compartments. The fat-free mass component has a much higher density (approximately 1.10 g/cc) than does the fat mass component (approximately 0.90 g/cc.) The earliest 2-component model was established by Behnke, Feen, and Welham in 1942. Their model was based on measurements of body density using hydrostatic weighing. They established an inverse relationship between body density and adipose tissue, finding that excess fat is the biggest factor affecting body density (Behnke et al.). In 1956, Siri established another 2-component model equation to convert body density to percent body fat. Typically, these component model equations provide a reasonable estimation of percent body fat as long as the assumptions of the model are met.

For years, hydrodensitometry has been considered the gold standard for measuring body volume which is critical for determining body density and subsequently the 2-component model. Recently, however, a new system has been developed that utilizes air displacement plethysmography (ADP) called the Bod Pod® to estimate body volume. Rather than using water displacement, the Bod Pod® uses air displacement measurements to obtain body volume values. These values are used to calculate body density, which is then applied to the Siri (1961) equation to estimate percent body fat values.

When measuring body volume using air displacement plethysmography (Bod Pod®), it is important to obtain a measurement of thoracic gas volume. Any measurement of gas in the thoracic cavity cannot be included in a measurement of body volume. Doing so will invalidate the results. Using the Bod Pod® to measure thoracic gas volume can sometimes take a long time to get an accurate reading. As a result, manufacturers of the Bod Pod® have established predictive values of thoracic gas volume based on height and age. The main purpose of this study was to determine if predicted gas volume estimates, rather than direct measurements of thoracic gas volume, are adequate for measuring body volume using the Bod Pod®. The hypothesis was that there will be no significant difference when using predicted thoracic gas volume values rather than measured thoracic gas volume values when using the Bod Pod® to estimate body volume.

The purpose of this literature review will be to review prior studies that investigate the Bod Pod®, and more specifically, measured versus predicted estimates of thoracic gas volume. The researcher will first discuss air displacement plethysmography by looking at the purpose and history of the Bod Pod®, the principles and assumptions associated with it, and a review of research conducted on the validity and reliability of the Bod Pod®. The researcher will then cover prior studies that have examined measured versus predicted estimates of thoracic gas volume and their accuracy in determining total body volume using air displacement plethysmography (Bod Pod®).

## Air Displacement Plethysmography

ADP is used to measure body volume and body density. This method is similar to hydrostatic weighing except it uses air displacement, instead of water displacement, to estimate body volume. Because ADP is faster than hydrostatic weighing (approximately 30 min), requires less preparation time, minimal compliance and minimal technician skill, it is becoming an excellent alternative to hydrostatic weighing.

Early attempts at assessing body composition by using air displacement plethysmography were not successful, but, Dempster and Aitkens (1995) introduced a new system (i.e., the Bod Pod®) that overcame many of the limitations of earlier ADP technology. The Bod Pod® is a large, fiberglass, egg-shaped chamber that uses air displacement and pressure-volume relationships to derive body volume (see Figure 1).

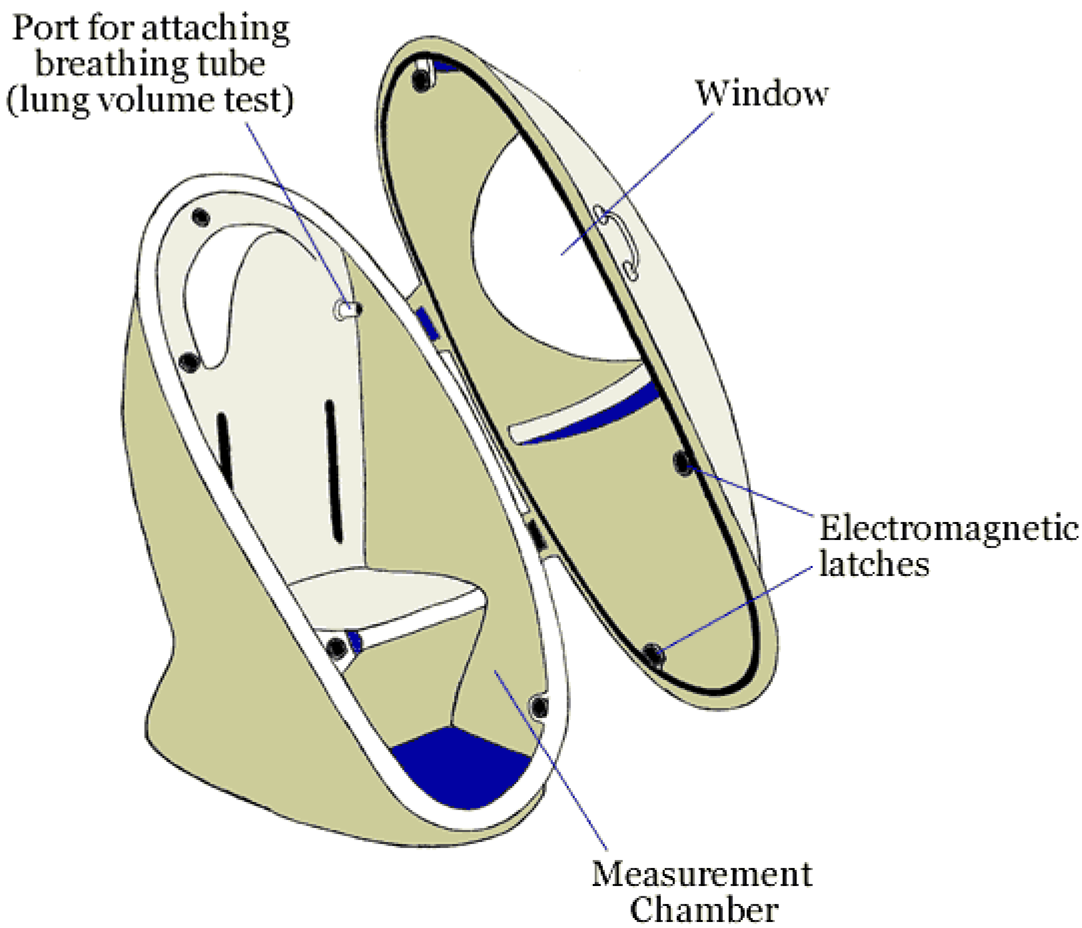


*Figure 1.* Air displacement plethysmograph (Bod Pod®)

In a recent study that subjectively rated various body composition reference methods, the Bod Pod® ranked near the top in categories such as maintenance, cost, time, ease of use, and the ability to accommodate people with limitations (Fields, Goran, & McCrory, 2002). As a result, this body composition tool has recently received greater attention from researchers.

*Principles and Assumptions of ADP*

The Bod Pod® determines body volume by measuring changes in pressure within an enclosed chamber. The principles and assumptions of the Bod Pod® focus on the relationship between pressure and volume. According to the Ideal Gas Law:

$$PV = nRT \tag{1}$$

where P = pressure, V = volume, n = moles of gas, R = the gas law constant, and T = temperature. Pressure and volume are inversely related, while both are directly related to temperature. The Bod Pod® attempts to control for changes in temperature and gas pressure that occur when a human is placed in an enclosed chamber. Volume and pressure are also expressed as inversely related according to Boyle's law:

$$\frac{P1}{P2} = \frac{V2}{V1} \tag{2}$$

where P1 and V1 represent one condition of pressure and volume, while P2 and V2 represent another condition. With regard to the Bod Pod®, P1 and V1 correspond to the pressure and volume of the Bod Pod® chamber when it is empty; while P2 and V2 represent the pressure and volume of the Bod Pod® when the individual being tested is sitting in the chamber.

Boyle's law assumes that air temperature remains constant as volume changes. This is known as an isothermal condition. The majority of the air in the enclosed Bod Pod® however is under adiabatic conditions. This means that the air compresses or expands as the temperature changes within the chamber. For example, when an individual is sitting in the Bod Pod®, his or her body will give off heat. This heat changes the temperature in the chamber and causes the pressure, and consequently the volume of air to change. To correct for this discrepancy, the Bod Pod® software uses a variation of Boyle's law that is more appropriate for the adiabatic air found within the chamber called Poisson's law**:**

$$P1/P2 = (V2/V1)^{\lambda} \tag{3}$$

where ($\lambda$) is the ratio of the specific heat of the gas at constant pressure to that of constant volume. For air, it is equal to 1.4, representing the 40% difference between isothermic and adiabatic conditions.

This difference between isothermal and adiabatic air is both statistically significant and meaningful because air under isothermal conditions is much more compressible than air under adiabatic conditions. This creates an apparent negative volume (Dempster & Aitkens, 1995). For example, clothing is isothermal, so wearing bulky clothing in the Bod Pod® will result in an artificially reduced body volume. Thus, a major assumption of the Bod Pod® is that isothermal effects that could alter the body volume estimate have been identified (clothing, hair, thoracic gas volume, and body surface area) and are controlled (Heyward & Wagner, 2004). In order to minimize the effects of clothing, hair, and anything else that may cause an isothermal effect, individuals tested by the Bod Pod® are tested wearing minimal clothing (usually spandex or a swimsuit) and a swim cap to compress the hair. An estimate of body surface area is calculated from the height and weight of the individual being tested. This estimate is used to correct for the isothermal effects of the body's surface area. The volume of air in the lungs and thorax, or thoracic gas volume (TGV), can be either measured or estimated by the Bod Pod® to control for any isothermal conditions in the lungs.

The Bod Pod® system actually consists of two chambers: a front chamber in which the client sits during the measurement and a rear (reference) chamber. A molded fiberglass seat forms the wall between the two chambers, and a moving diaphragm is mounted here that oscillates during testing (see Figure 2). The oscillating diaphragm creates small volume changes, equal in magnitude but opposite in sign between the two chambers, which produce small pressure fluctuations. The pressure-volume relationship (i.e., Poisson's law) is used to solve for the volume in the front chamber. This process is done twice, once with an empty chamber and once with a client in the chamber. Body volume is simply calculated as the difference between the chamber volume when it is empty and when the client is seated inside of the chamber (Heyward & Wagner, 2004).

Before an accurate estimate of body volume can be obtained, two variables that have an isothermal effect causing an erroneously low value for the raw body volume score given by the Bod Pod® must be corrected for. These variables are body surface area and thoracic gas volume. Body surface area is estimated by the DuBois and DuBois (1916) formula:

$$B.S.A. (m^2) = 0.20247 \times Height(m)^{0.725} \times Weight(kg)^{0.425} \quad (4)$$

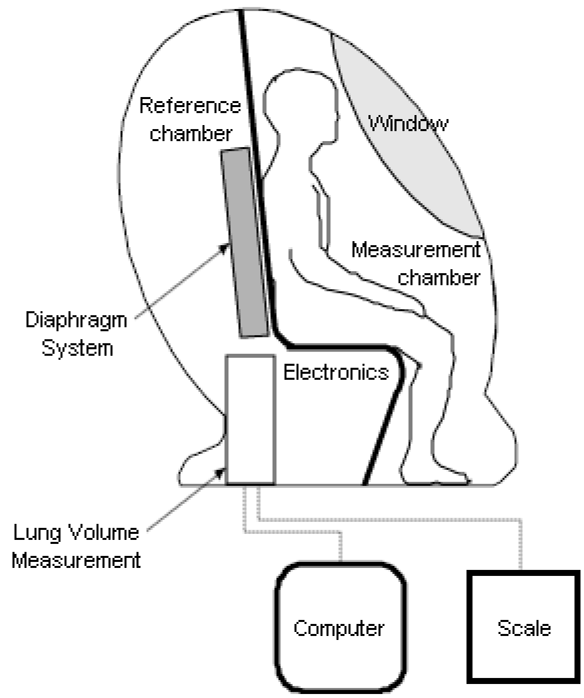


*Figure 2.* Two-chamber Bod Pod® system.

The surface area artifact is automatically accounted for by the Bod Pod® software. Thoracic gas volume has been accurately predicted in the research and clinical settings; however, direct measurement of thoracic gas volume is highly recommended (McCrory et al., 1998). Measuring thoracic gas volume involves connecting the client to a breathing hose following the initial body volume measurement. While the client is undergoing normal tidal breathing, the airway is occluded at mid-exhalation. At this time, the client gently puffs against the closed airway, alternately contracting and relaxing the diaphragm muscle. The small pressure changes in the lungs and external volume that this puffing maneuver creates are used to measure thoracic gas volume (Heyward & Wagner, 2004). The Bod Pod® software uses the following equation to derive body volume (Dempster & Aitkens, 1995):

$$\text{Body Volume(l)} = \text{Body Volume} - \text{surface area artifact} + 40\%\ \text{T.G.V.} \quad (5)$$

Body density can be calculated from body volume according to:

$$\text{Body Density} = \frac{\text{Body Mass}}{\text{Body Volume}} \quad (6)$$

This body density value can be used by any of the 2-C or multi-component model software defaults then applied to the Siri 2-C model equations (Heyward & Wagner, 2004).

*Validity of Bod Pod*

The accuracy of the Bod Pod was first evaluated against inanimate objects (cubes & cylinders) of varying volumes ranging from 25 to 150 L (Dempster & Aitkens, 1995). Error estimates were at < 0.1% volume and standard error of estimate (*SEE*) was 0.004 L. The team of McCrory, Gomez, Bernauer, and Mole (1995) was the first to test the Bod Pod® on human participants. Their findings reported excellent validity compared to hydrostatic weighing. The difference between the Bod Pod® and hydrostatic weighing estimates of percent body fat with the 2-C model was a mere 0.3% body fat (*SEE* = 1.81% body fat with 95% limits of agreement = -4.0% to 3.4% body fat) (Heyward & Wagner, 2004).

Since the first study conducted by Dempster and Aikens (1995), many other studies have been conducted to assess the accuracy of the Bod Pod® for measuring body density. Many researchers reported only minimal differences in average body density (< 0.002 g/cc) measured by the Bod Pod® versus hydrostatic weighing (Fields et al., 2001; VesCovi et al., 2001; Yee et al., 2001), while other researchers have reported slightly higher and statistically significant difference (0.003-0.007 g/cc) in adults (Collins et al., 1999; Demerath et al., 2002; Dewit, Fuller, Fewtrell, Elia, & Wells, 2000; Millard-Stafford et al., 2001; Wagner, Heyward, & Gibson 2000). Several studies have also shown "good" group prediction errors (*SEE* < 0.008 g/cc) in adults (Fields, Hunter, & Goran, 2000; Nunez et al., 1999; Wagner et al., 2000). As with other methods however, the individual accuracy is not as precise. Dewit et al. (2000) reported 95% limits of agreement for Db of -0.021 to 0.024 g/cc for children and 0.018 to 0.003 g/cc for adults (Heyward & Wagner 2004).

Most ADP validation studies compared percent body fat estimates from the Bod Pod® (percent body fat $_{ADP}$) to those measured by hydrostatic weighing (body fat $_{HW}$), dual-energy X-ray absorptiometry (DXA) (percent body fat $_{DXA}$), or both. Fields and colleagues (2002) reported, in a review of 15 separate studies, each containing adult participants, that the average difference (i.e., constant error or bias (CE)) between percent body fat $_{ADP}$, percent body fat $_{HW}$, or percent body fat $_{DXA}$ ranged from -4.0% to 1.9%, with *SEE*'s ranging from 2.2% - 3.7% body fat. Overall, the average CE for ADP method was estimated at < 1% body fat. The 95% limits of agreement, however, were typically 12% body fat (-7% to 5% body fat) or greater, indicating large difference for some individuals (Heyward & Wagner, 2004). Some research teams did note that gender may systematically bias Bod Pod® results, with percent body fat of men being underestimated and that of women being overestimated (Biaggi et al., 1999; Levenhagen et al., 1999). However, others reported that gender had little if any effect on the degree of differences observed between ADP and hydrostatic weighing estimates of percent body fat (McCrory et al., 1995; Nunez et al., 1999).

Many researchers evaluated the accuracy of ADP predictions using multi-component models to obtain reference measures of percent body fat (Collins et al., 1999; Fields et al., 2001; Millard-Stafford et al., 2001). Compared to 4-C model estimates of percent body fat (percent body $fat_{4\text{-}C}$), the Bod Pod® 2-C default calculations underestimated the average body fat considerably (1.8% - 2.8% body fat.) In a separate study, body density estimates from the Bod Pod® and hydrostatic weighing were entered into the same 4-C model equations (Millard-Stafford et al.); these researchers reported a substantial difference between percent body fat $_{4\text{-}C}$ estimated by the Bod Pod® (17.8% body fat) and by hydrostatic weighing (19.3% body fat). The range for the 95% limits of agreement in these studies was about 9% body fat and the *SEE's* were very good to excellent (2.4-2.7% body fat) (Heyward & Wagner, 2004). Fields and colleagues concluded that the predictive accuracy of the Bod Pod® and hydrostatic weighing is similar when each method is evaluated against 4-C models (Heyward & Wagner).

## Measured Versus Predicted Estimates of Thoracic Gas Volume

For years, hydrodensitometry or hydrostatic weighing (HW) has been the most widely used method in evaluating body composition using the 2-component model. This method is based on Archimedes' principle, which states that the volume of an object submerged in water equals the volume of water displaced by the object (Cutnell & Johnson). This principle deals with the buoyancy of objects when placed in a fluid. Because weight scales are typically used in under water weighing, another way of stating this principle is that a body, wholly or partially immersed in a fluid, will be buoyed up by a force equal to the weight of the fluid that it displaces (Cutnell & Johnson, 2004). In other words, when any object is placed in a fluid, it displaces some of that fluid, and the weight of the displaced fluid equals the magnitude of the upward buoyant force which the fluid exerts on the object. Once an individual's underwater weight is determined, it is used to calculate weight loss under water. This value is directly proportional to the volume and weight displaced by body volume (Heyward & Wagner, 2004).

The first hydrodensitometry testing was conducted by the Behnke research team (1942). They found, according to Archimedes' principle, the body volume of an individual is equal to the difference between the individual's mass in air and mass under water (Heyward & Wagner, 2004). This being the case, to accurately estimate body density using underwater weighing, this value must be corrected for by two measurements: density of the water, which corresponds to the water temperature at the time of submersion, and the residual volume (or whatever volume they are at for the underwater weighing) of air in the lungs and gas in the gastrointestinal tract, both of which add to the buoyancy of the individual. Both of these values are corrected for by the following body volume equation:

$$BV = \frac{BM(kg) - \text{net } UWW(kg)}{\text{Water Density}} - (RV + GV) \quad (7)$$

where BM = body mass, U.W.W. = under water weight, RV = residual lung volume, and GV = gastrointestinal tract volume. The volume of gas in the gastrointestinal tract is much smaller than the residual lung volume. Therefore, this volume is simply assumed to be 100 ml (Buskirk, 1961). It is much more important to get an accurate measurement of residual lung volume because there is a much greater amount of gas in the lungs and this will have a more substantial effect on the buoyant force of the individual.

When a hydrodensitometry test is performed on an individual, that individual is asked to expel as much air as possible out of their lungs before they fully submerge into the water. This can sometimes be a difficult task and is an unnatural maneuver. However, it is somewhat obvious that failure to maximally expel as much air as possible out of the lungs will make the individual more buoyant, resulting in a lighter under water weight, lower body density, and higher percent body fat (Heyward & Wagner, 2004). Several residual volume prediction equations have been developed to try to remedy this problem. These equations are based on the individual's age, height, gender, and even smoking status. These equations however have large prediction errors (*SEE* = 400-500 ml). When the residual volume is measured, the accuracy of hydrostatic weighing is excellent (≤ 1% body fat), but when residual volume is estimated the measurement error is greatly decreased (± 2.8 – 3.7% body fat) (Morrow et al., 1986).

Air displacement plethysmography has been developed using many of the same principles that are observed in hydrodensitometry. As previously stated, it uses air displacement rather than water displacement to estimate body volume. Because air displacement plethysmography measures thoracic gas volume rather than residual lung volume, it uses a different equation to estimate body volume (see Equation 5) that corrects for thoracic gas volume rather than the equation (see Equation 7) that corrects for residual lung volume and gastrointestinal gas volume.

Some differences in accuracy of body volume estimates may potentially be seen between these methods by looking at their respective procedures of obtaining a body volume measurement. Just as there are predictive equations to estimate residual lung volume, there are predictive equations that estimate thoracic gas volume as well. Previously published literature seems to be inconclusive as to whether predicted thoracic gas volume values are accurate. McCrory et al. (1998) tested 15 adult subjects and reported an insignificant difference (54 ml) between measured and predicted thoracic gas volume, however the *SEE* was large (442 ml). Other researchers have reported much larger mean differences (344 - 400 ml) and *SEE* (650 ml) (Collins et al., 1999; Lockner, Heyward, Baumgartner, & Jenkins, 2000). However, the prediction errors found by either research team are comparable to the *SEE* reported by researchers testing predicted values of residual lung volume (400 – 500 ml). Furthermore, the *SEE* for thoracic gas volume predicted values may not have as big of an effect on body volume estimates. This can be seen from the equations used by each method to estimate body volume. In Equation 7, 100% of the residual volume value is accounted for in the equation. In contrast, Equation 5 only accounts for 40% of the thoracic gas volume value. Given that only 40% of the thoracic gas volume is used in the calculation of body volume, using a predicted thoracic gas volume has a relatively smaller effect on estimates of body volume, body density, and percent body fat compared to using predicted residual volume values for hydrodensitometry (Heyward & Wagner, 2004). It may then be inferred that when using predicted values, air displacement plethysmography may provide a more accurate measurement of body volume than hydrodensitometry.

For this reason, as well as reasons previously discussed (ease of use, maintenance, cost, time), air displacement plethysmography by using the Bod Pod® is proving to be a viable and accurate alternative to hydrostatic weighing. If predicted values of thoracic gas volume could be shown to generate identical or near identical estimates of body volume this would further cut down on time and cost of body composition testing as well as increase the ease of use of the Bod Pod®. Though recent studies have shown that thoracic gas volume measurements made by the Bod Pod® are both reliable and valid (Davis et al., 2007), there have been few studies that examine measured versus predicted values explicitly (Collins et. al., 1999; Lockner et al., 2000; McCrory et al., 1998) to see if applying predicted thoracic gas volume values to body volume equations will give an accurate measurement of body fat percentage. Furthermore, the studies that have examined this aspect of the Bod Pod® did so using few participants and specific populations that should not be generalized to the larger population.

## Summary

Air displacement plethysmography (ADP) is a relatively new method used to obtain an estimate of body fat percentage. By using scientific principles, it estimates body volume measurements through measures of air displacement. Thoracic gas volume measurements must be obtained to correct for the gas volume in the thoracic cavity. The developers of the Bod Pod® (Dempster & Aitkens, 1995) have established predicted thoracic gas volume values based on height to apply to volume measurements rather than measuring gas volume directly. Minimal research, involving few participants, has been conducted to assess whether these values can provide an accurate estimate of body volume. Much more research is needed to conclusively argue that these predicted values are adequate in providing identical or near identical estimates of body fat percentage to values obtained by measuring thoracic gas volume. If it is proven that these predicted values are adequate in producing precise estimates of body fat percentage, the Bod Pod® may prove to be the fastest and most convenient and accurate method of assessing body fat percentage.

# CHAPTER III

# METHODS

The purpose of this study was to determine if predicted gas volume estimates, rather than direct measurements of thoracic gas volume, are adequate for measuring body volume using the Bod Pod®. As such, the methods used were similar to the procedures recommended by the makers of the Bod Pod® for body composition tests with the use of both the predicted and measured thoracic gas volume. This section contains information about participants and describes the design model and instrumentation used. The procedures for each method of measurement are then described as well as the statistical analyses.

## Participants

One hundred and twenty four (64 females & 60 males) traditional college freshman, aged 18-19 years, were recruited for this study. Eleven participants were unable to perform the thoracic gas volume maneuver; thus subsequent data analyses were done on only those 113 participants that completed the test. Inclusion criteria were (a) beginning university study (first semester), (b) being a full-time student (minimum of 12 credit hours, and (c) living in an on-campus residence hall. These criteria were designed to keep uniformity among participants and to make use of a parallel study being conducted on the same participants that limited the sample to this specific population. The only exclusion to this defined sample was students who were pregnant or planning pregnancy during their freshman year.

Each participant was in “on campus” student living in a variety of student housing dormitories across the campus of Utah State University. Participants were generally healthy and active, none of which had any major injuries. At the beginning of the testing procedures, participants self reported age, major, and residence hall whereas height, weight, and body volume were all measured by the researchers. A large variety of intended majors were reported by the participants. A variety of ethnicities were also represented as well as physical activity levels and body types. Table 1 lists descriptive characteristics of the participants.

Table 1

*Participant Descriptive Data for Age (y), Height (cm), Weight (kg), Body Volume (L) (N = 113)*

| | Age | Height | Weight | Body Vol. | BMI |
|---|---|---|---|---|---|
| Mean | 18 | 174.1 | 68.43 | 64.82 | 22.58 |
| Minimum | 18 | 157.5 | 45.12 | 42.24 | 18.19 |
| Maximum | 19 | 197.2 | 137.3 | 132.32 | 35.31 |
| *SD* | 0.55 | 8.62 | 13.46 | 12.87 | .61 |

Potential participants were identified from a list provided by university housing services at Utah State University. A computer-generated random numbers list was used to begin randomly selecting students from this housing list. These students were contacted by phone during the first week of the fall 2007 semester and asked to participate in the study. This recruitment process continued until approximately 60 females and 60 males had agreed to participate. Upon agreeing to participation, an appointment for data collection was made, pre-testing instructions were given, and informed consent (Appendix) was obtained.

## Research Design

This was a within subject comparison study with the purpose of answering the research question of whether the predicted values given for thoracic gas volume by the Bod Pod® are adequate for obtaining an accurate measure of body volume compared to measuring thoracic gas volume directly. The independent variable in this study is the method of obtaining a value for thoracic gas volume and the dependant variable is the actual value of thoracic gas volume.

## Instrumentation

The instrument most used, and being tested itself, in this study is the Bod Pod® system. This Bod Pod® system actually consists of two chambers: a front chamber in which the client sits during the measurement and a rear (reference) chamber. A molded fiberglass seat forms the wall between the two chambers, and a moving diaphragm is mounted here that oscillates during testing (see Figure 2). The oscillating diaphragm creates small volume changes, equal in magnitude but opposite in sign between the two chambers, which produce small pressure fluctuations. The pressure-volume relationship (i.e., Poisson's law) is used to solve for the volume in the front chamber. The estimates of body surface area are calculated using the Dubois and Dubois equation (1916) (equation 4) from the height, and weight of the individual being tested.

The accuracy of the Bod Pod® was first evaluated against inanimate objects (cubes & cylinders) of varying volumes ranging from 25-150 L (Dempster & Aitkens 1995). Error estimates were at < 0.1% volume and standard error of estimate (*SEE*) was 0.004 L. McCrory et al. (1995) were the first to test the Bod Pod® on human participants. Their findings reported excellent validity compared to hydrostatic weighing.  The criterion measure for this study was percent body fat. The difference between the Bod Pod® and hydrostatic weighing was a mere -0.3% body fat (SEE=1.81% body fat). Since that first study, many others have been conducted to assess the accuracy of the Body Pod® for measuring body density. Many researchers reported only minimal differences in average body density (< 0.002 g/cc) measured by the Bod Pod® versus hydrostatic weighing (Fields et al., 2001; VesCovi et al., 2001; Yee et al., 2001). Several studies have also shown “good” group prediction errors (*SEE* < 0.008 g/cc) in adults (Fields et al., 2000; Nunez et al., 1999; Wagner et al., 2000).

Most ADP validation studies compared percent body fat estimates from the Bod Pod® (percent body fat $_{ADP}$) to those measured by hydrostatic weighing (body fat $_{HW}$), dual-energy X-ray absorptiometry (DXA) (percent body fat $_{DXA}$), or both. Fields and colleagues (2002) reported in a review of 15 separate studies, each containing adult participants, that the average difference (i.e., constant error or bias (CE)) between percent body fat $_{ADP}$, percent body fat $_{HW}$, or percent body fat $_{DXA}$ ranged from -4.0% to 1.9%, with *SEE* ranging from 2.2-3.7% body fat. Overall, the average

CE for ADP method was estimated at < 1% body fat. In a recent study that subjectively rated various body composition reference methods, the Bod Pod® ranked near the top in categories such as maintenance, cost, time, ease of use and the ability to accommodate people with limitations (Fields, et al., 2002). As a result, this body composition tool has recently received much attention from researchers.

Also used in this study was a tape measure mounted to a wall to measure height in inches that was then converted into cm, and a weight scale to measure weight in kg.

## Procedures

Participants received a phone call and an email reminder 1-2 days before their appointment for data collection. As part of this reminder, participants were given directions to the Exercise Physiology Laboratory in the Health, Physical Education and Recreation (HPER) building at Utah State University and were given the following published pretesting guidelines for the Bod Pod® (Heyward & Wagner, 2004):

1. Do not eat or engage in strenuous exercise for at least 4 hr prior to your appointment.
2. Avoid any gas-producing foods (e.g., baked beans and diet soda) for at least 12 hr prior to the test.
3. Bring tight-fitting, lightweight form-fitting lycra-type clothing such as a bathing suit, compression shorts, sports bra, etc.

All testing took place in the Exercise Physiology Laboratory in the HPER building at Utah State University. All data collection for the entire sample was completed during the second and third weeks of the fall 2007 semester. Upon entering the laboratory, each participant was first asked whether he or she had followed all pretesting protocol. Upon confirmation of completion of all pretesting protocol, the participant was instructed to urinate and eliminate as much gas and feces as possible in the restroom before changing into their specified testing clothing. Height (Ht) and body weight (Wt) were measured while the participant was wearing only his or her testing attire (including tight-fitting, lightweight form-fitting lycra-type clothing such as a bathing suit, compression shorts, and sports bra.) Height was measured to the nearest 0.25 inch with the wall-mounted tape measure and converted to centimeters. Weight was measured to the nearest 0.1 kg with the Bod Pod® scale (Life Measurements, Inc., Concord, CA).

Once each participant was wearing the proper clothing and all descriptive measures had been taken, testing with the Bod Pod® began. Height and weight measurements were used by the Bod Pod® software to calculate body surface area. Following the prompts from the Bod Pod® software, a two-point calibration was performed: baseline calibration with the chamber empty, and phantom calibration using a 50-L calibration cylinder. Utmost care was observed when handling the calibration cylinder because any dent in the cylinder could alter its volume. Each participant was instructed to sit in the chamber, as still as possible, while breathing normally throughout the test. Continuing to follow the prompts of the Bod Pod® software, two tests were completed using the predicted thoracic gas volume values provided by the Bod Pod® software. The results of these two tests were then averaged by the software, yielding the first measure of body volume. If the two tests differed by more than 150 ml, additional tests were performed until two tests were within 150 ml.

Once values were obtained using the predicted thoracic gas volume values, each participant repeated the previous test but during the second test, when calibration was completed, the Bod Pod® breathing circuit was connected to begin the process of obtaining a measurement of thoracic gas volume. Once connected to the breathing circuit and the door was closed, a 20-second equilibration period took place. During this time, each participant was instructed to hold the breathing tube in their right hand and follow the breathing cadence displayed on the screen. An increasing green progress bar with the word "IN" next to it, indicated to the participants when to inhale, and a decreasing red progress bar with the word "OUT" next to it indicated when to exhale. This measurement of a normal breathing cycle was recorded so the Bod Pod® software could obtain a normal tidal volume. During the last 2 seconds of this equilibration period while the participant was inhaling, the message "prepare to put tube in mouth" appeared on the computer screen followed by the message "put tube in mouth." At this point the participant put the breathing tube into his or her mouth and continued breathing with the cadence on the screen. Participants were instructed to keep a tight seal between their mouth and the tube so that all the air flowing in and out of their mouth would flow through the tube. At a certain point between the fourth and sixth breath into the tube, a message appeared on the screen that said "prepare to puff" as the participant was inhaling. This message was followed during the next exhalation with the message “puff puff puff” which coincided with the airway connected to the tube being closed for 2 seconds. At this point the participant was instructed to give three distinct and gentle puffs, analogous to the same force used to fog up eye glasses before cleaning them. At the end of the third puff, the thoracic gas volume measurement was complete. For some participants, measurements were not able to be obtained because of movement in the chamber during the test or not following the prompts with exactness. In this case, the tests were repeated up to six times until valid measures could be obtained. If after six trials, a measurement of thoracic gas volume could not be obtained, the participant was excluded from the study.

At the conclusion of the test, the participant was asked to step out of the Bod Pod® and allowed to change into normal clothing. A printout containing measures of thoracic gas volume, fat mass, fat-free mass, and other descriptive statistics, was obtained from the Bod Pod® software so that a hard copy of the data could be stored in a locked file cabinet.

## Statistical Analyses

Descriptive data including means and standard deviations of age, height, weight, body volume, predicted thoracic gas volume and measured thoracic gas volume were each reported. A dependant *t* test was used to determine a significant difference between measured thoracic gas volume and predicted thoracic gas volume. To analyze the variability in the scores, degree of agreement was determined by calculating the differences between the methods against their means as outlined by

Bland and Altman (Bland & Altman, 1983). To determine statistical significance the alpha level was set at .05. The Statistical Package for Social Sciences (SPSS, version 15.0) was used for calculating the *t* test and all descriptive statistics. The Bland and Altman plot was created using GraphPad Prism version 5.00 for Windows.

# CHAPTER IV

# RESULTS

The purpose of this study was to determine whether there is a significant difference between measured values of thoracic gas volume and predicted values of thoracic gas volume using the Bod Pod®. One hundred and thirteen college freshmen, both males and females, were tested using the Bod Pod® by first, measuring thoracic gas volume with the Bod Pod® technique, then by using pre-determined values based on height, weight and age that predict thoracic gas volume. A paired *t* test was performed to determine whether a significant difference between measured and predicted values of thoracic gas volume existed. Table 2 displays the results of the paired t test.

Results of the paired *t* test showed that measured thoracic gas volume and predicted thoracic gas volume were significantly different. A Pearson's product-moment correlation coefficient was calculated to be $r = .60$, which is significant at the $p \leq .05$ level. This represents a moderately positive correlation between the two variables (MTGV and PTGV).

The Bland and Altman plot (Bland & Altman, 1983) displayed in Figure 3 was used to reveal the variability about the mean for individual participants measured thoracic gas volume and predicted thoracic gas volume and the averages of each. The plot was also used to look for any systematic bias and to identify possible outliers. The graph displays a scatter diagram of the differences plotted against the averages of the two measurements. Horizontal lines are drawn at the mean difference, and at the mean difference plus and minus 1.96 times the standard deviation of the differences. It is important to note that while the midpoint of the graph on the y-axis is 0, indicating that the average difference between thoracic gas volume values is 0 L, the actual average difference between values is .14 L. This is done because the software used to create the graph does not have the precision or resolution to show this small difference.

Table 3 displays descriptive data used for the Bland and Altman plot.

Table 2

*Paired t Test for Sample Means of Measured and Predicted Values of Thoracic Gas Volume (N = 113)*

| | MTGV | PTGV |
|---|---|---|
| Means | 3.74 L | 3.60 L |
| *SD* | 0.78 L | 0.46 L |
| T Stat | 2.19 L | |
| Pearson Correlation (r) | 0.60 | |
| *df* | 112 | |
| $P_{(T \leq t)}$ two-tail | 0.03 | |
| $T_{critical}$ two-tail | 1.98 | |

*Note*. MTGV = Measured thoracic gas volume, PTGV = predicted thoracic gas volume.

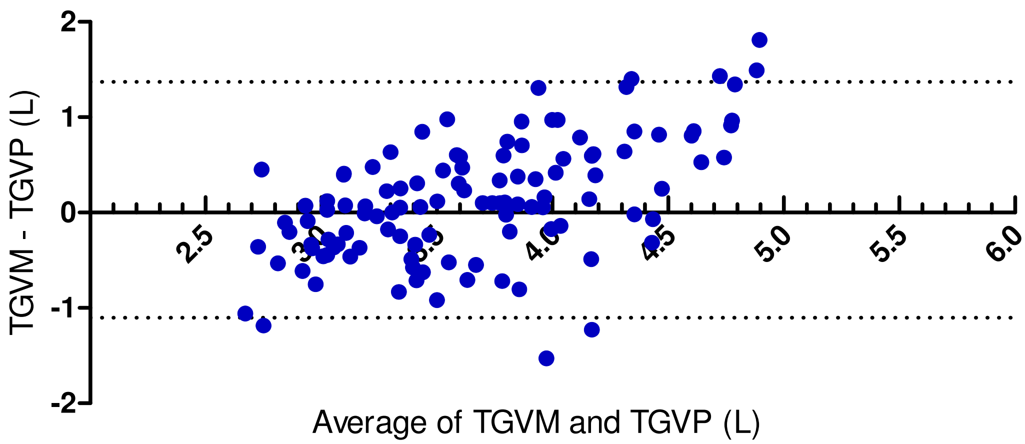


*Figure 3.* Bland and Altman plot of differences of thoracic gas volume measurement against their averages.

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Table 3

Statistical Data Used for the Bland and Altman Plot

| Differences | |
|---|---|
| 95% CI | 0.01253 to 0.2479 |
| Standard deviation | 0.6315 |
| Lower limit | -1.1075 |
| 95% CI | -1.3092 to -0.9057 |
| Upper limit | 1.3679 |
| 95% CI | 1.1662 to 1.5697 |

# CHAPTER V

# DISCUSSION

The purpose of this study was to compare predicted thoracic gas volume and direct measurements of thoracic gas volume to determine if predicted gas volumes are adequate for measuring body volume and predicting body composition using the Bod Pod®. The procedures were designed to measure the body composition of 124 male and female college freshmen using the Bod Pod® by first, measuring thoracic gas volume with the Bod Pod® technique, then by using pre-determined values based on height, weight and age that predict thoracic gas volume. This was done to answer the question of whether there is a significant difference between measured and predicted values of thoracic gas volume using the Bod Pod®. The hypothesis of this study was that predicted thoracic gas volume values based on height, weight, and age, used to estimate body volume, density, and composition in 18-year-old college freshman using the Bod Pod® will not be significantly different than thoracic gas volume values obtained by measuring thoracic gas volume directly using the Bod Pod® measurement technique at the $p \leq .05$ level. Thus, using predicted values of thoracic gas volume will be adequate in obtaining measures of body fat percentage within 2% of values obtained when measuring thoracic gas volume directly.

Eleven participants were unable to perform the proper breathing maneuver required to obtain an accurate measurement of thoracic gas volume. As a result, their measurements were thrown out leaving 113 participants to be included in the study. A paired *t* test was used to identify whether there was a significant difference and a

Bland and Altman plot (Bland & Altman, 1983) was used to analyze measurement differences among each participant.

This chapter is designed to address the results of the study and discuss their importance. It is organized according to the following headings: results related to statistical analysis, limitations, implications, future research, and conclusions.

## Results Related to Statistical Analysis

Results of the paired *t* test showed that measured thoracic gas volume and predicted thoracic gas volume were significantly different ($p = .03$). A Pearson's product-moment correlation coefficient was calculated ($r = .60$) representing a moderately positive correlation between the two variables (MTGV and PTGV).

In most cases, a Pearson's product-moment correlation coefficient of .60 would be considered relatively strong. In this instance, however, we are comparing two values that are supposed to be Identical. For a study of this nature, a correlation of .60 indicates a moderate relationship that is fairly weak. To consider a correlation between these two data sets as strong the correlation should be around .80 or greater.

These results proved to reject the first portion of the research hypothesis stating that Predicted thoracic gas volume values based on height, weight, and age, used to estimate body volume, density, and composition in 18-year-old college freshman using the Bod Pod® will not be significantly different than thoracic gas volume values obtained by measuring thoracic gas volume directly using the Bod Pod® measurement technique at the $p \leq .05$ level. Originally, when designing this study particular attention was given to similarities between air displacement plethysmography and hydrodensitometry. When a hydrodensitometry test is performed on an individual, that individual is asked to expel as much air as possible out of their lungs before they fully submerge into the water. This volume of air left in the lungs after this maximal exhalation is referred to as residual lung volume. Residual lung volume is somewhat analogous to thoracic gas volume in air displacement plethysmography. When using the hydrostatic weighing method, failure to maximally expel as much air as possible out of the lungs will make the individual more buoyant, resulting in an artificially high residual volume and a lighter under water weight, lower body density, and an inaccurately higher percent body fat (Heyward & Wagner, 2004). The same inaccuracies will also occur when the thoracic gas volume values are not accurate. Just as with air displacement plethysmography, several residual volume prediction equations have been developed to best predict this volume. These equations are based on the individual's age, height, gender, and even smoking status. These residual volume prediction equations do however have large prediction errors (*SEE* = 400-500 ml). When the residual volume is measured, the accuracy of hydrostatic weighing is excellent (≤ 1% body fat), but when residual volume is estimated the measurement error is greatly increased (± 2.8 – 3.7% body fat) (Morrow et al., 1986).

As previously stated, air displacement plethysmography was developed using many of the same principles that are observed in hydrodensitometry. It uses air displacement rather than water displacement to estimate body volume. Because air displacement plethysmography measures thoracic gas volume rather than residual lung volume, it uses a different equation (equation 5) to estimate body volume:

$$\text{Body Volume (l)} = \text{Body Volume} - \text{surface area artifact} + 40\%\ \text{T.G.V.} \qquad (5)$$

This equation corrects for thoracic gas volume rather than the equation (equation 7) that corrects for residual lung volume and gastrointestinal gas volume:

$$BV = \frac{BM(kg) - \text{net } UWW(kg)}{\text{Water Density}} - (RV + GV) \qquad (7)$$

Given that only 40% of the thoracic gas volume is used in the calculation of body volume, we inferred that using a predicted thoracic gas volume has a relatively smaller effect on estimates of body volume, body density, and percent body fat compared to using predicted residual volume values in hydrodensitometry (Heyward & Wagner, 2004). It was for this reason that it was hypothesized that using predicted values of thoracic gas volume would be adequate to obtain accurate measures of body volume and body fat percentage. Because only 40% of the thoracic gas volume is used in the calculation of body volume the effect of the thoracic gas volume measurement being slightly off would be relatively small compared to hydrodensitometry. The results of the paired samples *t*-test found significant differences between the predicted values and the measured values of thoracic gas volume. The average measured thoracic gas volume among all participants included in this study was 3.74 L. The average predicted thoracic gas volume was 3.60 L. The average difference between these two values was .14 L. When inserted into the proper body composition equations this difference in thoracic gas volume yields a difference of 2.1% body fat, which also rejects the second part of the research hypothesis of this study which states that using predicted values of thoracic gas volume will be adequate in obtaining measures of body fat percentage within 2% of values obtained when measuring thoracic gas volume directly. Though a difference of 2.1% is relatively small, it may be considered physiologically significant.

The Bland and Altman plot (Bland & Altman, 1983) displayed in Figure 3 was used to reveal any relationship in the differences between each participants measured thoracic gas volume and predicted thoracic gas volume and the averages of each. It was also used to look for any systematic bias and to identify possible outliers. It is important to note that while the midpoint of the graph on the y-axis is 0, indicating that the average difference between thoracic gas volume values is 0 L, the actual average difference between values is .14 L. This is done because the software used to create the graph does not have the precision or resolution to show this small difference. When looking at the spread of scores an interesting relationship arises as the size of thoracic gas volume increases. The plot shows that as thoracic gas volume increases the variability among scores increases. A Pearson's product-moment correlation coefficient was calculated for the data in the Bland and Altman plot, namely, between the differences of each individual's thoracic gas volume values and their averages. The correlation was calculated as .56, which is significant at the $p \leq .001$ level. This correlation reveals that individuals who are either larger or smaller than average are more likely to yield inaccurate predicted thoracic gas volume values Conversely, individuals who are of average size, may be able to obtain more accurate results when using predicted thoracic gas volume values than people with larger than average or smaller than average thoracic gas volumes. The graph also reveals that the larger the thoracic gas volume, the more positive the difference between measured thoracic gas volume and predicted thoracic gas volume, (i.e., TGVM – TGVP). This indicates that as thoracic gas volume increases, it becomes more likely that the predicted value will underestimate the actual measured value of thoracic gas volume. Specifically, those individuals with thoracic gas volumes $\geq$ 4.5 L will have predicted thoracic gas volume values that are underestimated. When dealing with smaller volumes however, it appears equally likely that the prediction values will overestimate the measured values. According to the Bland and Altman plot, those with thoracic gas volumes $\leq$ 3.0 L will have predicted thoracic gas volume values that are overestimated. Ninety five percent of the values in the Bland-Altman plot were within two standard deviations of the average scores. Six of the 113 scores were plotted outside of this range.

Although the results of our study show that there is a significant difference between predicted thoracic gas volume values and measured thoracic gas volume values, the prediction values can still be useful. Originally, 124 participants were recruited for our study but 11 of these participants were unable to perform the breathing maneuvers required to obtain an accurate measurement. This maneuver included breathing in and out at specific times and also breathing with specific amounts of force in ways that are somewhat unnatural. If a participant was not able to perform the maneuver the first time, they would repeat the maneuver up to six times in order to obtain an accurate measurement. If after six trials the participant was unable to produce an accurate value, the test would be canceled and their data would be discarded. Nine percent of those tested were unable to perform the maneuver.

Although it is best to measure thoracic gas volume, when a participant is unable to perform the maneuver, the predicted values of thoracic gas volume can be used as a substitute to obtain an approximation of body composition.

## Limitations

Some limitations existed within this study. To better understand the true significance of the results, each of these limitations will be addressed and considered.

In order to collect data for multiple studies, only 18-year-old participants were used. The original validation studies of the Bod Pod® used participants in the approximate age range of 18 – 60 years old. This study's entire sample of participants is at the extreme low end of the population for which the Bod Pod® was validated. Using participants in this age group exclusively restricts our ability to generalize the results of this study to the general public. While several researchers have reported no significant differences (< 1.2% BF) between percent body fat estimates from the Bod Pod® and hydrodensitometry in children (Demerath et al., 2002; Dewit et al., 2000; Nunez et al., 1999), others reported that the average body density of children measured with the Bod Pod® was either significantly overestimated (Lockner et al. 2000) or underestimated (Fields et al., 2000) by 0.0052 to 0.0063 g/cc. These discrepancies may still occur when testing individuals who are 18 years old and whose bodies have not fully developed (Heyward & Wagner, 2004).

Another limitation is that most individuals in our population were in the lean category, meaning a percent body fat of ≤ 12% for men and ≤ 18% for women. This is another restricting factor when attempting to apply this study's results to the general population. Participants were recruited by identifying potential participants from a list provided by university housing services at Utah State University. A computer-generated random numbers list was used to begin randomly selecting students from this housing list. These students were contacted by phone during the first week of the fall 2007 semester and asked to participate in the study. This recruitment process continued until approximately 60 females and 60 males had agreed to participate. People who were overweight or obese may not have volunteered for the study as readily as those who were thin or lean. Additionally, people who were disinterested in health and exercise may not have cared to find out their body composition and simply ignored the invitation to participate in the study. As a result, individuals in our test population were generally similar in body composition and fitness levels.

Because the young age of our test population and the body type of most participants are fairly extreme when compared to the general population, the generalizability of our results is limited. Typically extreme cases in a population do not predict well for the population of interest. These results are however useful when conducting body composition tests on individuals who would fit in the test population.

Pre-protocol procedures may also be a limitation to this study. Upon agreeing to participation, an appointment for data collection was made, and pre-testing instructions were given at that time. Participants were instructed to refrain from eating or engaging in strenuous exercise for at least 4 hr prior to their appointment. They were also instructed to avoid any gas-producing foods (e.g., baked beans and diet soda) for at least 12 hr prior to the test. The only follow-up procedure to ensure participants complied with pre-test protocol was to simply ask each participant whether they followed all pre-testing protocol instructions. Participants were simply trusted to follow these guidelines. If some participants failed to follow the pre-test procedures, the results may have been distorted. Other outside factors such as hydration levels and excess body hair may also have altered the results.

## Implications

The results of this study indicate that when using the Bod Pod® to assess body composition, utilizing predicted values of thoracic gas volume established by the makers of the Bod Pod® will produce inaccurate measurements of body volume for most individuals as compared to using measured values of thoracic gas volume. With this information, it is apparent that, for the specific population tested, the attempt by the makers of the Bod Pod® to establish adequate predictions of thoracic gas volume based on height, weight, and age proved to be unsuccessful. This also implies that those who use the Bod Pod® to obtain body composition values should always measure thoracic gas volume as instructed by the prompts in the Bod Pod® software.

Another implication of the study that was revealed during testing procedures is that though using measured values of thoracic gas volume is ideal; there are times when it is not possible. Nine percent of those tested were unable to perform the breathing maneuver needed to measure thoracic gas volume. In this situation, predicted values may need to be used as a substitute to obtain an approximation of body composition.

## Future Research

This study leads to many recommendations for future research, especially in light of the limitations. Future research should be aimed at evaluating a population with greater diversity than the present study. People of various ages, sizes, and physical fitness levels should be used as participants for further research into a similar research question explored by this study. Though the results of this study found that using predicted values of thoracic gas volume will yield less accurate results than using measured values of thoracic gas volume, future studies may do well to compare body composition values produced by using predicted thoracic gas volume measures when employing the Bod Pod® method to body composition values produced through bioelectrical impedance, skin fold testing or any other methods of assessing body composition. Though not as accurate as using measured values of thoracic gas volume, using predicted values while utilizing the Bod Pod® may produce more accurate measures of body composition than other methods, especially when dealing with individuals who can't perform the breathing maneuver required to measure thoracic gas volume. Lastly, another area that would be valuable to assess would be to compare body composition values produced by using predicted values of thoracic gas volume when using the Bod Pod® to predicted residual lung volume when using the hydrostatic weighing method. Given that only 40% of the thoracic gas volume is used in the calculation of body volume it might be inferred that when using predicted values, air displacement plethysmography could provide a more accurate measurement of body volume than hydrodensitometry though further research is needed to either prove or disprove this theory. Because both prediction values were established to save time, it may be of interest to see which one would save the most time while sacrificing the least amount of accuracy of body composition values.

## Conclusions

Within the limitations of this study, the following conclusions were made:

1. There is a significant difference between measured values of thoracic gas volume and predicted values of thoracic gas volume when using the Bod Pod® air displacement plethysmography system.

2. Using predicted thoracic gas volume values rather than measured thoracic gas volume values when assessing body composition of an individual will yield physiologically significant differences of body volume and body fat percentage, especially in the case of outliers and larger individuals.

3. When using the Bod Pod® air displacement plethysmography system to assess body composition, thoracic gas volume should be measured directly, rather than using predicted values, except when the individual being tested cannot perform the breathing maneuvers required for measurement of thoracic gas volume.

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# APPENDIX

**Date Created: 10 July, 2006**
**Modified: 21 June, 2007**

**INFORMED CONSENT**
**Body Composition Change during the First Year of College:**
**A Study of Traditional Residence Hall Freshman**

**Introduction/Purpose**
The purpose of this research is to assess physical changes to include height, weight, waist circumference, and body fat percentage of both male and female traditional college freshmen as well as freshmen athletes residing on-campus over the course of the entire freshmen school year (two semesters). Drs. Dale Wagner and Ed Heath of the Health, Physical Education, and Recreation Department at Utah State University are conducting research to better understand and quantify these changes. There will be 100 nonathletes (50 female and 50 male) and 30 athletes (15 female and 15 male) in this study.

**Procedures**
If you agree to participate in this study, you will be asked to come to the Exercise Physiology Laboratory in the HPER building on the USU-Logan campus three separate times:

1) Once during weeks #2 or #3 of the fall semester: the purpose of this testing session is to obtain baseline information. The total time for this session should be less than 30 minutes. During this visit, the following procedures will occur:
    a) You will be asked to follow pre-testing guidelines:
        1. Do not eat or engage in strenuous exercise for 2 hours prior to your scheduled appointment.
        2. Avoid eating any gas-producing foods (e.g., baked beans, etc.) for 12 hours prior to test.
        3. Bring a tight-fitting, lightweight swimsuit (e.g. Speedo) or non-padded lycra compression shorts and a jog bra with you.
    b) You will be asked to urinate and eliminate as much gas and feces as possible before changing into your swimsuit.
    c) While wearing your swimsuit, your height and weight will be measured.
    d) While wearing your swimsuit, a measurement will be taken with a tape measure of your waist circumference.
    e) Your body volume will be measured by the Bod Pod. You will sit in a large egg-shaped chamber with a large window with the door closed for two 20-second trials. During this time you will be required to sit motionless and breathe normally. This measurement will be used for the estimation of your body fat.

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f) A third Bod Pod trial will be done to measure your thoracic gas volume. This procedure involves wearing a nose clip and breathing normally into a plastic hose while inside the Bod Pod. You will be instructed to make 3 short "puffs" (similar to cleaning an eyeglass lens) at some point during your breathing cycle. This procedure is necessary to improve the accuracy of the Bod Pod test.
g) Two one-page questionnaires will be given to assess your perceived fitness and physical activity levels.

2) Once during weeks #14 or #15 of the fall semester: the purpose of this testing session is to quantify changes that have occurred during the fall semester. The total time for this session should be less than 15 minutes. Procedures "a-e" (described previously) will be repeated.

3) Once during weeks #14 or #15 of the spring semester: the purpose of this testing session is to quantify changes that have occurred during the spring semester. The total time for this session should be less than 20 minutes. Procedures "a-e" and "g" (described previously) will be repeated. Additionally, a brief questionnaire will be given in order to better understand changes that may have occurred in your dietary or exercise habits throughout the year.

**Risks**
There is minimal risk in participating in this study. Some people may feel claustrophobic inside the Bod Pod. However, the chamber door is closed for only about 30 seconds per trial. Also there is a very large window that allows you to see everything outside the chamber. Furthermore, there is an emergency button inside the chamber that will allow you to open the chamber door from the inside. There have been no reported incidences of injury associated with the Bod Pod since its inception in 1994. A technician will be available to assist you if needed. An office adjacent to the lab contains a phone for "911" emergencies.

**Benefits**
You will be given an estimate of your body fat percentage and an interpretation of this value at the end of the study. Knowledge of your body fat percentage can help you assess your health and fitness status. Furthermore, the information gained from this study may help researchers better understand the physical changes that take place during the freshman year of college.

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**Body Composition Change during the First Year of College:**
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**Explanation & Offer to Answer Questions**
Dr. Wagner and/or his research associates have explained this research study to you. You have been given the opportunity and encouraged to ask questions. If you have other questions or research-related problems, you may reach Dr. Wagner at 797-8253 or by email at dale.wagner@usu.edu. Co-investigator, Dr. Ed Heath may be reached at 797-3306 or by email at edward.heath@usu.edu.

**Extra Costs & Payments**
There is no cost for your participation in this study. If you complete all three testing sessions, you will be paid $25.

**Withdrawal due to Pregnancy**
Should you become pregnant during the course of the study, it is your responsibility to inform the researchers. You will be withdrawn from the study without consequence or loss of benefits as pregnancy will create obvious changes in body composition that will confound the study.

**Voluntary Participation & Right to Withdraw**
Your participation in this research is entirely voluntary. You may refuse to participate or withdraw at any time without consequence or loss of benefits; simply inform the researchers of your desire to withdraw from the study.

**Confidentiality**
Research records will be kept confidential, consistent with federal and state regulations. Your data will be identified by a number, not by your name. Your data and information about your identity will be kept in separate locked file cabinets in a locked room accessible by only Drs. Dale Wagner and Ed Heath and research assistant Stephanie Christensen. Any information linking you to your data will be destroyed following the final data analyses within a year of the completion of the study.

**IRB Approval Statement**
The Institutional Review Board (IRB) for the protection of human participants at USU has reviewed and approved this research study. If you have questions or concerns about your rights you may contact them at (435) 797-1821.

**Date Created: 10 July, 2006**
**Modified: 21 June, 2007**

**INFORMED CONSENT**
**Body Composition Change during the First Year of College:**
**A Study of Traditional Residence Hall Freshman**

**Copy of Consent**
You have been given two copies of this Informed Consent. Please sign both copies and retain one copy for your files.

**Investigator Statement**
"I certify that the research study has been explained to the individual, by me or my research staff, and that the individual understands the nature and purpose, the possible risks and benefits associated with taking part in this research study. Any questions that have been raised have been answered."

______________________________ ______________ ______________________________ ____________

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______________________________ ______________

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**Signature of Participant**
By signing below, I agree to participate.

____________________________________________ ____________________________

Participant's signature Date