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The validity of percent body fat estimates by Jackson & Pollock skinfold equation, near infrared, bioelectrical impedance and body mass index

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THE VALIDITY OF PERCENT BODY FAT ESTIMATES BY JACKSON & POLLOCK SKINFOLD EQUATION , NEAR INFRARED , BIOELECTRICAL IMPEDANCE AND BODY MASS INDEX

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ABSTRACT

The Validity of Percent Body Fat Estimates by Jackson & Pollock Skinfold Equation, Near Infrared, Bioelectrical Impedance and Body Mass Index

by

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This study compared the validity of percent fat estimates by the Jackson & Pollock sum of four skinfold equation (JPSF), bioelectrical impedance (BIA), near infrared (NIR) and body mass index (BMI) when compared to the criterion method of underwater weighing (UWW). Subjects consisted of 57 males and 54 females between the ages of 18 and 55 years. Skinfolds were measured at four sites, the triceps, ilium, abdomen and thigh using the Harpenden skinfold caliper. The Jackson & Pollock sum of four skinfold equation was used to calculate percent body fat. Infrared interactance was determined on a Futrex 5000 measured at the biceps halfway between the axillary fold and the anticubital space. Bioelectrical impedance was determined with the Bio-analgenics ELG analyzer using the four electrode placement technique. Electrodes were placed on the dorsal surfaces of the ankle and wrist and the distal surfaces of the metacarpals and metatarsals.

Underwater weighing was determined in a seated position with functional residual volume measured in the tank at the time of weighing. Statistical analysis was determined using an repeated measures ANOVA, Pearson correlation coefficient (r), standard error of estimate (SEE), R^2, and total error (TE).

The results from this study found the JPSF equation to be the most valid when compared to underwater weighing. This was based on high correlation coefficients, low standard error of estimates, low total errors and high R^2 values. The bioelectrical impedance method produced moderate results when compared to UWW. However with the use of more specific prediction equations, the BIA method can be substituted for the skinfold method without the loss of much accuracy. The NIR and BMI produced the poorest results compared to UWW. The NIR and BMI methods should not be used to assess a person's health status based on measurements of percent body fat.

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CHAPTER 1

INTRODUCTION

The assessment of body fat is used in hospitals, health clubs, doctor's offices, diet centers and by exercise leaders and personal trainers. Excess body fat has been determined to have physiological, medical, and psychological consequences, and has been linked to heat intolerance and diseases such as diabetes, hypertension, heart disease, (Safrit, 1986; Jackson & Pollock, 1982; Lohman, 1992). Obesity and being overweight is a major health problem in the United States. The public's awareness of the need for proper weight control has caused emphasis to be placed on exercise, diet, and weight loss programs. The health problems associated with being overweight makes the assessment of body fat and the determination of a desirable weight necessary, and therefore the valid assessment of determining body fat is of great importance.

Today's society is becoming aware that physical fitness and nutrition are important parts of preventive medicine and they play a role in extending the quality years of life. With this awareness, there is great interest on how much of the body weight is fat, and to be within the desirable range of body fatness. An analysis of the methods used to determine body fat is needed to determine which methods are valid and reliable.

There are many methods used to determine body composition. These methods can be grouped into two categories: laboratory techniques and field techniques. Some techniques such as underwater weighing and skinfolds have been well studied, validated, and determined reliable, others like bioelectrical impedance and infrared are relatively new, experimental, and often unvalidated.

The most recognized and accepted methods of body composition is through the determination of body density by underwater weighing (Jackson & Pollock, 1985). Although underwater weighing is considered the "gold standard" its use is mainly confined to a laboratory setting and is not well suited for field testing. The method requires relatively expensive equipment, trained personnel and is relatively time consuming.

Other methods of fat assessment including height and weight indexes, skinfolds, body circumferences, and bone diameters have been developed that are easier to administer and require less time. Through the use of prediction equations, anthropometric measurements have made field testing more convenient without the loss of much accuracy or reliability. As new methods and techniques are developed for the assessment of body composition it is mandatory that these techniques be studied for validity and reliability before they can be used for measurement.

The following is a brief description of body mass index, overweight index, waist to hip ratio, bioelectrical impedance, and infrared. A detailed description of these methods along with height and weight tables, prediction

equations, body circumferences, bone diameters, total body water, skinfolds, and body density determined by underwater weighing are found in chapter two.

Body mass index (BMI) and overweight index (OI) are indices that are commonly used to assess the status of obesity. These indices attempt to adjust body weight for height to derive a measure of obesity (Smalley et, al. 1990). The overweight index is the simplest of the body mass indices. Although it has not received as much attention as the body mass index, it is still used and provides a simple way to adjust weight for height. It uses the following formulae, weight in kilograms x 100 divided by height in centimeters - 100. Values over 100 for males and 95.5 for females are considered overweight.

The body mass index or Quetelet's index is commonly used by clinical personnel as an indicator of health risk in obesity. This index divides weight in kilograms by height in meters squared. The body mass index provides a direct measure of under or overweight and indicates the role of fatness and mortality risk.

The waist to hip ratio or abdominal to gluteal ratio is a fast and easy measurement that is used for measuring risk of disease and obesity. In the waist to hip ratio the waist circumference is an indicator of subcutaneous and deep adipose tissue (Borkan et, al. 1983), and is related to fat free mass (Jackson & Pollock, 1976). The hip circumference measures subcutaneous adipose tissue and reflects lower body fatness. When used together in the

waist to hip ratio, it measures subcutaneous fat patterning with high ratios being related to increased risk of type 2 diabetes, cardiovascular disease, and obesity (Lohman et, al. 1988).

Bioelectrical impedance (BIA) is based on the principle that the resistance or impedance to a low-level electrical current is related to total body water (Hoffer et, al. 1969). This resistance or impedance is dependent on the amount of water that is present in the body. Fat is comprised of practically no water and lean tissue is comprised of 73.2% water (Durnin & Wormersley, 1974). When an electrical current passes through lean tissue comprised of mostly water the current will travel with less difficulty or less resistance from one electrode to another. When an electrical current passes through fat tissue comprised of very little water the fat tissue acts as an insulator which will increase the resistance and will make it more difficult for the current to travel from one electrode to another. From this resistance the and the amount of water in fat and muscle, equations have been developed to determine total body water. Other equations have been developed to change total body water to percent body fat.

Near infrared photospectometry (NIR) uses principles of light absorption and light reflection, and is based on the observation that lean tissue will reflect and absorb light differently than fat (Conway et, al. 1992; Quatrochi et, al. 1992; Cassidy et, al. 1993; Clark et, al. 1993).

The Futrex 5000 used in this study measures optical density at two wavelengths, 940 nm and 950 nm. This instrument emits a low-level

electromagnetic light beam up to four centimeters that penetrates subcutaneous fat and intramuscular fat (Quatroche et, al. 1992; Mclean & Skinner, 1992). Prior to measuring body fat certain descriptive characteristics of the subject is entered into the Futrex 5000. These factors are height (ins), weight (lbs.), frame size, and exercise level. Frame size was determined by measuring the circumference of the wrist by placing the thumb and middle finger around the dominant wrist. Exercise level was determined as no exercise, light, moderate, and heavy. The measurement is taken on the anterior belly of the biceps muscle midway between the shoulder and the elbow.

Purpose of the Study

The purpose of the study was to compare the body composition results derived from the Jackson & Pollock sum of four skinfold equation, bioelectrical impedance (BIA), and near-infrared (NIR) and body mass index (BMI) with the body fat results from underwater weighing (UWW).

Statement of the Problem

In addition the skinfold prediction equations and the underwater weighing technique has been in the literature for several decades. Bioelectrical impedance and especially near infrared photospectometry are relatively new methods for determining human body composition. Both methods offer a fast, convenient, non-invasive procedure for determining percent body fat.

However the validity of these methods need to be investigated. Bioelectrical impedance has been studied fairly extensively, however, near infrared has little supportive research.

Need for the study

The assessment of body composition is an important aspect of cardiovascular disease, obesity, and fitness. With the increased desire to develop a method that is user friendly, fast, and convenient, more research is needed to assess the validity of these newer methods by comparing them to proven traditional methods.

Limitations

1. Subjects were recruited based on convenience and were not randomly sampled from the population.
2. Exercise and diet habits were not controlled.
3. Menstrual cycle was not monitored with female subjects.
4. It appears that subjects were skewed towards the leaner side of the body fat continuum.
5. All subjects were apparently healthy between the ages of 18 and 55.

Definition of Terms

Impedance - A measure of total opposition to the flow of an electrical current.

Ohm - A unit of electrical resistance.

Resistance - The opposition to the flow of a direct electrical current through a conductor.

KHz - Kilohertz, a unit of electrical frequency equal to 1000 cycles per second.

Density - mass divided by volume.

Functional Residual Volume - The amount of air left in the lungs after a comfortable expiration.

CHAPTER 2

LITERATURE REVIEW

Due the increased awareness and concern about obesity and detailed diseases, the assessment of body composition has enjoyed a renewed interest and traditional methods have been refined and modified and new methods developed. Many of the new methods are quick and easy, and therefor, become attractive to those wanting to assess body fatness. Differences in age, sex, and physiological condition need to be studied as to their effect on the newer methods.

This chapter reviews the scientific literature in body composition and evaluates the amount and quality of the research available for the various techniques of body composition. There are early and traditional methods for determining body weight, percent body fat, lean body weight, and body density. Each of the various techniques or methods and the research on that technique are separately discussed.

Height & Weight Tables

Historically, height and weight tables have been widely used to determine proper body weight and for the evaluation of nutritional status (Frisancho, 1990). Many height and weight tables are based on a minimal amount of

body fat and depend largely on skeletal size (Astrand & Rodahl, 1986). Earlier height and weight tables only took into account height and occasionally age as the point of reference, but variation in body build was not considered (Brozek, 1961; Brozek & Keys, 1950).

As early as 1912, height and weight tables were developed in response to the Medical-Actuarial Investigations (Brozek, 1961). These tables were developed without regards to the height of shoes or the weight of clothes worn by the insurance applicants. The major problem with earlier height and weight tables was the inability to recognize whether an individual was over or under weight, especially one who deviates a small degree from a standard weight for age, sex, and height (Behnke & Wilmore, 1974). The early tables did not have the ability to distinguish between under and overweight with regard to the increase or decrease in the development of muscles and fatty tissues (Brozek & Keys, 1950; Benhke & Wilmore, 1974). It was assumed that a weight greater than a reference weight from height and weight tables was associated with obesity (Frisancho, 1990). In a study conducted by Welham and Behnke, a group of professional football players were found to be obese when using height and weight tables and were turned down by the armed services. When body composition was determined, the players were found to have little body fat and the increase in weight was due to an increase in musclemass (Welham & Behnke, 1942). To help alleviate some of the problems of height and weight tables, Brozek suggested that the use of lateral dimensions or measurements of frame size would help distinguish

between leanness and fatness (Brozek, 1961). For this reason the most widely used height and weight tables are provided by the Metropolitan Life Insurance Company in 1959 and 1983 which beside weight and height also took into account skeletal size. This attempted to distinguish between those who were heavy because of a large fat free mass and those who were overweight because of an increase in body fat. The 1959 tables incorporated three categories of frame size: small, medium, and large, along with height and gender to evaluate proper weight in adults (Metropolitan Life Insurance Company, 1959; Himes & Bouchard, 1985; Frisancho, 1990). The problem with the 1959 tables was that frame size was not based on anthropometric measurements of the insurance policy holders. The 1959 tables divided the group of policyholders into four quarters to determine frame size (Himes & Bouchard, 1985; Frisancho, 1990). The first or lowest quarter was considered small frame, the second and third quarters were considered medium frame, and the last quarter was considered large frame. The categories of frame size found in the 1959 tables had no relationship with skeletal size (Frisancho, 1990).

In 1983 the Metropolitan Life Insurance Company used elbow breadth to estimate frame size. Previous findings have found that frame size measurements have been correlated to fat free mass (Behnke, 1959; Jackson & Pollock, 1976). Height and weight tables based on frame size also provide a better estimation of fat free mass beyond that provided from height (Himes & Bouchard, 1985). This allows for a better distinction

between those that are heavy due to a large skeletal frame and those that are overweight due to an increase in fat tissue.

However, the problem with the 1983 tables, was that the measure of elbow breadth was not included in the insurance applicants' examination. Instead, elbow breadths were taken from the National Health and Nutrition Examination Survey I (NHANES I) data and applied to the body weights derived from the Metropolitan Life Insurance data. Another problem associated with both the 1959 and 1983 height and weight tables was that they did not take in account aging. Although height and weight tables are widely used to determine proper body weight, they are inadequate when assessing nutritional and body composition status and should only be used as a general guide descriptive of an individuals weight.

Prediction Equations

The most accurate and valid method for measuring body density, is underwater weighing. Because of equipment, technique, and needed personnel underwater weighing is strictly confined to the laboratory setting and is not suitable for field or mass testing. However, underwater weighing does produce a valid, reproducible, and accurate body density. Since density units are seldom used, density must be converted to percent body fat, this requires a prediction equation, which hampers the accuracy of the underwater weighing method.

Through the use of reasonably easy to obtain anthropometrical measurements and using regression analysis, body density can be predicted with little loss of accuracy (Jackson & Pollock, 1985). The most common field measurements that are used in prediction equations, are skinfolds, circumferences, and body diameters (Jackson & Pollock, 1982). In the literature are over 100 different prediction equations for various populations. ie. athletes, sedentary individuals, children, elderly, males, and females, and the like. (Lohman, 1981; Jackson & Pollock, 1985).

Some of the first prediction equations were published by Brozek and Keys in 1951 (Brozek & Keys, 1951; Jackson & Pollock, 1978; 1982; 1985; Lohman, 1981). Using skinfolds they developed prediction equations for young and middle aged men (Brozek & Keys, 1951, Jackson & Pollock, 1978; 1982; 1985). Body fat was estimated by measuring the subcutaneous fat with calipers and was statistically related to the specific gravity measured by water immersion. Although specific gravity and density are closely related and in early literature were used interchangeably, specific gravity differs from body density in that with specific gravity the temperature of the water is not taken into account and the density of water is assumed to be 1.0. In Brozek & Keys study the correlation between skinfolds and specific gravity was .876 for younger men and .744 for middle age men (Brozek & Keys, 1951). These earlier prediction equations developed by Brozek and Keys 1951 were later found to be invalid and have since not been widely used (Durnin & Rahaman, 1967). During the following thirty years several prediction

equations were developed for both men and women. In 1956 Pascale et, al. published the first study correlating skinfold thickness to body density (Pascale et, al, 1956). Eighty eight soldiers were weighed underwater to determine body density and the following prediction equation was developed using regression analyses (Density = 1.088468 - (0.007123 x Axillary skinfold + 0.004834 x Chest skinfold + 0.005513 x Triceps skinfold). In the 1960's several prediction equations were developed for men and women. In 1962 Sloan developed prediction equations for young women and in 1967 developed prediction equations for young men. Durnin and Rahaman 1967 using measurements of skinfold thickness developed prediction equations for men and women. Katch and Michael 1968 using various skinfold and girth measurements developed prediction equations in college females. Finally in 1969 Wilmore and Behnke developed prediction equations in young men and women.

In the 1970s Katch & McArdle, Durnin & Wormersley, Pollock et, al. and Jackson & Pollock developed prediction equations in men and women. In 1973 Katch & McArdle were using simple anthropometric measurements developed prediction equations in college-aged men and women. Durnin & Wormsley 1974 developed prediction equations in men and women based on the measurement of skinfold thickness. Pollock et, al. 1975. 1976 developed prediction equations in young and middle age women and men. In 1978 Jackson and Pollock published generalized prediction equations for men and in 1980 published them for women. These equations used age as a factor.

Although most of the early equations compared well with hydrostatically determined body density, these equations were population specific rather than generalized across various age groups, body fatness, and different populations (Jackson & Pollock, 1978). The problem with early equations was that the equations were based on small homogeneous samples, linear regression, and did not take into account the aging process.

When using regression equations it is important to use a large sample size with the fewest number of independent or predictor variables. It had been established that a large number of anthropometric measurements were not necessary to develop a valid prediction equation, and a smaller number of measurements per subject produced the most regression stability (Jackson & Pollock, 1976). Another problem with the previous population specific equations was that it was assumed that the relationship between body density and subcutaneous fat was linear, however it was found to be quadratic or curvilinear (Durnin & Wormersley, 1974; Jackson & Pollock, 1982). Prediction equations based on linear regression produce bias results especially at the extremes of the body fat distribution. The use of linear regression tends to underestimate body density in lean subjects and overestimate body density in fatter subjects (Durnin & Wormersley, 1974; Flint et, al. 1977; Jackson & Pollock, 1977; Pollock et, al. 1975; Pollock et, al. 1977; Pollock et, al. 1976).

Age was another factor that had hampered earlier prediction equations. Age has been shown to be independently related to body composition and

should be included when developing prediction equations. Several studies have shown that prediction equations developed on one age group produced larger prediction errors when applied to different age groups (Brozek & Keys, 1951; Durnin & Wormersley, 1974; Flint et, al. 1977; Jackson & Pollock, 1976; 1977; 1978; Jackson et, al. 1980; Pollock et, al. 1975; 1976).

To overcome errors associated with population specific equations, generalized equations were developed (Jackson & Pollock, 1982). The first published generalized equations were developed by Durnin and Wormersley using the log of the sum of four skinfolds (logarithm sum of biceps, triceps, subscapular, and supra-iliac). They also used different intercepts for various age groups. Their body fat tables were based on 481 males and females ranging in age from 16 to 72 (Durnin & Wormersley, 1974).

A second approach to help overcome the limitations of population specific equations was developed by Jackson and Pollock. Their equations were developed based on a curvilinear regression; using the sum of three and seven skinfolds and as well as age (Jackson & Pollock , 1977;1978). These equations were based on 403 adult males between the ages of 18 and 61, and 331 adult females between the ages of 18 and 55 (Jackson & Pollock, 1978; 1980). These generalized equations are the most valid and have produced correlation as high as .97 with hydrostatic weighing. The advantage of generalized equations is it is not population specific and can be used on a wide range of ages and body fat (Jackson & Pollock, 1985).

Percent body fat estimated from hydrostatic weighing has a 2.5% error

involved (Lohman, 1981). The standard error of estimate (SEE), standard deviation (SD), and accuracy of anthropmetric measures is dependent on the prediction equation used. The standard errors of percent body fat determined by generalized prediction equations range between 3.5% body fat for men and 3.8% body fat for women (Jackson & Pollock, 1982; 1985). The generalized equations only add about 1% to the prediction error when compared to hydrostatic weighing. Therefore, through the use of generalized prediction equations, body density and percent body fat can be predicted for populations varying in age and body fatness without much loss of accuracy.

Anthropometrical measurements

The best methods for the measurement of body composition: underwater weighing, total body water, and total body potassium involves time and a considerable amount of expensive equipment and technician training. These methods are restricted to laboratory testing and are not applicable for mass or field-testing. The use of easy-to-take anthropometrical measurements such as body circumferences and skeletal diameters are more appropriate for field testing therefore equations have been developed to use the measurements to estimate body composition and several equations are relatively well correlated with laboratory techniques.

Circumference measurements measure the size of a body part, which reflects muscle, fat, and organ size. Skeletal heights and diameters measure the size of the skeleton. From all these measurements a description of the

total body can be determined. These measurements have been used to evaluate growth patterns, nutritional status as well as body composition. The advantage of circumference measurements is the limited amount of equipment needed for measurement (cloth or steel tape), a minimal amount of technician training, and minimal cost (McArdle et, al. 1986). Typical circumference measurements are the head, neck, chest, waist, abdomen, hips, thigh, calf, ankle, arm, forearm, and wrist. The tape measure should be a flexible non-elastic tape graduated in centimeters and millimeters and be approximately 150 centimeters long and 0.7 centimeters wide. Most of the measurements are taken in the standing position. The tension applied by the tape should be "snug" but should not indent the skin. Especially constructed anthropometrical tapes which have a tension scale at the end of the tape are available. However, these tapes are expensive and break easily. A regular cloth tape, with practice, gives the same measurement.

Bone length and diameters are used to determine the frame size, and the potential for lean weight gains (Lohman et, al. 1988). The measurement of skeletal diameters is performed using special calipers depending on the location of the measurement. A small sliding compass is used to measure the breadth of small segments such as the wrist and ankle. A large sliding compass is used to measure large segments for example biacromial or bitrochanter breadths. A large and small olive branch also known as a spreading caliper are used to measure chest depth and face and jaw widths. Typically the measurement of body diameters are taken on bony landmarks

where there is little tissue except skin covering the bone allowing for the landmark to be located relatively easily in both lean and obese individuals.

Circumference and skeletal measurements alone, or in conjunction with other anthropometrical measurements such as skinfold measurements can estimate the nutritional status, body density, and percent body fat of an individual.

Behnke (1959) studied the estimation of lean body weight from skeletal and girth measurements. These measurements were compared to the criterion measurements of body density determined by the helium dilution technique and total body water determined by the tritium technique. Seven skeletal and three girth measurements were measured on 31 navy males. The correlation coefficients ranged from 0.80 to 0.90 and standard error of estimate's ranging from 6 to 10% of the mean lean body weight of 63.5kg. The highest correlation's were found when both trunk and limb dimensions were included in the prediction equation.

Michael E.D. and Katch F.I. (1968) estimated body density from skinfold and circumference measurements in seventeen-year-old boys. Body density (UWW), six skinfold measurements (triceps, chest, iliac, scapula, abdomen, and thigh) and eleven circumferences (shoulder, chest, buttocks, abdomen 1 (the minimal abdominal circumference located half way between the umbilicus and the xyphoid process of the sternum) abdomen 2 (circumference made at the level of the umbilicus), knee, thigh, ankle, wrist, biceps, forearm, and calf) were measured on forty eight 17 year old

Caucasian high school boys. When skinfolds alone were compared to body density, the iliac skinfold produced the highest correlation coefficient (.86). When the iliac skinfold was added to any of the other skinfolds the correlation coefficient increased to .88. When circumferences were used alone the highest correlation coefficient .73 was found for the abdomen 1 & 2 circumferences. The correlation increased when adding the circumference of the wrist .75, the buttocks .78, and shoulder .79. When using a combination of skinfold and circumference measurements to predict body density the correlation coefficient increased slightly to .89. These results indicate that the iliac skinfold combined with any one of the other skinfolds can be used to predict body density with moderately high accuracy .88. The addition of circumference measurements insignificantly increased the correlation.

In 1968, Katch F.I. and Michael E.D. enlarged their study to include college age females. Sixty-four college females were measured on body density, skinfolds (triceps, iliac, abdomen, scapula, chest, and ninth rib) circumferences (biceps, abdomen, thigh, and buttocks) and skeletal diameters (wrist, knee, bitrochanter, and ankle). The correlation coefficients between density and skinfolds were somewhat lower than previous studies ranging from .33 for the abdomen skinfold to .59 for the triceps skinfold. The correlation coefficients between density and circumference measurements were also lower than the previous study ranging from .28 for the upper arm circumference to .52 for the buttock circumference. When the triceps skinfold alone was added to the buttocks circumference, the correlation

increased to .64. The addition of the upper arm circumference further increased the correlation to .68. When the triceps and scapula skinfold were combined with the buttocks and upper arm circumferences the correlation increased to .70. The results from this study show significant increases in r values when combining selected circumference measurements to skinfold measurements. This was not apparent in their first study using only males. In addition, using skinfolds produced substantially lower r values compared to previous studies (Durnin & Rahaman, 1967; Sloan et, al. 1962; Young et, al. 1962).

Katch and McArdle (1973) using regression analysis developed prediction equations for estimating percent body fat based on the combination of three circumference measurements in four groups of subjects: young men aged 17 to 26 years, older men aged 27 to 50 years, young women aged 17 to 26 years and older women aged 27 to 50 years. Percent body fat was calculated from constants corresponding to various circumference measurements. The predicted percent fat for each group were within 2.5 to 4.0% of values determined from underwater weighing. Katch & McArdle emphasized that the equations used to predict percent body fat may not be valid when applied to athletic men and women or for subjects that can be classified as either thin or obese.

Waist to Hip Ratio

Circumferences used in conjunction with other circumference

measurements have been used to assess nutritional and health status. One of these is the waist to hip ratio (abdomen to gluteal ratio). This ratio divides the waist girth in centimeters divided by the buttocks or hip measured in centimeters. Ratios have been related to an increased risk of cardiovascular disease, type II diabetes, and obesity.

The waist circumference is a measure of deep adipose tissue and is related to fat free mass (Borkan et, al. 1983, Jackson & Pollock, 1976). The hip circumference tends to reflect lower body fatness. When used together in the waist to hip ratio, high values have been associated with an increase risk of cardiovascular disease, type II diabetes, obesity, morbidity, and mortality (Hubert et, al. 1983; Lapidus et, al. 1984; Larsson et, al. 1984; Roche & Siervogel 1991; Sverker, 1992; Folsom et, al. 1993; Hodgson et, al. 1994). The following studies report statistics relating the waist to hip ratio to the various health related problems previously mentioned.

Vague (1956) was the first to report that fat distribution in the male was correlated with endocrine and metabolic diseases. In the 1980's several studies related high waist to hip ratio's to an increase glucose tolerance leading to type II diabetes; heart disease; hypertension; stroke; and an increase risk of premature mortality (Bray, 1987; Donahue et, al. 1987; Haines et, al. 1987; Larsson et, al. 1984; Seidell et, al. 1985; Selby et, al. 1989). Also high ratio's were associated with a higher saturated fat content in adipose tissue, higher blood triglycerides, and lower high density lipoprotein (HDL) levels (Baumgartner et, al. 1987; Kaplan, 1989; Leclevc et,al. 1983; Sedgwick et, al. 1984; Segal et, al. 1987).

Lapidus et, al. 1984 studied the distribution of adipose tissue and risk of cardiovascular disease and mortality. The waist to hip ratio showed a positive association with myocardial infarction, angina, stroke, and death in patients. Myocardial infarction was found to be independent of age, body mass index, smoking habit, cholesterol concentration, triglyceride concentration, and systolic blood pressure. Lapidus concluded that the relation between the waist to hip ratio and myocardial infarction, angina, stroke, and death was stronger than the other anthropometrical measurements of weight, body mass index, subscapula and triceps skinfolds.

Larsson et, al. (1984) also studied abdominal adipose tissue distribution and its relation to obesity, cardiovascular disease, and death. They found a significant association between the waist to hip ratio and stroke and ischemic heart disease. The ratio, however, was not a long term independent predictor when smoking, blood pressure, and cholesterol were taken into account. The results of this study indicate that adipose fat distribution is a better predictor of cardiovascular disease compared to overall adiposity.

Folsom et, al. (1993) studied the relationship between carotid wall thickness to the measures: body mass, waist to hip ratio, physical inactivity, diabetes, hyperglycemia, and fasting insulin. Body mass, waist to hip ratio, physical inactivity, diabetes, and fasting insulin were all positively related with carotid artery wall thickness. When the waist to hip ratio was used independently from other risk factors, the carotid wall thickness increased 0.02 mm in women and 0.03 mm in men for a 0.07 unit increase in the waist to hip ratio. Folsom concluded that abdominal adiposity measured by the

waist to hip ratio, in conjunction with lack of physical activity, and abnormal glucose metabolism, all positively related with an increase in carotid wall thickness.

In 1994 Folsom et, al. again studied the risk of cardiovascular disease as it relates to body mass and fat distribution. Cardiovascular risk factors were studied in men and women between the ages of 28-69 years in Guanagzhou, China. After accounting for age and body mass index the waist to hip ratio produced a negative correlation with HDL cholesterol in both men and women and was positively correlated with triglycerides in both men and women. There was also a positive relationship with total and LDL cholesterol in men, uric acid in men and women, glucose in women, and mean systolic blood pressure in women. Folsom concluded that abdominal adiposity is independently related to cardiovascular risk factors in Asian men and women.

Finally, Hodgson et, al. (1994) studied the relationship between coronary atherosclerosis, and the distribution of body fatness. Two hundred and twenty six patients, one hundred sixty men and sixty-six women who had recent angiography were studied. Two different scoring systems were used in this study: the extent and myocardial scores were used to assess the degree of coronary artery disease. The extent score provided an estimate of the extent of coronary atherosclerosis. The scoring system ranged from 0 meaning no coronary blockage to 10 meaning total blockage. The myocardial score assesses the amount of stenosis in coronary ateries and the damage

that occurred to the myocardium due to coronary lesions. This scoring system ranges from 1 to 15 with one meaning no damage and 15 meaning extensive damage. Body mass index was used to determine total body fatness and the waist to hip ratio was used to assess abdominal fat distribution. Both the body mass index and the waist to hip ratio were correlated with several risk factors which contributed to coronary heart disease which included total cholesterol, apolipoprotein, triglycerides, HDL cholesterol and age. However the body mass index was not associated with either the extent or myocardial scores. The waist to hip ratio was positively associated with both scores for men and women combined. The waist to hip ratio was also positively associated with the myocardial score in women aged 40 to 70 years. However when adjusting for several risk factors for coronary heart disease the association between the waist to hip ratio and each score were not significant. Hodgson concluded that other risk factors for coronary heart disease may be involved than just the association between waist to hip ratio and coronary heart disease.

The use of anthropometrical measurements has made mass and field-testing more convenient and practical. Circumference and skeletal diameter measurements alone seem to be less accurate when compared to body density. However when circumference and skeletal measurements are added to skinfold measurements considerable increases in correlation have occurred. Although this is true, in most cases the use of skinfolds alone seems to be better predictors of body density and body fat.

The use of circumference measurements in the form of ratio's have been used in the assessment of various diseases, the complications of adipose tissue distribution, and how this relates to mortality. The waist to hip ratio (abdomen to gluteal ratio) is one ratio used for this assessment. High values of the waist to hip ratio have been associated with cardiovascular disease, type II diabetes, obesity, morbidity, and mortality. Several studies show a positive association between the waist to hip ratio and several risk factors for coronary heart disease, abnormal glucose metabolism, hypertension, hyperlipidemia, and mortality. Although the waist to hip ratio has been correlated with these health problems, the influence of other risk factors such as smoking, diet, and stress may play a positive role in the occurrence of these various health related problems.

Total Body Water

The early assumption that fat did not contain water and that water constituted 73.2% of the fat free body sparked an interest for the determination of total body water as a method for determining human body composition. As early as 1857, Von Bezold studied a number of species including the human fetus and concluded that a constant amount of body water was present in each animal. Bezold was also the first to discover that as an animal grows or ages the amount of body water decreases, which is still apparent today (Sheng & Huggins, 1979).

The first studies conducted on fluid compartments of the body attempted to indirectly measure blood volume. In 1859 Welcher made the first attempt to measure total hemoglobin content. In 1882 Grehant and Quinquand were the first to measure blood volume using the dilution principle. They used carbon monoxide as a label to measure hemoglobin content (Sheng & Huggins, 1979). In 1915 the first tracer substance, dye vital red was used to indirectly measure blood volume and in 1920 the dye T-1824 Evans blue was introduced and became the standard substance for measuring blood volume. This triumph in the area of measuring blood volume increased the interest to find a tracer substance that would measure total body water.

In 1932 the discovery of the radioisotope deuterium oxide by Urey paved the way for the potential to measure total body water (Urey et, al. 1932). The first study utilizing deuterium oxide was conducted by Hevesy and Hofer on two rabbits and one human in 1934 (Heresy & Hofer, 1934; Panaretto, 1968). Their work was followed by McDougall et,al. on rats that agreed with the findings of Hevesy and Hofer. Over the next ten years several studies were conducted mainly on farm animals using deuterium oxide.

In the late 1940s and early 1950s the use of antipyrine was introduced as a tracer substance to estimate total body water. However its use was short lived because of conflicting results (Sheng & Huggins, 1979). In the mid to late 1950s with the development of liquid scintillation counting, triated water replaced deuterium oxide as the choice substance (Panaretto, 1968). Tritium, being a radioactive isotope, had to be administered in small doses to

reduce the risk of radiation exposure. The development of liquid scintillation counting made this possible and made tritium analysis fast, cheap, and easy to perform.

The principle of isotope dilution to estimate total body water is based on the concept that a certain amount of tracer substance injected into an unknown volume or mass will be the same before and after mixing in that volume (Moore, 1963). The following formula depicts the principle of total body water estimated by isotope dilution.

$$C1V1 = C2V2$$

$$V2 = \frac{C1V1}{C2}$$

C1V1 = weight of injected tracer

C2 = equilibrium concentration of the isotope after it has completed mixing

V2 = total body water volume

Typically the most common substances used to measure total body water are antipyrene, deuterium, tritium, and more recently a heavy stable isotope of oxygen. Antipyrene's use to measure body water was short lived because it was easily metabolized and excreted, bound to proteins, and did not distribute to all fluid compartments of the body (Schloerb et, al. 1950; Schoeller et, al. 1980). The use of tritium became popular with the development of liquid scintillation counting. This gave tritium the advantage

over other tracer substances because scintillation counting made tritium easy to measure upon equilibration. The fact that tritium was a radioactive isotope, however, was a major drawback because this did not allow for the testing of children or women of child bearing age. Another drawback of tritium was the prevention of repeated testing of subjects in a short period of time (Garrow, 1982; Jebb & Elia, 1993; Jensen, 1992; Lukaski, 1987).

The most common tracer substance used in the estimation of total body water has been deuterium. This did not occur, however, until more sophisticated devices were developed to measure deuterium in solution (Lukaski, 1987). The use of gas chromatography, mass spectometry and fixed filter infrared absorption has allowed deuterium to be measured with great accuracy (Mendez et, al. 1970; Nielson et, al. 1971; Halliday & Miller, 1979; Lukaski & Johnson, 1985; Lukaski, 1987; Jebb & Elia, 1993). The major advantage of deuterium is the relatively inexpensive cost compared to other substances. Although deuterium is cheap and can be measured with precise accuracy the tracer substance preparation for analysis is delicate and lengthy (Garrow, 1982).

In recent years the use of a stable isotope of oxygen has been proposed to measure total body water. The advantage of oxygen-18 is that the substance is nonradioactive and can be conveniently measured in expired air (Garrow, 1982). The major drawback to using oxygen-18 is that the procedure is tedious, difficult, and requires sophisticated equipment only found in a specialized research laboratory (Lukaski H, 1987). The cost of

oxygen-18 is in the neighborhood of $300 per trial compared to 13$ per trial using deuterium. This makes oxygen-18 unacceptable for mass testing (Lukaski H, 1987; Jebb & Elia, 1993).

The procedure of total body water measurement using either deuterium or tritium includes either the ingestion or the intravenous injection of a precise amount of tracer substance. The amount of tracer ingested or injected depends on the type of tracer being used and the type of device used to analyze the solution. For example, a dose of 10 grams of deuterium combined with 300 milliliters of distilled water is used to measure total body water in healthy men and women (Lukaski, 1987) upon ingestion the tracer substance must equilibrate in the fluid compartments. For an average healthy adult the equilibration period takes between 2 to 4 hours (Lukaski, 1987; Jebb & Elia, 1993). To assure that a true equilibration of the tracer substance will occur, the subject is not allowed to eat or drink during the equilibration period.

Once the tracer has equilibrated in the body, a sample of either blood, urine, or saliva is taken. Blood samples have been used to measure total body water although it is time consuming and not very convenient. Using urine and saliva samples, however, are more common which makes sampling in the field more convenient. The sampling of oxygen-18 is somewhat different then previous procedures mentioned because it is conveniently measured in the expired air of the subject (Garrow, 1982; Schoeller et, al. 1980).

When indirectly measuring total body water some error does occur and this percentage of error is dependent on the type of tracer substance used. When estimating total body water tritium, deuterium, and oxygen-18 overestimate the measured space of total body water by 5%, 4%, and 1% respectively (Halliday & Miller, 1977; Lukaski, 1987; Jebb & Elia, 1993). Other factors that hamper the accuracy of measuring total body water are the equal distribution of the tracer substance within the total body water pool and the accuracy of measuring the sample of tracer after equilibration (Halliday & Miller, 1979). Other sources of error that could interfere with the accuracy in which total body water is determined is the precise measurement of the tracer dosage, not to allow the subject to drink during equilibration, and to carefully handle samples to avoid contamination (Garrow, 1982).

The early assumption that 73.2% of the fat free body was made up of water and that fat contained no water led to the prediction of body fat based on total body water. Rathbun and Pace in their studies on guinea pigs were the first to conclude that the fat free body consisted of 73.2% water (Pace & Rathbun, 1945). However this assumption is not quite valid and leads to errors when estimating the fat content of various species.

Early studies on various species of animals indirectly measured total body water with the isotope dilution method using either deuterium or tritium. Body water percentages were estimated at 74.4% for the rat, 80.5% for Angus cattle, and 75.4% for Jersey cattle (Tisavipae et, al. 1974; Carnegie & Tulloh, 1968). Later studies determining the chemical analysis of human cadavers

revealed that humans did not contain a constant amount of water especially 73.2% in the fat free body (Sheng & Huggins, 1979). The reason for this difference in the amount of body water between species and human individuals is that adipose tissue is made up of 15% water and 2% protein (Wang & Pierson, 1973; Sheng & Huggins, 1979; Garrow, 1982; Jensen et, al. 1992). When estimating body fat using the constant of 73.2% water in the fat free body, an underestimate in the prediction of body fat will occur (Sheng & Huggins, 1979; Garrow, 1982). The determination of total body water is fairly accurate and can be used to determine fat free body mass. However it does not measure body fat and is not appropriate when looking at changes in the amount of fat in and between individuals.

Body Mass Indices

The occurrence of obesity in the United States is an increasing problem in both children and adults. Typically the assessment of underweight, overweight, and obesity are made by various weight to height indices. These indices combine the weight or mass with the height or stature of an individual, which reflects the size of the individual. The body mass indices explain more than just the height and weight of a person. Weight in the body mass indice is more informative than height and the coefficient of variation (CV) of weight is three to four times that of height (Cole, 1991). So for height to be equal to weight height must be scaled up or weight scaled down to a point where weight and height can be cancelled out. Once this is

achieved the shape of a person can be made (Colliver et, al. 1983). In essence the definition or goal of a body mass indice is to measure shape independent of size because shape is felt to be suggestive of body composition (Keys et, al. 1972).

There are two general forms of body mass indices. One being W - b.H and two being W/H^N or W/H^P . where W = weight, H = height, and b, N, and P is the exponent that scales height to a point where height and weight are equal and can be cancelled out. One of the simplest body mass indices was developed by Broca in 1879. This index took weight in kilograms - 100.H where height is measured in meters. The index explained the relative weight of a person. This weight was expressed as a percentage of a reference weight, which was found in a height, and weight table (Cole, 1991). Another simple index is the overweight index (O.I.) developed by Fabry in 1962. This index took weight in kilograms x 100 divided by height in centimeters – 100.

$$\frac{\text{Wt(kg)} \times 100}{\text{Ht(cm)} - 100} = \text{O.I}$$

Values over 100 for males and over 95.5 for females were considered overweight.

The second form of body mass indices used the general formula W/H^N. Based on this formula many body mass indices have been developed. A widely used index the Quetelet Index developed by Quetelet in 1869 and later renamed the body mass index (BMI) by Keys et, al. 1972, took weight in kilograms divided by height in meters squared W/H^2. Studies have shown

that the body mass index is the best index and has the highest correlation with mortality, body fat, and obesity and produces the lowest correlation with height (Roche et, al. 1981; Norgan & Ferroluzzi 1982; Fresancho & Flegel 1982; Micozzi et, al. 1986).

Other indices that have been used to assess obesity are W/H (weight-height ratio or relative weight), Rohrer index (W/H^3), Sheldon's index ($H/W^{.33}$), Ponderal index ($W^{.33}/H$), and the Benn index (W/H^p). The weight-height ratio (W/H) offers an easy way to adjust weight for height but in the literature has not received as much attention as other indices. The Rohrer index has gained some popularity because mathematically it is a measure of body density. Density is defined as mass divided by volume (M/V) and in the Rohrer index height cubed is grossly proportional to volume (Cole, 1991). Other forms of the Rohrer index are the Sheldon index and the Ponderal index (Sheldon et, al. 1940). Although these indices have been used to assess obesity, they tend to predict leanness rather than fatness and produce a negative correlation with height and body fat (Wormersley & Durnin 1977; Lee et, al. 1981; Micozzi et, al. 1986; Smalley et, al. 1990).

In 1971 Benn developed the Benn index (W/H^P) which differed from other body mass indices in that the p value was not a constant and changed depending on the population being studied. The goal of the Benn index was to produce p values that were not correlated with height. This was accomplished by one of three ways. The first was to correlate stature and the index for a wide range of p values so that the p value produced a

correlation of zero. Another method was to determine a regression coefficient b for weight on height for that specific population and then p was calculated by the following formula:

$$p = b.So/Wo$$

where Wo and So are the mean of the population for weight and stature. The third approach was similar to the second but instead of using the mean of weight and stature for the population the regression of log weight and log stature were used producing the following formula:

$$\log W = p.\log S + \log k + error$$

Many studies have used one of the previously mentioned methods to calculate the optimal p value and have concluded that the p value for men tends to be close to 2 and between 1 and 2 for women (Koshla & Lowe 1967; Benn, 1971; Lee et, al. 1981; Garn & Pesick 1982).

There are many body mass indices, but which one is considered best and what criteria must be met for it to be classified as a good index? A body mass indice must produce a measure of obesity independent of height and produce a relatively high correlation with mortality and body fat determined by body density. Many studies have been conducted to determine which indices are better than others based on the previously mentioned criteria.

Wormersley & Durnin (1977) compared the skinfold method with various body mass indices in the assessment of obesity. The following measurements: body weight, height, skinfold thickness, and body density by UWW was determined in 245 men and 324 females between the ages of 17

and 72 years. The body mass indices used were relative weight (W/H), body mass index (W/H^2), Rohrer index (W/H^3), Ponderal index ($W^{.33}/H$), and Sheldon's index ($H/W^{.33}$). Each index was tested for its correlation with height and percent body fat which are requirements for a valid body mass indice. In both males and females the Rohrer (W/H^3), Ponderal ($W^{.33}/H$), and Sheldon ($H/W^{.33}$) indices produced a significant negative or positive correlation with height making them inappropriate as an obesity indice. The skinfold method and body mass index (W/H^2) produced the lowest correlation with height.

The second requirement needed for a good index is that it should correlate well with body fat. The skinfold method produced the highest correlation with body fat especially in males. Of the body mass indices, the body mass index produced the highest correlation with body fat ranging from .49 to .62 in men and from .64 to .91 in women. However there was not much difference between the BMI and the other indices. Skinfold measurements also produced the lowest standard error of estimates when compared to the body mass indices. The body mass indices tended to overestimate body fat in lean individuals and underestimate body fat in obese females. The skinfold method did not show this and was in better agreement with body fat determined by densitometry. Wormersley and Durnin concluded that if skinfold measurements were not available the body mass index would be the most appropriate index for the assessment of obesity.

Lee et, al. (1981) compared the traditional weight-height indices weight - height ratio (W/H), body mass index (W/H^2), Rohrer index (W/H^3), and Ponderal index ($W^{.33}/H$) with the Benn index (W/H^P). Weight and height was measured in 35,523 adult male and female subjects from five diverse ethnic populations. Each indice was studied in terms of maximum correlation with weight and it's minimum correlation with height. Of the traditional indices the Rohrer index (W/H^3) and the Ponderal index ($W^{.33}/H$) were considered unacceptable obesity indices because of their moderate correlation with weight and their moderately high correlation with height. A body mass indice must produce a strong correlation with weight and a low correlation with height for it to be accepted. The W/H and the BMI (W/H^2) produced high correlation with weight and relatively low correlation with height, although all correlation were significantly different from zero. The W/H indice produced the highest correlation with weight and lower correlation with height in female subjects compared to the BMI. However the opposite was true for the BMI in males. The Benn index also produced relatively high correlation with weight and produced the lowest correlation with height. In each group the Benn index produced the lowest correlation with height and in each case was not significantly different from zero. Lee et, al. concluded that the Rohrer and the Ponderal indices were inappropriate indices for assessing obesity. The W/H and BMI were consistently better but this was not the case in every ethnic group. The Benn index seemed to be the best indice because of the low correlation with height in all situations.

However more research is necessary to determine how the Benn index compares to more appropriate measures of body fat such as densitometry.

Garn & Pesick (1982) compared the Benn index with body weight alone, height divided by weight (H/W), and height divided by the cube root of weight. The subjects consisted of 58,468 adult males and females collected from data found in the Western Scotland Survey, the National Collaborative Perinatal Project, the National Health and Nutritional Examination Survey, and the Tecumseh, Michigan Community Health Survey. Correlations were made between the Benn index and each indice along with the triceps, subscapula, ilium, and abdomen skinfolds collected from the Tecumseh data that consisted of 1,933 males and 2,126 females. The Benn index correlated high with the other indices ranging from .853 in Scottish white males to .976 in Tecumseh white females. When comparing each body mass indice to the triceps, subscapular, ilium, and abdomen skinfolds the Benn index was only slightly better than weight alone (.09), and only (.04) of a difference with H/W. It was concluded that the *p* value of the Benn index did not produce results that were significantly better than the other indices. It also should be pointed out that the indices used to compare the Benn index with are not considered the best of the body mass indices.

Frisancho and Flegel (1986) compared new and old body mass indices to the triceps and subscapula skinfold measurements. They used the data collected from the U.S. Health and Nutrition Survey I, from 1971 to 1974, which consisted of 16,459 black and white adult males and females. When

comparing the three indices used in this study the Rohrer (W/H^3), Quetlet's (W/H^2), and the Benn (W/H^P) index all had higher correlations with the subscapula skinfold than the triceps skinfold. The BMI and the Benn index showed the highest correlation's with skinfolds in both black and white males and females. When comparing the BMI and Benn index with the skinfold measurements, the correlations were almost identical with the BMI being slightly better. When comparing the body mass indices to the skinfold technique, weight alone explained about 48 to 52% of the variability. When using either the BMI or the Benn index the explained variability increased to 58%. This relatively low explained variability makes it necessary to use body mass indices along with more direct measures of body fatness such as skinfold thickness for the assessment of obesity. Finally, the Benn index in this study did not produce results better than the body mass index. In addition, the lengthy calculations found in the gender and age regression equations make the Benn index less attractive.

In 1986 Micozzi et, al. studied the correlation of body mass indices with weight, height, and body composition measured by skinfold thickness, using the data found in the U.S. Health and Nutrition Survery I & II. The body mass indices that were independent of height and highly correlated with weight were the BMI (W/H^2) in men and the W/H and $W/H^{1.5}$ in women. The Rohrer index (W/H^3) and Ponderal index ($W^{.33}/H$) were more inversely correlated with height and less correlated with weight. When looking at the extremes of the body fat continuum the BMI in men and the W/H in women

maintained their high correlation with weight, independent of height. When comparing the body mass indices with skinfold thickness, all indices correlated better with the subscapula skinfold than the triceps skinfold. This might suggest that body mass indices are better predictors of central fat, which have been associated with type II diabetes and cardiovascular disease. Micozzi et, al. concluded that the best body mass indices based on the correlations with weight, height, and body fatness were the BMI in men and the W/H in women.

Smalley et, al. (1990) assessed the accuracy of body mass indices to measure obesity. Two hundred thirteen women and one hundred fifty men underwent measurements of body weight, height, and densitometry to determine percent body fat. The following six obesity indices were used in this study: W/H (Relative weight), W/H^2 (BMI), $W^{.33}/H$ (Ponderal index), $H/W^{.33}$ (Sheldon's index), and $cW^{1.2}/H^{3.3}$ (Abdel-Malek's index). The correlation between each body mass indice and weight and height followed similar patterns found in previous studies (Wormersley & Durnin 1977; Lee et, al. 1981). W/H produced the highest correlation with weight (.98) and the lowest correlation with height (.02) in females. In male subjects the BMI produced the best correlations with weight (.92) and height (-.06). The correlation coefficients between all body mass indices and percent body fat were higher in women (.82-.86) than men (.67-.70). The results from this study indicated that an index based on weight and height alone would not accurately assess obesity on an individual basis. The BMI produced slightly

better results than the other indices. However they were somewhat insensitive when assessing obesity compared to densitometry, and usually led to the underprediction of obesity. The use of body mass indices alone to assess obesity in individuals is somewhat questionable especially in individuals who are borderline obese.

Traditional and new body mass indices have been used to assess obesity. However, not all indices meet the criteria needed to be classified as an acceptable obesity index. There are many body mass indices that have been developed but only the BMI and the Benn index have been proven to be adequate obesity indexes.

The strength of the Benn index is it's ability to directly measure relative weight specific to the population being studied (Cole, 1991). The disadvantages of the Benn index is that a new P value must be developed for every separate population being studied, studies can not be compared to other studies due to different values for p, and the Benn index requires lengthy regression equations which are not suitable for field testing.

The strength of the Quetlet's or body mass index is that it provides a direct measure of under or overweight and tends to correlate better with body fat and mortality risk. The body mass index is also very easy to calculate and requires only a calculator to achieve results. The drawbacks of the body mass index are that it predicts leanness almost the same as fatness and tends to be less valid at the extremes of the body fat continuum.

Although all body mass indices possess some limitations, the Quetlet's or

BMI has been identified as the best indice and is useful in the screening of obesity or malnutrition in both children and adults. However when used to predict percent body fat, standard errors of estimate equal or exceed 5% body fat. This means that an individual that is estimated at 25% body fat can be anywhere from 20% to 30% body fat. The BMI is useful in epidemiologic research for the screening of disease and risk factors among various populations. However, even though the BMI has been recognized as the best body mass indice, it is not accurate enough to make predictions of percent body fat on an individual basis without the use of more direct methods for measuring body fat.

Bioelectrical Impedance

The use of the tetrapolar method to measure bioelectrical impedance dates back as far as the 1930s (Chumlea, et al. 1988). The focus of these early studies was to study the effect of various electrode configurations, to establish specific properties of bioelectrical impedance in the body, and the effects it had on various body tissues (Chumlea et, al. 1988). However, the potential use of bioelectrical impedance for the measurement of body composition was not discovered until the work of Nyboer, Thomasset et, al., and Hoffer et, al. (Nyboer, 1959; Thomasset et, al., 1962; Hoffer et, al., 1969).

The basic concept of bioelectrical impedance is based on the amount of water and electrolytes found in lean tissue, which acts as a conductor. When

an electrical current travels through lean tissue, the water and electrolyte content will offer less resistance than fat. Fat tissue on the other hand has very little water and electrolyte content. Fat tissue will act as an insulator and will resist an electrical current. Therefore, the amount of resistance is almost entirely dependent on the amount of lean tissue present in the body.

The underlying principle of bioelectrical impedance is that the impedance (Z) of an cylindrical conductor is determined by the length of the conductor (L), the specific resistivity of the tissues (p), the cross-sectional area (A), and applied signal frequency (Nyboer, 1959, Kushner, 1992). The equation for impedance would be

$$Z = \frac{pL}{A}$$

Since any fraction multiplied or divided by one will remain unchanged, and assuming the human body to be a cylinder and that resistance (R) is equal to specific resistivity (p) if the cross-sectional area and length are equal to one. Multiplying equation one by L/L=1 will result in the following equation.

$$Z = \frac{p(L^2)}{AL}$$

Since the AL (cross-section area x length) portion of this equation is equal to the volume (V) of the cylinder. Volume (V) can replace AL and the new equation is:

$$V = \frac{pL^2}{Z}$$

Knowing or by measuring the length, resistivity, and resistance of the conductor (human body) the calculation of lean tissue volume can be made.

In the literature the terms impedance and resistance are often used interchangeably when in fact impedance (Z) measured in ohms is a function of resistance (R) and reactance (Xc) and is dependent on signal frequency. Nyboer et, al. 1943 were the first to demonstrate that electrically determined biological volumes were related inversely to impedance (Z), resistance (R), and reactance (Xc) where $Z = R + Xc$. Baumgartner et, al. (1988, p. 16) gives the following definition of bioelectrical resistance and bioelectrical reactance.

> "Bioelectrical resistance is the pure opposition of a biological conductor to the flow of an alternating current. Bioelectrical reactance is the resistive effect due to capacitance produced by tissue interfaces and cell membranes."

At low frequencies typical of BIA analyzer's, the applied current flows mainly through extracellular water. This is due to the capacitance of the cell membrane, which acts like a barrier and does not allow the current to penetrate the cell. This barrier of cells and tissue interfaces is what causes bioelectrical reactance. In this case the reactive (Xc) component increases proportionate to the resistive (R) component. However at high frequencies the body becomes mainly resistive and the reactive component of impedance is very small. At high frequencies the cell membrane becomes short-circuited and the current penetrates the cell. In this case both extracellular and intracellular water can be measured. Although the measurement of total

body impedance is a function of both resistance (R) and reactance (Xc), reactance is usually ignored. Since reactance is very small contributing less than two percent in proportion to resistance in the total impedance measurement and that resistance is a better predictor of impedance than the previous equation $V = pL^2/Z$ can be changed to $V = pL^2/R$ (Lukaski et, al. 1985).

The first studies relating bioelectrical impedance to the biological functions of the human body were performed by Nyboer in 1959. Nyboer using an bioelectrical impedance plethysmography, measured arterial pulse waveforms and pulsatile blood flow to organs (Nyboer, 1959). Nyboer's work was followed by the work of Thomasset who was the first to use electrical impedance as an index for total body water (Thomasset, 1962; 1963). Hoffer et, al. (1969) extended the work of Thomasset by measuring total body water in 20 normal subjects using bioelectrical impedance and tritium dilution. Hoffer et, al. using a tetrapolar impedance technique which applied a 100 amp current at a frequency of 100 kilohertz. The best predictor of total body water determined by tritium dilution was the equation Ht^2/Z which accounted for 84% of the total variance between BIA and tritium dilution. The correlation coefficient between tritium dilution and bioelectrical impedance was very good .92 (Hoffer et, al. 1969).

The first study using bioelectrical impedance (BIA) to measure human body composition was conducted by Lusaski et, al. (1985). This study estimated fat free mass (FFM) and total body water (TBW) in 37 healthy

males using an electrical impedance plethysmograph. These results were then compared to FFM determined by hydordensitometry. TBW was determined by the standard laboratory procedures using deuterium oxide dilution (D_2O). Total body potassium (TBK) was also determined. The test-retest reliability for BIA was high (.99).

When Ht^2/R was regressed against the criterion methods, correlation coefficients were high compared to dFFM (r=.98), TBW (r=.95), and TBK (r=.96). From these results Lukaski et, al. concluded that BIA was a reliable and valid method for estimating human body composition.

Segal et, al. (1985) compared bioelectrical impedance (BIA) to existing body composition techniques densitometry (UWW), TBW (D2O), TBK, skinfolds (Durnin & Wormersley) and girth measurements (Steinkamp). Lean body mass (LBM) was determined for 75 males and females ranging from 4.9 - 54.9% body fat. LBM estimated using the BIA prediction equation supplied by the manufacture when compared with UWW was high (.912). However in the more obese subjects the BIA overestimated LBM when compared to densitometry. When weight, height, and gender were added to the manufactor's regression equation, the correlation coefficient increased to .962 (SEE 3.06kg). When LBM was converted to percent body fat the correlation between BIA and UWW was .934 (SEE 6.10%). Segal et, al. concluded that Ht^2/R with the addition of weight to the regression equation strengthened the relationship between densitometry and BIA.

Kushner & Schoeller (1986) estimated TBW by bioelectrical impedance

and deuterium oxide dilution in 40 healthy subjects and 18 obese patients. Gender specific and group equations were developed for both groups. Ht^2/R was the most significant independent variable when compared to TBW estimated by deuterium oxide and accounted for 94% of the total variance. In the normal subjects, when compared to D_2O, the group specific equation estimated TBW very well in males and females combined .986. The gender specific equations did not increase the correlation between BIA and TBW, males .988 and females .975 In the obese subjects the group equation correlation with D_2O were not quite as good .97 for males and .95 for females. The gender specific equations had coefficients of .96 for males and .93 for females when compared to D_2O. There was no significant difference between TBW estimated by BIA and TBW estimated by deuterium oxide dilution. Kushner and Schoeller concluded that multiple regression equations greatlyimproved the prediction accuracy of BIA to predict TBW as estimated by deuterium oxide dilution.

Lukaski et, al. (1986) also studied the relationship between bioelectrical impedance and densitometry in determining FFM. They compared the prediction errors when determining percent body fat by BIA and the skinfold equation (D&W) with underwater weighing. FFM and percent body fat was determined on 114 male and female subjects varying in FFM from 34-96kg and from 4-41% body fat. Lukaski et, al. crossvalidated the 1985 linear regression developed for men using HT^2/R to predict FFM. Lukaski et, al. again as in 1985 found Ht^2/R to be the best predictor variable accounting for

98% of the total variance between BIA and densitometry. The correlation coefficients for FFM determined by BIA and densitometry were .979 for males and .954 for females. In both males and females no significant difference was found between the slopes and intercepts of regression lines supporting the reliability and validity of Ht^2/R to predict FFM. The regression line was not significantly different than the line of identity. When comparing percent body fat and the prediction errors for predicting percent body fat, the BIA method had a better correlation coefficient with densitometry .928 SEE 2.7% than the skinfold equation of Durnin & Wormersley .877 SEE 3.9%. They concluded that BIA is a valid and reliable method and can be used to determine human body composition.

Jackson et, al. (1988) examined the reliability and validity of bioelectrical impedance to predict body fat when compared to skinfolds and hydrostatic weighing. Body fat was measured on 44 women and 24 men and on a second sample of 26 men and 38 women for cross validation. Each subject was tested four times by two testers on two separate days. BIA was found to be reliable with intra-class coefficients of .957 for men and .967 for women. The correlation coefficients for the sum of 7 skinfolds to estimate hydrostatically determined percent fat was .92 for males and .88 for females. This was compared to bioelectrical impedance, which produced coefficients of .71 for males and .76 for females. The correlation coefficients for body mass index when compared to hydrostatic weighing were .75 for men and .74 for women. The standard errors of estimate for BIA ranged from 4.6 to

6.4% compared to 2.6 to 3.6% for skinfolds. Jackson et, al. concluded that bioelectrical impedance was less accurate compared to the measurement of skinfold fat.

In 1988, Segal et, al. using four different laboratories, validated bioelectrical impedance by using UWW in 1069 males and 498 females. They estimated lean body mass and percent fat using the generalized equations provided by the manufacture and compared these results to the results obtained by fatness specific equations developed by Segal et, al.. They reported that height squared and resistance individually were better predictors of lean body mass determined by densitometry than was height^2/resistance. This differs from the results of Lukaski et, al. (1985 & 86), and Segal et, al. (1985) who found Ht^2/R to be the best predictor variable. A quadruple cross validation was performed between the four laboratories to determine the reproducibility of lean body mass estimated by BIA. When adjustments were made for the subjects body fatness no significant difference was found between laboratories. When lean body mass determined by the generalized equations were compared to LBM determined by fatness specific equations correlation increased and SEE decreased. Correlation coefficients for males increased from .896 to .938 and SEE decreased from 3.62 to 2.84kg. For women, the correlation coefficient increased from .889 to .930 and SEE decreased from 2.43 to 1.95kg. When the data was expressed as percent body fat the correlation coefficients increased from .809 to .896 and the SEE decreased from 4.44 to

3.35% body fat for males. For women, the correlation coefficients increased from .852 to .909 and the SEE decrease from 3.98 to 3.18% body fat. Segal et, al. concluded that the BIA method could estimate LBM with reproducibility between laboratories and that the prediction of LBM and percent body fat is significantly increased with the use of fatness specific equations.

The above studies used bioelectrical impedance to measure whole body impedance, on the assumption that the body is an isotropic conductor where resistance is proportional to its length and inversely proportional to the cross-sectional area and where $Z = pL/A$ (Kushner, 1992).

However, the body is not one cylinder but consists of five separate cylinders, two arms, two legs, and the trunk minus the head. Since resistance is inversely proportional to the cross-sectional area, the cylinders with the smallest cross-sectional area i.e. the arms and legs will have the greatest influence on whole body resistance measurements. On the other hand the trunk which makes up 50% of the body mass will contribute much less ranging from 5 to 12% of whole body resistance measurements (Patterson, 1989).

Also, if the body were an isotropic conductor the current density would be uniformly distributed along axes in all directions. However this does not occur in the human body because of dielectric conductors in the body such as organs, and intramuscular fat that causes conduction to be anisotropic or heterogeneous throughout various body segments (Patterson, 1989).

Finally the specific resistivity of tissue (p) in the equation $V = pL^2/Z$ has

been used as a constant and usually ignored in BIA studies. However, it is not a constant and will vary depending on the tissue microstructure, hydration, and concentration of electrolyte ion concentration (Baumgartner et. al. 1990; Khaled et, al. 1988).

Many studies using bioelectrical impedance have ignored the specific resistivity of different body segments. The only studies prior to 1988 using segmental specific resistivity were conducted by Nyboer (1970) and Chumlea et, al. (1987). Nyboer 1970 stated that, "...it is well recognized that the mean specific resistivity varies in different limb segments of the body because of the different ratios of the various tissues in each segment." Also due to inter-individual and intra-individual differences the specific resistivity of a tissue will vary depending on the body segment (Chumlea et al. 1988).

Chumlea et, al. (1988) estimated mean specific resistivity from measures of BIA of body segments on 123 children and adults between the ages of 9 and 62 years of age. The mean specific resistivity was used to estimate FFM from the total conductive volume of the body for each individual. Body segment and whole body means and standard deviations for bioelectrical resistance, reactance, and impedance measurements were higher in women than men except for reactance of the trunk. There was greater variability for resistance, reactance, and impedance in boys than girls and in women than in men. The FFM content was estimated by either dividing the total conductive volumes by .73 L/kg the water content of FFM or by multiplying the conductive volumes by 1.1 kg/L the density of FFM. When comparing

estimates of FFM by BIA and body density the best prediction of FFM in men and girls was the actual length of the conductor, the squared sum of the arm length (AL^2), and acromial height (AH^2) divided by whole body impedance ($AL^2 + AH^2$)/Z. The best predictor for boys and women was the use of height squared divided by impedance H^2/Z. Although whole body impedance was a better predictor of FFM, the use of segmental impedance with specific resistivity could be used as a method to predict body composition.

Based on the findings of Settle et, al. (1988) which found that most of the whole-body resistance was determined by the resistance of the leg and arm lead Baumgartner et, al. (1989) to estimate body composition from bioelectric impedance of body segments compared to whole-body impedance. The following measurements were done on 135 Caucasian males and females between the ages of 18-58 years, weight, stature, whole-body resistance, resistance for each segment, the lengths of each segment, and circumferences of the leg, trunk, and arm were performed on 135 Caucasian men and women aged 18-58 years. When comparing the results for estimating FFM by either whole-body impedance (H^2/R) or from segmental impedance (L^2/R), whole-body impedance had larger R^2 values than either of the body segments. Whole-body impedance produced R^2 values of .65 SEE 4.10kg for men, .73 SEE 2.80kg for women, and .90 SEE 3.65kg for men and women combined. However, FFM estimated from arm length^2/resistance produced R^2 values vary similar to H^2/R. The arm

impedance produced R^2 values of .58 (SEE 4.48kg) for men, .49 SEE 3.90kg for women, and .86 SEE 4.25kg for men and women combined. When estimating percent body fat, whole-body impedance (WR/S^2) produced larger R^2 values than either of the body segments. The R^2 values for WR/S^2 were .61 SEE 5.25% for men, .74 SEE 4.55% for women, and .75 (SEE 4.98%) for men and women combined. The arm impedance again produced R^2 values similar to whole-body .61 SEE 5.20kg for men, and .65 SEE 5.23kg for women.

Baumgartner et, al. concluded that segmental impedance of the arm and leg can be used to accurately estimate body composition. Thus the bioelectrical impedance method can be adapted to estimate body composition in subjects for whom accurate measurements of stature cannot be made. However, caution should be used until these equations are cross-validated.

Most studies validating the BIA method for estimating body composition have been conducted on young healthy adults. Houtkooper et, al. (1989) studied the validity and reliability of BIA for estimating body composition in children. Ninety Caucasian children between the ages of 10-14 years were measured for: whole-body impedance, underwater weighing, TBW by deuterium oxide, and anthropometric measures of weight, skinfold thickness, circumferences, skeletal widths, standing and sitting height. The criterion method was based on multiple-component models based on body density (UWW) and total body water (D_2O). The equation for %FAT determined by

the equation was:

%FAT-DW = (2.057/D - 0.786 x W - 1.286) x 100

and the equation for fat free body was:

FFB-DW = Wt - (Wt x %FAT-DW/100)

where D = density from underwater weighing, Wt is body weight in kilograms, and W is the water fraction of the body determined by deuterium oxide.

Regression analysis showed that S^2/R and body weight were significant predictors of fat free body (FFB) determined by FFB-DW. The R^2 value for S^2/R alone was .88 (SEE 2.6kg) and for weight alone was .77 SEE 3.6kg. When S^2/R and weight were used to predict FFB the R^2 value increased to .93 and the SEE decreased by 2.0kg when compared to FFB-DW. When S^2/R and weight were used to predict percent body fat compared to %FAT-DW, the R^2 value was lower .74 SEE 4.2% compared to predicted FFM. Houtkooper et, al. also used whole-body impedance combined with various anthropometric measurements in regression analysis to determine which measurements were significant predictors of FFB and percent body fat. The best equation predicting FFB-DW was: 0.713(S^2/R) + 0.150(chest circumference cm) + 0.493(hip skeletal width cm) - 0.121 (reactance) - 21.41. This equation produced a correlation coefficient of .97, a R^2 value of .94 and a SEE of 1.91kg when compared to the criterion method. This is compared to a correlation of .96, an R^2 value of .92 and a SEE of 2.1kg for anthropometry alone. The best equation relating %body fat predicted by

UWW was: -0.235(S2/R) + 0.252(abdomen circumference) + 0.281(sum of triceps, abdomen, and thigh skinfolds) - 0.044. This equation produced a correlation coefficient of .92, R^2 value of .85 with a SEE of 3.3% body fat. This is compared to a correlation of .92 SEE 3.2% and an R^2 value of .85, which is very similar BIA. Houtkooper et, al. concluded that BIA was a valid and reliable method of estimating body composition in 10-14 year old children. The prediction accuracy of BIA was greatly improved when adding selected anthropometric measurements. Also the prediction accuracy of BIA and anthropometry alone were very similar. However, the equations developed on this sample of children needs to be cross-validated on other populations of children before full acceptance can be made.

Oppleger et, al. (1991) compared the validity of BIA, anthropometry, and hydrostic weighing to assess minimal weight in 57 high school wrestlers. The BIA used 3 manufacture's systems the Berkely Medical Research (BMR), RJL Systems, Detroit MI (RJL), and Valhalla Scientific (VAL). The 3 anthropometric methods were the skinfold equation of Oppliger & Tipton (1985), and 2 skeletal dimension equations by Tcheng & Tipton (1973), and Oppliger & Tipton (1988).

The following data shows the correlation coefficients, SEE, and total error of each method compared to hydrostatic weighing.

Method	r	SEE	TE
BMR	.975	.98 kg	2.3 kg
RJL	.978	.43 kg	4.4 kg
VAL	.964	.70 kg	3.9 kg
SF	.990	.19 kg	1.8 kg
Tch-Tip	.923	1.47 kg	4.3 kg
Opp-Tip	.965	.98 kg	3.1 kg

The results show that the skinfold equation was the best predictor of minimal weight in high school wrestlers. When the means were analyzed for significance the only methods that were not significantly different from hydrostatic weighing were the skinfold equation and the BMR. One speculation to why the BMR system was more accurate is that the BMR equation included eight circumference measurements and height. Oppliger et, al. concluded that the results from this study found skinfolds and the BMR system to be the most valid methods for determining minimal weight in high school wrestlers.

A recent study involving BIA was conducted by Eckerson et, al. (1996). The emphasis of this study was to determine the validity of selected BIA equations for predicting percent body fat in males and compare this validity to the commonly used sum of three skinfold equation of Jackson & Pollock (1978). The validity of these methods was compared to the criterion method UWW. One hundred twenty-two adult, Caucasian males between the ages

of 18 and 40 years under were measured on height, weight, UWW, skinfolds, and BIA. The sum of three skinfold equation (Jackson and Pollock, 1978) was used to predict body density or %body fat and the equation of Brozek et, al. (1963) converted body density to percent body fat. A RJL systems BIA-106 Spectrum analyzer was used to measure resistance and seven different prediction equations along with the manufactures equation was used to predict percent body fat. The BIA equations were chosen based on at least one of the following criteria:

1) Developed from a previous interlaboratory investigation,
2) Derived on a large sample greater than 200 subjects, or
3) Previously been shown to accurately estimate body composition when cross-validated against a criterion method.

The following equations were used to predict percent body fat using BIA. The RJL manufacture, RJL equation, Oppliger et, al. (1991), Guo et, al. (1987), Deurenberg et, al. (1991), Segal et, al. generalized equation and fat specific equations (1988), Lohman et, al. (1992), and Van Loan et, al. (1990). The Jackson & Pollock skinfold equation and the Brozek et, al. equation was used to predict percent body fat. The skinfold equation of Jackson & Pollock produced the highest correlation coefficient of .90 and the lowest SEE of 2.6% body fat, and had a total error of 3.4% body fat. Only two other equations had correlations, SEE, and total errors that were somewhat close to the skinfold equation. The equation of Guo et, al. (1987) had a correlation coefficient of .86, a SEE of 2.9% body fat, and a total error of 4.1% body fat.

The other equation was the fat-specific equation of Segal et, al. (1988) for subjects over 20% body fat. This equation had a correlation coefficient of .80, a SEE of 2.6% fat, and a total error of 3.0% fat. Eckerson et, al. concluded that the sum of 3 skinfold equation met most of the cross-validation criteria and is recommended over BIA in Caucasian males with lean to average body fatness. Also the results from multiple regression analyses suggest that the anthropometric measures skinfolds and body weight account for the majority of the prediction accuracy in BIA equations. Although the skinfold equation produced the best results the equations of Guo et, al. and the fat-specific equation of Segal et, al. may be considered alternatives to the sum of 3 skinfold equation.

All of the studies reviewed have validated BIA method in healthy, young, weight-stable subjects. However the validity of BIA in subjects with disease, abnormal hydration, and extreme weight loss or gain has been questioned. Cohn (1985) questioned the validity of BIA in subjects with disease, abnormal hydration or osmolariy, and in subjects involved in physical training or weight loss. Katch et, al. (1986) also questioned the validity of BIA for determining body fat in the elderly and diseased patients. Katch et, al. estimated percent body fat by BIA and UWW in 13 cardiac and 11 pulmonary patients. The cardiac patients had either angina, previous myocardial infarction, or bypass surgery in the last three years. The pulmonary patients all had chronic obstructive pulmonary disease and were on medication and oxygen therapy. The following data demonstrates the R^2, SEE, and mean

difference (MD) values between BIA and UWW for pulmonary and cardiac patients.

	R^2	SEE	MD
Cardiac	.08	6.9%	6.5%
Pulmonary	.42	3.94%	10.7%
Total Group	.15	5.58%	

Katch et, al. concluded that BIA was not a valid method for estimating body composition in subjects with cardiac or pulmonary disease.

Gray (1988) studied the changes in TBW in 6 obese females during a two week fast. Daily measurements of BIA were made and compared to changes in TBW estimated by deuterium oxide. Resistance, reactance, and impedance increased more during the first week then the second week. H^2/R, reactance, and impedance followed similar patterns during the fast. There was a rapid increase during week one and stayed stable over the next week. A correlation coefficient of .94 with a SEE of .7 liters was found between BIA and deuterium oxide at the end of the two-week fast. Gray concluded that BIA could measure changes in TBW over time. However if TBW changes occur to rapidly for example in the treatment of congestive heart failure, BIA would not produce accurate changes in TBW.

Deurenberg et, al. (1989) studied the changes in FFM estimated by BIA and UWW in 12 healthy subjects. Each subject followed a very low calorie diet for two days. The mean change in FFM determined by UWW was 1.2kg. The BIA method found a mean change in FFM of 1.3kg, which was not

significantly different from UWW. However each BIA equation consistently underestimated weight changes. Deurenberg et, al. concluded that even though BIA was not significant compared to UWW, the BIA method maybe inaccurate to small changes in body composition.

Gray et, al. (1989) studied the validity of BIA in assessing body composition and its use with obese subjects. Eighty seven adults, 25 males and 62 females, age 19 to 74 years and ranging from 8.8 to 59.0% body fat were measured by BIA and UWW. The subjects were divided into four quartiles ranging in body fat. The first quartile ranged from 8.8 to 29.0 %fat, the second quartile ranged from 29.2 to 41.1 %fat, the third quartile ranged from 41.8 to 47.6 %fat, and the fourth quartile ranged from 47.8 to 59.1 %fat. The following data demonstrates the correlation coefficients between UWW and Ht^2/R for each quartile using the present equations and the generalized and fat specific equations of Segal et, al. (1988)

		Quartile's			
		1	2	3	4
%fat		8-29%	29-41%	41-47%	47-59%
Gray	r	.95	.96	.95	.82
	SEE	3.30kg	3.90kg	4.72kg	3.68kg
Segal (Generalized)	r	.95	.98	.99	.96
	SEE	3.21kg	2.82kg	2.03kg	2.03kg
Segal (Fat-Specific)					
	r	.98	.98	.99	.97
	SEE	1.76kg	2.55kg	2.51kg	3.12kg

As can be seen from the above table, the generalized equation of Segal slightly increased the correlation especially in quartile 4. The fat specific equation only offered a minimal improvement when compared to the generalized equation.. Although the correlations were high at all levels of body fatness, the impedance method overestimated body fat in the two most obesed groups. The estimates of FFM derived from density and FFM from BIA were not significantly different except for subjects who were over 41.1% fat. New equations were derived from the present data and found correlation coefficients of .97 for men, .92 for women, and .96 for women between 47.8 and 59.1% body fat. Gray et, al. concluded that the regression equations of Segal et, al. are valid when predicting body composition in subjects who widely vary in body fatness. However the Segal et, al. equations inaccurately predict FFM in subjects with greater than 48% body fat. The over prediction of body fat in very obese subjects maybe due to expanded extracellular water or a greater intramuscular fat content which would effect the volume of the conductor.

Finally Kushner et, al. (1990) using the same method as Gray (1989) studied if BIA could accurately assess changes in TBW during long term weight loss. Measures of BIA, deuterium oxide and skinfolds were made on twelve obese females at 5% decrements in weight in individuals on a low caloric diet for 7 to 19 weeks. Correlation coefficients were high for BIA .97 and for skinfolds .93. These results agree with the findings of Gray (1989) who found a correlation coefficient of .94 between TBW estimated by deuterium oxide and BIA.

The typical BIA analyzers used in the studies reviewed have measured R and Xc at a set frequency of 50 KHz. At this frequency the electrical current introduced into the body mainly flows through extracellular water due to the capacitance of cell membranes. Since the tissues of the body are frequency dependent, at higher frequencies the cellular membranes are crossed by the electrical current and the measurement of extracellular and intracellular water can be assessed (Kanai et, al. 1987). By using multifrequency ranging from 1KHz to 1MHz information about the distribution of body water compartments can be made.

Jenin et, al.(1975) found the relationship between extracellular fluid volume to be a linear function of H^2/Z at frequencies less than 5 KHz. Espejo et, al. (1989) estimated extracellular water (ECW) in nine rabbits similar in size. They found a correlation coefficient of .95 between ECW and L^2/Z at a frequency of 1 KHz.

Segal et, al. (1991) measured whole-body impedance in 36 healthy men at two frequencies, 5 KHz and 100 KHz. The best predictor of ECW was Ht^2/R and weight measured at 5 KHz producing a correlation of .93 with a SEE of 1.94L. TBW measured at 100 KHz by Ht^2/R and weight produced a correlation of .95 with a SEE of 2.64L.

Tedner et, al. (1984;85) measured the fluid change during hemodialysis and intravenous infusion. They concluded that fluid volume change could be more accurately measured with impedance at two frequencies, 1.5 KHz and 150 KHz. Also the impedance value at 1.5 KHz was larger compared to 150

KHz. This indicates that most of the water added or removed came from extracellular water (ECW). Although multifrequency methods can detect changes in fluid volumes and direct measure of changes in body water may not be as accurate.

BIA offers a fast, non-invasive measurement of body composition. The BIA method has been validated by many investigators and has been used to measure TBW, FFM and to predict percent fat in adult and children populations. BIA can be used as a substitute for skinfolds with slightly less accurate results. However, caution needs to be expressed to the BIA prediction equation being used to estimate FFM or percent body fat. The BIA equations supplied by the manufacture tend to be less accurate and produce greater prediction errors. Also, the valid assessment of body composition and the estimation of body fluids in patients with disease needs to studied more before being accepted as a valid method. The use of segmental and multifrequency methods should expand the clinical use and improve the application of the BIA method. BIA can be an effective method for the estimation of body composition. However, the user must have a good understanding of the principle application techniques and limitations of BIA for it to be used to measure body composition.

Near-Infrared Photospectometry

As early as 1965 near-infrared spectroscopy has been used to determine the moisture, protein, and oil content of grains, oilseeds, and forages

(Conway & Norris, 1987; Lanza, 1983). In 1968 Ben-Gera and Norris used NIR spectometry to determine the fat and moisture content of various meat products (Ben-Gera & Norris, 1968b). Lanza (1983) determined the fat, protein, moisture, and caloric composition of raw pork and beef. This earlier research conducted in the area of agriculture has led to the development of infrared interactance as a method used to estimate human body composition.

The principle of NIR is based on the reflectance and absorption of electromagnetic radiation (Lukaski, 1987). When electromagnetic radiation penetrates the tissue sample, the energy is either absorbed, reflected, or transmitted depending on the scattering and absorption properties of the tissue (Lukaski, 1987). The absorption and reflection of protein, fat, and water is due to the stretching and bending of hydrogen atoms in regards to oxygen, nitrogen, and carbon (Conway & Norris, 1987) which affects the shape of the spectrum (Lohman, 1992).

The first studies estimating human body composition used equipment that was much more sophisticated compared to the hand held Futrex 5000 which was developed with less precision and accuracy (Conway et, al. 1985; Conway & Norris 1987). Essentially, the measurement of human body composition by NIR is performed using a computerized spectrophotometer using a single beam rapid scanning monochromator and a fiber optic probe. The spectrophotmeter is used in the transittance mode and scans are made over the midrange wavelengths of 700-1100 nm. The fiber optic probe emits electromagnetic radiation from a monchromator to the selected site on the

body. In return the monochromator collects the reflected and scattered energy and transmits it to the detector.

The instrument is calibrated by measuring a signal from a reference 1cm teflon block. The measurement of interactance (I) is determined by dividing the signal obtained at the site being measured by the signal obtained from the reference teflon block where I = Es/Er, Es = energy received from the subject, Er = energy received from the teflon block. The data is transformed to log (1/I) which is similar to the absorption spectra plotted as log (1/T) which has been shown to vary linearly with the concentration of a specific absorber with other materials (Conway et al. 1985).

The method used to analyze the spectra uses the ratio of two-second derivatives of log (1/I) data retrieved at two different wavelengths. This is done to reduce the effects on reflectance due to variables such as particle size and temperature (Conway et, al. 1985; Conway & Norris, 1987).

The first study using NIR to determine human body composition was conducted by Conway et, al. (1985). Body fat was estimated in 53 adult males and females varying in age. Total body water estimated by deuterium oxide (D_2O) was used as the criterion method from which infrared (NIR), skinfolds (SKF) using the equation of Dunin & Womersley (1974), and ultrasound (US) were compared. Interanctance was measured at the biceps, triceps, subscapula, suprailiac, and thigh at two wavelenghts 916nm and 1026nm. The following data demonstrates the correlation coefficients and standard error of estimates between D2O and NIR, SKF, and US.

	Infrared	Skinfolds	Ultrasound
Males	.84(SEE 3.3%)	.86(SEE 3.1%)	.83(SEE 5.3%)
Females	.95(SEE 2.6%)	.86(SEE 4.5%)	.81(SEE 5.3%)
Combined	.94(SEE 3.0%)	.89(SEE 4.0%)	.84(SEE 4.76%)

NIR was also validated on a subgroup of 17 subjects and produced a correlation coefficient of .91 with D_2O. When comparing the coefficients of each method, the skinfold and ultrasound methods seem to produce more consistent results when comparing males and females. However the NIR method produced a larger discrepancy when comparing the results of males and females and this seems to question the validity of this method. Conway et, al. (1984) concluded that although the NIR method slightly overestimated percent body fat in these subjects, the results suggest that the NIR method can be used for body composition assessment in individuals and groups.

Conway & Norris (1987) conducted two studies to determine the validity of NIR for measuring percent body fat in humans. The first study consisted of 53 men and women between the ages of 23 and 65 years and ranging in percent body fat from 12 to 50%. Body fat measured by NIR was compared to body fat measured by skinfold thickness and by D_2O. NIR was measured at 916nm/1026nm on the biceps, triceps, subscapula, suprailiac, and mid thigh. The correlation coefficient between NIR and D_20 was .94 SEE 3.0%, and with skinfolds .86 SEE 4.4%.

In the second study NIR was compared to D_20, skinfolds, and UWW in 68 men and women between the ages of 20 & 65 years and ranging in percent

body fat from 4.5 to 40.0%. NIR was measured at each previous site at wavelenghts of 870/945nm. Correlation coefficients were determined for biceps, triceps, biceps & triceps, and for the average of all five. NIR measured at the biceps produced the highest correlations with D_2O .90 SEE 3.2%, UWW .89 SEE 3.8%, and skinfolds .82 SEE 3.9%. Also a comparison was made between the spectra generated from the computerized spectrophotmeter and a spectra generated from a computer simulated wide slit instrument which was somewhat similar to the Futrex 5000. NIR was measured at 930/950nm and 965/950nm. This was placed into a regression equation with weight alone, weight + gender, and weight + gender + height. The correlation coefficient between the spectra data 930/950nm and 965/950nm and D_20 was .72 SEE 5.2%. When weight was added to the equation the correlation increased to .82 SEE 5.2%, weight and gender increased the correlation to .88 SEE 4.5%, and weight, gender, and height increased the correlation to .90 SEE 4.4%. Conway & Norris conclude that the biceps site was the single best site of measurement. However reasons for this is not known, but maybe due to the combination of skin thickness and subcutaneous fat thickness which seems to be sufficient for allowing the penetration of electromagnetic radiation. Also the results found between the computerized spectrophotometer and the wide slit simulation provides some promise for future refinement of a portable system, which could be used in a field setting. However further validation is needed before this method can be applied for the assessment of body composition.

Davis et, al. (1988) studied the reliability and validity of NIR against measures of hydrostatic weighing, skinfolds (Jackson & Pollock), and circumference techniques. Percent body fat was measured on 85 subjects differing in age, gender, body fat, and skin color. The test re-test correlation over several days measured on 10 subjects was .94. The correlation coefficient between NIR and hydrostatic weighing was .83 and increased to .92 with additional input measures, which are not stated in the abstract. Davis et, al. concluded that NIR could evaluate body composition with excellent reliability and somewhat good validity.

Elia et, al. (1990) compared NIR to predict body composition to densitometry (Siri), skinfolds (Durnin & Wormersley 1974), BIA (Valhalla & Holtain), BMI (Black et, al. 1983), and weight & height (Hume & Weyers 1971). Percent body fat and FFM were estimated in a group of 29 healthy volunteers, 15 males, 14 females, aged 18-40 years with a body mass index (BMI) ranging from 18.3 to 28.5 kg/m2. NIR was measured at the biceps, triceps, and thigh using the wavelengths 940 and 950nm. All methods were significantly different from densitometry. The correlation between FFM measured by densitometry and other methods tended to better in men than women. However correlation for percent body fat tended to be better in women than men. The correlation coefficients and standard error of estimates between percent body fat determined by UWW and near infrared (NIR), skinfolds (SKF), bioelectrical impedance (Valhalla & Holtain) body mass index (BMI) and height and weight (H&W) are as follows.

	Males	Females	Combined
NIR	.80(SEE 3.1%)	.82(SEE 4.33%)	.85(SEE 3.88%)
SKF	.71(SEE 3.66%)	.94(SEE 2.54%)	.88(SEE 3.44%)
Valhalla	.84(SEE 3.44%)	.89(SEE 3.04%)	.89(SEE 3.27%)
Holtain	.83(SEE 2.89%)	.86(SEE 3.87%)	.89(SEE 3.27%)
BMI	.71(SEE 3.66%)	.94(SEE 2.64%)	.88(SEE 3.41%)
H&W	.74(SEE 3.49%)	.90(SEE 3.32%)	.88(SEE 3.48%)

When comparing the correlation coefficients of each method the skinfold equation of Durnin and Wormersley (1974) and the body mass index equation of Black et, al. (1983) produced the highest correlation of .94 for females. For males the highest correlation were produced by BIA equations of Valhalla and Holtain. The prediction of FFM ranged from .96 for NIR, BMI, and height-weight to .97 for skinfolds and the two BIA equations.

The NIR technique tended to underestimate body fat as the percentage of body fat increased especially in obese individuals. This was demonstrated in 5 obese subjects with a BMI greater than 50 kg/m2. Body fat was estimated using UWW and k-40 and was compared to body fat estimated by NIR. The UWW and K-40 techniques produced results very similar 57.3% UWW and 56.4% K-40. However the NIR method estimated percent body fat much lower at 41.2% body fat. Elia et, al. concluded that the prediction of body composition by the NIR method had no advantage over the other predictors. Also that height and weight alone were found to predict body composition as well as the NIR method. Finally skinfold thickness were generally better predictors of body composition that NIR and other techniques.

In 1992 several studies were conducted to determine the validity of the NIR method. Hortobagyi et, al. (1992) compared the validity of the NIR

method to predict percent body fat compared to UWW and the 7-site skinfold equation of Jackson & Pollock (1978) in 171 men. NIR was measured at the biceps, triceps, mid-axillary, chest, abdomen, supra-iliac, subscapula, and thigh. NIR measured at the biceps region produced the highest correlation - .68 with skinfolds and a test-retest reliability of .966. The NIR method significantly underestimated percent body fat at the biceps 12.9%, chest 11.3%, abdomen 10.2%, subscapula 11.3%, and thigh 9.9% when compared to UWW 13.4%. The seven site skinfold equation predicted body fat at 13.7% which was only .3% higher than UWW. The skinfold equation produced the highest correlation coefficient of .94 with UWW. Hortobagyi et, al. (1992) concluded that NIR significantly underestimated percent body fat at five of the eight sites including the biceps, which is recommended by the manufacturer. When comparing NIR to UWW the prediction error could reach 4% body fat. NIR did not account for significant variance in percent body fat beyond what is accounted for by mass, stature, and activity. Also the optical density readings did not increase the prediction accuracy and that skinfolds are much better predictors of percent body fat.

Mclean and Skinner (1992) determined the validity of the Futrex 5000 in 30 males and 31 females. Percent body fat measured by NIR and skinfolds (Y's Way) to the criterion method UWW. NIR was measured at the biceps along with six other sites for men and five other sites for women. The correlation coefficients were much higher for skinfolds than NIR (.95 vs .80) for males, (.88 vs .63) for females, and (.94 vs .81) for males females

combined. When comparing the percentage of subjects that were within 4% of UWW, only 52% of the subjects fell within 4% using NIR compared to 87% using the skinfold equation. The Futrex 5000 tended to overestimate percent body fat in lean subjects under 8% body fat, and underestimate percent body fat in subjects over 30% body fat. Also measuring NIR at additional sites did not improve the prediction accuracy. Mclean & Skinner concluded that skinfolds give more information and more accurately predict percent body fat especially at the extremes of the body fat continuum than the Futrex 5000.

Heyward et, al. (1992) developed a multi-site NIR model I equation that used the sum of two optical densities, age, body weight, height, and physical activity level. This was compared the predictive accuracy of the manufactures equation measured at the biceps at 940nm & 950nm, weight, height, gender, and physical activity level (Model IIA). A third equation was developed based on the manufactures equation plus age (Model IIB). The Futrex 5000 was used to measure body composition in 148 women between the ages of 20 and 72 years. This was compared to body density measured by hydrostatic weighing. NIR was measured at 10 sites and only two the pectoral and biceps were found to significantly contribute to the variance in body density. The multi-site model I equation using the sum of OD at the pectoral and OD at the biceps explained 85.7% of the total variance in body density with a SEE of 3.3%. The model IIA explained 76.3% of the total variance with a SEE of 4.1%. However when age was added in model IIB, explained variability increased to 86% with a SEE of 3.1%. The correlation

coefficients were .926, .873, and .927 for model I, IIA, and IIB. Also the manufacturers equation significantly underestimated percent body fat by an average of 3% compared to UWW. Heyward et, al. concluded that the equation supplied by the manufacturer should not be used to estimate percent body fat in women who vary in age and body fatness. Either the model I or IIB is recommended to estimate body composition.

Nielson et, al. (1992) studied the reliability and validity of the Futrex 5000 to estimate percent body fat & FFM in 34 Caucasian males aged 28 to 53 years. The test-retest reliability for within day measurements were < 0.5% and < 0.5 kg FFM. The intraclass correlation for between day measurements were high ranging from .90 to .98. The correlation coefficients for percent body fat and FFM estimated by NIR compared to underwater weighing (UWW) were .83 SEE 4.2% and .86 SEE 3.77kg. When comparing means for percent body fat and FFM no significance was found between NIR and UWW. Nielson et, al. concluded that the NIR method produced excellent reliability for within day and between day trials. The non-significant mean differences and fairly high correlation coefficients suggest good measurement agreement. The results from this study provide promise for the NIR method for the measurement of body composition.

In 1992 Quatrochi et, al. studied the relationship between optical density measurements by the Futrex 5000 and skinfold measurements and the effects of age and levels of body fatness. Optical density and skinfold measurements were taken at the chest, midaxillary, triceps, biceps, ilium,

abdomen, subscapula, thigh, and mid calf on 153 healthy women between the ages of 20 and 72 years. The between day test retest reliability coefficients for skinfolds ranged from .94 to .99 with a significant difference found for the chest skinfold $F(1,28)=5.66, p<(.05)$. The reliability coefficients for optical density measurements ranged from .76 to .99 with a significant difference found for the suprailiac $F(1,28) = 5.73$, $p< (.05)$. The correlation between skinfolds and optical density readings were significantly positive at all sites except the thigh $p < (.05)$. The regression analysis of the sum of optical densities and skinfolds indicated a significant positive relationship for the chest and biceps sites, which accounted for 37.0% and 43.6% of the variance in optical density. The age factor accounted for an additional 8.2% and 3.7% for the chest and biceps. There was also a significant interaction for (skinfolds x age) which accounted for an additional 2.5% for the chest optical density and 6.6% for the biceps optical density. Percent body fat was significantly related to the sum of the chest and biceps optical density. The slope comparisons between younger and older women were significantly different from zero and each other. When comparing leaner and fatter women the skinfold x percent body fat interaction indicated that the relationship between skinfolds and the sum of optical density measurements at the chest and biceps differed significantly from zero and were larger for leaner women compared to obese women. Quatrochi et, al. concluded that the relationship between skinfolds and the sum of optical density measurements were better for younger and leaner women than older and

fatter women. This suggests that the age factor should be included in the NIR equation.The studies reviewed thus far have determined the reliability and validity of the Futrex 5000 to estimate body composition in the adult population. The following studies validated the Futrex 5000-A, which was developed to measure body composition in children and adolescents. Tavantzis et, al. (1992) studied the validity of the NIR method to determine body composition in 22 male and 14 female adolescents ranging in age from 14 to 16 years. Percent body fat determined by the Futrex 5000-A was validated against UWW using Siri's and Lohman's equations and the skinfold equations of Durnin & Rahaman (1967). The correlation coefficients between NIR and the skinfold equation of Durnin & Ramaham were (.93) for males, (.90) for females and (.95) for males and females combined. Significant correlation was found between NIR and UWW using both the Siri and Lohman equations (.85) and (.83) for males. However non-significant correlation was found for females (.32) for both equations. Klimis-Tavantzis et, al. concluded that the Futrex 5000-A could be applied in clinical and epidemiological settings. The results from this study show that NIR method assessed percent body fat in adolescent males significantly better than females. This inconsistency between males and females questions the validity of this method and should be used with caution until further refinement can be made.

In 1993 two studies were conducted using the Futrex 5000-A to estimate body composition in children and adolescents. Clark et, al. (1993) compared

the accuracy of various methods for assessing body fat and minimal weight in high school wrestlers. Measures of hydrostatic weighing, dual energy x-ray absorptiometry, bioelectrical impedance, near-infrared photospectomitry, and the skinfold equation of Lohman were taken on 95 Caucasian male wrestlers. Minimal weight predictions were evaluated by each method and compared to minimal weight estimated by hydrostatic weighing. The criteria used to evaluate the validity of each method when compared to hydrostitic weighing was the mean difference (MD), standard deviation difference (SDD), Pearson's correlation coefficient (r), standard error of estimate (SEE), and total error (TE). When comparing (MD) the Lohman skinfold equation had the smallest (MD) at 0.6 kg and the largest were found in NIR at 4.9 kg. The SEE ranged from 2.12 kg for skinfolds to 3.45 kg for NIR. The correlation coefficients ranged from .972 for skinfolds to .924 for NIR when predicting minimal weight. The correlation coefficients for predicting percent fat however where much lower ranging from .557 for NIR to .791 using skinfolds. Total error ranged from 2.25 kg using skinfolds to 6.03 kg using the NIR method. The results from this study indicate that skinfolds was the most valid method when predicting minimal weight in highschool wrestler's. Based on each validation criteria the skinfold equation of Lohman produced the highest correlation with hydrostatic weighing and the lowest standard error of estimate and total error. The NIR method produced the opposite results compared to skinfolds and was determined as an unacceptable method when predicting minimal weight in high school wrestlers.In the same

year Cassady et, al. (1993) studied the validity of the NIR method for determining body composition in children and adolescents. Forty-eight subjects 24 males and 24 females with an average age of 12.7 years underwent measurements of hydrostatic weighing, skinfolds, and near infrared. The prediction of percent body fat from hydrostatic weighing was done using the age adjusted Siri equation developed by Lohman. The skinfold equation of Slaughter based on the triceps and calf skinfold sites was used to predict fat free mass. The validity of each method was determined based on the mean differences (MD), Pearson's correlation (r), standard error of estimate (SEE), and total error (TE) when compared to hydrostatic weighing. The following data demonstrates the results found in this study.

Method	MD	r	SEE	TE
Males(NIR)	4.1%	.71	5.5%	8.0%
Males(SKF)	0.1%	.87	3.9%	3.7%
Females(NIR)	2.5%	.62	4.9%	5.5%
Females(SKF)	1.6%	.83	3.5%	3.7%

The results found the skinfold method to be the most acceptable method when predicting percent body fat in children of this age range. The NIR method over predicted percent body fat in lean children and a larger overprediction was noticed as the children became more obese. The relatively low correlation and large standard errors and total errors when compared to hydrostatic weighing again question the validity of the NIR method. Until results become more consistent and are comparable to

criterion methods the NIR method does not possess the validity necessary when measuring body composition.

In recent years the major research in the area of body composition has been to develop a method that is user friendly, fast, noninvasive, and requires less tester training. The Futrex 5000 near infrared device is one device that has been developed in regards to the previously mentioned criteria. However, before this method can be accepted in the area of body composition it must possess the reliability and validity necessary to allow for this acceptance. The previously reviewed literature addresses both the reliability and validity of the NIR method. In all cases the Futrex 5000 was found to produce good to excellent reliability with intraclass correlation as high a .99. However the validity of the NIR method has produced mixed reviews with most studies questioning the validity. The early studies by Conway and Norris using sophisticated equipment found in a laboratory have produced the most valid results. The development of the hand held Futrex 5000 greatly increased the error associated with this method and has led investigators too caution the use of this method for determining body composition. Until prediction equations and the measurement accuracy greatly improve the infrared method is an unacceptable method for measuring body composition.

Skinfolds

The largest fat deposit found in the human body is located subcutaneously. The underlying principle of skinfolds is based on the assumption that the amount of fat is related to total body fat. Since the measurement of various skinfolds has been shown to offer a good prediction of total fat, an equation using the sum of several skinfolds can be used to predict total body fat. Although the largest amount of fat is located just under the skin, fat is also found intermuscularly, intramuscularly, and in regions of the abdomen and pelvis. The fat located in these regions can either be classified as essential or storage fat. Essential fat can be found in bone marrow, various organs, muscle, and the central nervous system. Essential fat is necessary for normal physiological functioning and has been estimated to be 4% of the total body weight of reference man (Behnke, 1969). In females essential fat tends to be higher at 12% of total body weight. This is due to fat found in the mammary glands and pelvic region.

Storage fat is the fat in adipose tissue and is located subcutaneously, intermuscularly (between), intramuscularly (within), with smaller percentages found in the abdomen and thoracic cavities. Behnke (1969) predicted the percentage of storage fat found in these regions to be 30.1% subcutaneously, 32.0% intermuscularly, 8.0% intramuscularly, and 10.0% found in the abdomen and thoracic cavities for reference man and 33.3%, 22.9%, 3.9%, and 7.8% for reference woman. Other predictions of various fat depots located in the human body included subcutaneous fat to be 33% of

total body weight (Allen et, al. 1956), intramuscular fat to be 10% of storage fat (Johnson et, al. 1972), intermuscular fat to be 3.3 kg for reference man and 3.5 kg for reference woman, and the fat content of the abdomen and thoracic cavities to be 12% of storage fat (Alexander, 1964).

Skinfold thickness is double layers of skin plus the underlying subcutatenous fat. The assessment of subcutaneous fat is measured using constant pressure calipers that measure the thickness of the fold in millimeters. The use of skinfold calipers and the measurement of skinfold fat date back to the late 1800s. The importance of measuring skinfold fat was first realized by Richer (1890) who used specialized calipers to measure skinfold fat and found the thickness of skin to be relatively constant between individuals. Several early studies dating back to the early 1900s using skinfolds were conducted on adults and children. A detailed description can be found in the article by Brozek and Keys (1950). The first formulae developed using skinfold measurements to determine total body fat was proposed by Matiegka in 1921. The formula was based on the average of six skinfolds and the surface area of the body.

During the 1950s several caliper prototypes were designed to measure skinfold fat (Brozek, 1961). The ideal caliper was one that had pressure built into the instrument, offered constant pressure from reading to reading and throughout the range of jaw openings. Most of the early models relied on the investigator to apply the proper pressure on the branches of the caliper when measuring the skinfold. A second type of caliper utilized a spring, which was

built into the caliper. The spring was designed to apply a constant pressure to the skinfold when the investigator released the jaws. The problem with the early spring tension calipers was the inconsistency of the spring tension. The spring tension was very low at small openings and increased in proportion to the increase in jaw opening (Keys & Brozek 1953).

It was not until the caliper developed by K.O. Lange did the specifications and spring tension meet standard requirements. The Lange caliper exerted a constant pressure of 10 g/mm^2 throughout the entire range of openings. The size of the contact surface of the jaws is recommended to be between 20 and 40 mm (Brozek, 1961). Presently the calipers that meet the previously mentioned standards and are approved by the Food and Nutrition Board of the National Research Council of the United States are the Lange and Harpenden skinfold calipers. Today there are several commercial brands of skinfold calipers on the market. Some are inexpensive plastic calipers that do not possess the rugged durability and tension. One model that shows some promise is the Skyndex caliper. The major advantages of the Skyndex caliper is the digital readout, hold buttons and some can be programmed to read skinfold thickness and calculate fat weight (Garn, 1991).

Besides the standardization of the caliper itself, other features had to be standardized to guarantee comparability of skinfold measurements from one investigator to another (Brozek, 1961). One important feature that had to be standardized was the technique used to properly pick up the skinfold prior to measurement. One method uses the index finger and thumb to elevate a

double fold of skin and subcutaneous fat 1cm proximal to where the skinfold is to be measured. A firm grip, not exceeding the pain threshold, at least reduces the variations in the skinfold thickness that otherwise might be present with large differences in the pulling force of the fingers (Brozek, 1961). A second technique uses all four fingers and thumb to elevate the fold. This technique allows for a firmer grip and better definition of the fold. In the third technique, an assistant uses both hands to elevate the skinfold. This technique is recommended for obese subjects due to the difficulty in elevating a skinfold with parallel sides.

Another feature that had to be standardized was the depth at which the calipers were applied to the fold. The skinfold in contrast to the two sides are not precisely parallel from top to bottom. Applying the calipers too deep on the skinfold result in larger values with the opposite occurring when the calipers are applied at the top of the skinfold. Brozek (1961) states that "the correct distance at which the calipers should be placed is defined as the minimal distance from the crest at which a true fold, with surfaces approximately parallel to each other and to the contact surface of the skin". The calipers are applied when the skinfold resembles parallel midway between the base of the site and the crest (Lohman et, al. 1988).

It has been estimated that the percentage of subcutaneous fat ranges from 20% to 70% of the total body fat found in the human body (Lohman, 1981). The distribution of subcutaneous fat is dependent on such biological factors as age, gender, and genetic differences associated with individuals.

Several studies have looked at these variables and how it effects the distribution of fat in animals and humans. The distribution of fat seems to change as the body ages. Brozek & Keys (1953) demonstrated this by comparing the average fat content of men for standard weight. Percent fat was determined for men aged 20 to 55 years for every five-year increment. The corresponding percent fat estimates were 10.3, 13.4, 16.2, 18.6, 20.7, 22.5, 23.9, and 25 percent. As a person ages fat accumulation seems more apparent in the thoracic and abdomen regions, with those sites initially thicker, gaining the most fat, while thinner sites gain less fat (Garn & Harper 1955; Garn, 1960). A study conducted by Garn & Harper (1955) found the iliac skinfold to have the largest age associated increase in thickness. Pollock et al. (1975) & (1976) studied the fat distribution in young versus older men and women. The results found women to have thicker skinfolds than men and were generally fatter in terms of relative and absolute fat. When looking at the age factor, older men and women had less subcutaneous fat than the younger subjects in proportion to total fat mass.

Several early studies compared the effect gender had on fat distribution. Edwards (1950) found females to have 1.75 times thicker skinfolds than males, however the pattern of fat distribution was similar in both sexes. Garn (1957) found women to carry more fat subcutaneously than men. Durnin & Wormersley (1974) found more fat externally on men than women. Based on cadaver dissections by Alexander (1964) on 11 men and 9 women, the internal fat contents of the abdomen and thoracic regions were 2.2 kg in men

and 1.8 kg in women. In light of all the studies comparing men and women and older versus younger subjects, it appears that women carry less fat subcutaneously than men and older subjects of the same gender carry less fat subcutaneouly than younger subjects when compared to total body fat (Lohman, 1981).

Genetic differences among individuals also play a role on the distribution of fat over the body. Garn 1955 found substantial differences in fat thickness of the arm, abdomen, and leg in adult men. Garn also studied the effect weight loss had on fat patterning after a period of food restriction. After considerable weight loss the relative fat patterning did not change. However with increases in body fat the pattern of fat distribution had slight changes. Brozek (1956) stated that "individuals vary both in the absolute thickness of the subcutaneous fat at a given site and in its distribution over the body surface."

To measure the fat distribution of the body, the selection of specified sites had to be determined before accurate measurement could be achieved. The determination of skinfold sites was dependent on accessibility, precision in site location, reproducibility, relative homogeneity of the double fold of skin and the underlying subcutaneous fat, and the validity they represent in the relation to total body fat (Brozek & Keys, 1951). Edwards (1950) studied the distribution of subcutaneous fat and the affect the previous criteria had on repeatability. Edwards selected 53 sites over the body and found these sites to produce good repeatability. Brozek and Keys (1951) attempted the first

study correlating specific skinfold sites to a criterion method. Brozek and Keys found the chest skinfold to have highest correlation in young men -.857 and in older men -.633 when compared to body's specific gravity. Brozek (1956) when evaluating all criteria for the selection of skinfold sites found the dorsal skinfold or triceps skinfold to have unlimited accessibility in both men and women. However the precise location of the site was vital, do to the large changes in fat thickness found between the shoulder and the elbow. Brozek also found the subscapular skinfold to meet the previously mentioned criteria. The major benefit was that the site was very uniform in contrast to its double fold of skin and subcutaneous fat. Also the demand for precise location was not as vital when compared to the triceps skinfold. Pett & Ogilvie (1956) found the triceps skinfold to be the best single measurement based on a survey of 22,000 subjects. Pascale et al. 1956 found the site at the mid-axillary line at the level of the xiphoid process to show the highest correlation (.82) compared to body density. Lee (1965) based on postmortem observations found the subscapular skinfold to produce higher readings compared to the actual fat present at the site. Lee concluded that the skin was thicker in this region and the subcutaneous fat somewhat denser compared to other sites. Lee suggested that trunk fat measured by the suprailiac skinfold would be more representative of subcutaneous fat compared to the subscapular skinfold. However, this site was less accessible than the subscapular skinfold and the location of the site was more tedious. The triceps skinfold demonstrated a high correlation between

skinfold thickness and actual fat making this site a better index of total fat. Lohman (1982) found the abdomen, triceps, thigh and subscapular skinfolds to offer good reliability and representative of the whole body. Roche et al. (1985) studied 13 sites for their reliability of measurement and correlation as a body fat index. The study indicates five sites as being correlated with body composition (subscapular, abdomen, triceps, chest and thigh) of which four are reliable (subscapular, abdomen, triceps, and thigh). When selecting skinfold sites the goal is to select a minimum number of sites representative of relative adiposity, highly correlated with total body fat and producing low correlation with each other (Brozek & Keys 1951; Brozek & Keys, 1953).

When measuring body fat, regardless of the procedure, some error does occur. The error involved in the estimation of percent fat from the use of skinfold equations varies between 3% and 4% body fat (Lohman, 1982). This is due to the assumption that anthropometric variables are related to body composition and the error associated with criterion methods such as body density, total body water and body potassium (Lohman, 1981).

The error involved in the estimation of body fat from skinfold measurements can be categorized as either biological or technical. Biological error consists of the estimate of variation in subcutaneous fat weight to total fat weight for specific populations, the individual variation in the distribution of subcutaneous fat in relation to total subcutaneous fat and the difference in compressibility in relation to site, gender, age and fatness. Alexander (1964) found the variation in subcutaneous fat to total body fat

weight for men to be 2.1% and 2.6% for women. The individual variation in the distribution of subcutaneous fat is apparent and must be taken into consideration (Garn, 1955).

Several studies have been conducted comparing skinfold thickness to total subcutaneous fat determined by soft tissue roentgenogrammetric values (Hammond 1955; Garn 1956; Garn & Gorman, 1956). Early studies showed promise with correlation ranging between .80 and .90 between caliper measurements and soft tissue roentgenograms. Brozek & Mori (1958) in a study on middle aged men found a correlation of .82 between caliper measurements and roentgenograms made at the dorsum of the upper arm. Garn (1956) found subcutaneous caliper measurements to equal 65% of the values found by roentgenographic measurements made at the level of the lowest rib on the midaxillary line in young men.

One last area that can contribute to the total error involved in the prediction of body fat by the use of skinfolds is compressibility. Variations in skinofold compressibility seem to vary in regards to site location, gender, and differences in age and degree of fatness. Brozek & Kinzey (1960) found differences in compressibility between young and middle age men. In their study they found 35% compression in young and 16% compression in middle aged individuals and concluded that there was a decrease in compressibility with age. Himes et al. (1979) found individual differences in skinfold compressibility among male youth. Martin et al. (1985) found compressibility to pose major problems, since it is both large and unpredictable. Although

variations in compressibility seem apparent, it does not seem to be an important source of variation (Lohman, 1981).

The second source of error that occurs when measuring body fat from skinfold measurements is technical error. Technical error is the variation that occurs from measurement errors in obtaining skinfold thickness (Johnson et, al. 1972). Technical error can be categorized as either intra-examiner or inter-examiner error. Intra-examiner error is the failure of one examiner to produce the same measurements on repeated tests. Intra-examiner error varies depending on skinfold site, technician experience, and degree of fatness and the method used to determine reliability (Lohman, 1981). Intra-examiner errors found for the triceps skinfold were small ranging from .5 mm to .84 mm (Wilmore & Behnke 1969; Johnson et, al. 1972; Wormersley & Durnin 1973).

The second source of technical error involved in skinfold measurements is inter-examiner error. Inter-examiner error is the failure of two or more investigators to produce the same results when comparing several measurements on many subjects. Somewhat larger errors exist from inter-examiner measurements compared to intra-examiner measurements. Johnson et al. (1972) when comparing standard deviation differences found differences of 1.47 mm for the midaxillary skinfold to 1.89 mm for the triceps skinfold. Keys & Brozek (1953) based on the same statistical method found differences of 1.42 mm for the triceps to 1.9 mm for the chest. Sloan & Shapiro (1972) based on standard error of estimates found differences of .88

mm for the scapula skinfold to 1.21 mm for the triceps skinfold. Jackson et al. (1978) studied the inter-tester reliability of various skinfold, circumference and percent fat estimates. Three different testers measured skinfolds and circumferences on 35 adult men. The results demonstrated small mean differences of .3 mm between any two testers. All investigators reliability estimates were high .93 when skinfold measurements were added to estimate percent fat. The largest inter-tester difference was .3% body fat. All inter-tester reliability coefficients exceeded .97 and the standard errors of estimate averaged 1%. Jackson et al. concluded that the inter-tester variation was a small source of measurement error and that the major variation was due to subject variation.

One last factor that adds to the technical error of skinfold measurements is tester training. Wormersley & Durnin (1973) compared the mean differences between one experienced and two inexperienced testers. The inexperienced tester produced measurements of 3 mm and larger depending on site location and gender. Jackson et al. (1979) found significant differences between two experienced and one inexperienced tester. The two experienced differed by only .2% body fat with standards errors of estimates of just over 1% body fat.

Lohman (1981) predicted the total error, biological plus technical of skinfold measurements to be 3.3% for a specific population. 2.5% of the error is due to the variation in subcutaneous fat to total subcutaneous fat,

1.8% is due to the variation in skinfold thickness of various sites and it's representation of total subcutaneous fat and .5% due to measurement error.

When utilizing the use of skinfold measurements for the assessment of percent body fat, three factors must be considered before valid application can be made to any individual. First, the prediction equations derived from one population can not be applied to other populations. For example, prediction equations developed to predict body fat on young adult males could not be applied to young adult females. When applying one equation derived from one population and applying it to another population an overestimation or underestimation of fat free body or percent body fat will occur. Secondly, the measurement procedures should be carefully standardized and carried out using the same techniques used by the original investigators. Thirdly, prediction equations developed using a criterion method based on the two-compartment model can not be applied to children, the elderly and maybe athletic populations where the density of the fat free body mass varies from the constants established for young adults. Specific equations are greatly needed for children and elderly populations based on equations derived from the four compartment model with measurements of fat, muscle, total body water and bone density.

Underwater Weighing

Many methods have been developed to measure body composition. These methods can be considered either laboratory methods or field

methods. Of the 3 laboratory methods, underwater weighing, total body water and total body potassium, underwater weighing has been considered the "Gold Standard" against which other methods are validated. The underwater weighing method measures the density of fat and fat-free body and is converted to percent body fat through the use of prediction equations.

The determination of body composition by underwater weighing dates back to the year 248 BC and the discovery of Archimedes. Archimedes while bathing discovered that a substance will lose weight underwater equal to the weight of the water displaced (Spivak, 1915). In relation to underwater weighing, an individual placed in water, will displace a volume of water equal to it's own. This total body volume is equal to the amount of weight lost underwater (Behnke et. al, 1942).

The calculation of density can be made from the ratio of mass (gm) to volume (cc):

(Equation 1) $$\textbf{Density} = \frac{\textbf{Mass}}{\textbf{Volume}}$$

Mass is the weight of the subject in air. The volume of the body is determined from the amount of water displaced. The weight of the water displaced is achieved by subtracting the mass of the subject in air by the mass of the subject in water (Wa – Ww).

The weight of the displaced water or loss of weight underwater will equal the volume of displaced water only when the density of water is one. Since the density of water at the time of underwater weighing rarely equals one the

measurement of the density of water is needed. To achieve the volume according to the mass of the water displaced by the body, and taking into account the density of water the volume of the body will be:

(Equation 2)

$$V = \frac{(Wa - Ww)}{Dw}$$

When measuring the density of the human body based on equation 1, applying Archimedes principle and the underwater weighing method the following equation is produced (Keys & Brozek 1953; von Dobeln, 1956; Goldman & Buskirk 1961; Behnke 1961; Behnke & Wilmore, 1974).

(Equation 3)

$$D = \frac{Wa}{\frac{(Wa - Ww)}{Dw}}$$

Where: Wa = Weight in air

Ww = Weight in water

Dw = Density of water

When measuring the density of the body two other volumes must be accounted for before true density can be achieved (Brozek & Keys, 1951; Keys & Brozek, 1953; Siri, 1956a; Siri, 1956b; Buskirk, 1961; Behnke & Wilmore, 1974). One volume is the amount of air left in the lungs following maximal expiration and the second is the air trapped in the gastrointestinal tract. These volumes when unaccounted for provide buoyancy to the body. This causes the body to be lighter underwater leading to inaccurate density

readings. When corrections are made for residual volume (RV) and gastrointestinal volume (VGI) the final formulae for body density is:

(Equation 4)

$$\textbf{Density} = \frac{Wa}{\frac{(Wa - Ww)}{Dw} - (RV - VGI)}$$

Where: RV = Residual Volume

VGI = Air in gastrointestinal tract

The significance and measurement of residual and gastrointestinal volumes will be covered later in this section. However, the measurement of residual air at the time of underwater weighing is vital for the accurate determination of body density.

Although specific gravity and density produce similar results they are different. Throughout the literature specific gravity and density are used interchangeably when in fact they are different. Both estimates are derived from Archimedes principle, and can be calculated by underwater weighing. Density is the ratio of mass to volume (Keys & Brozek, 1953). The measurement of density will not change as the temperature of the water changes. Specific gravity is the ratio of the weight of an object to the weight of an equal volume of water (Spivak, 1915). Specific gravity measures how much denser an object is than water. An individual is either more dense (>1.0) than water or less dense (<1.0) than water. The equation for specific gravity measured by underwater weighing is:

$$\textbf{Specific Gravity} = \frac{Wa}{(Wa - Ww)}$$

The denominator in the specific gravity equation is not equal to the volume of the body unless the density of water is 1.0 gm/cc.

Early studies of body volume utilized the measurement of specific gravity of the human body and date back to the year 1757. John Robertson an English librarian was credited with the first study measuring the specific gravity of the human body (Spivak, 1915). John Robertson designed a cistern 72 inches long, 30 inches wide and 30 inches deep. A ruler measuring inches was attached to one end of the cistern. After persuasion of 10 subjects, the height and weight was measured on each subject. The height of the water was indicated before each subject entered the water and after complete submersion. Values for specific gravity ranged from 0.800 to 1.002 (Boyd, 1933).

In 1828 John Davey studied the specific gravity of eighty different tissues and organs. He hoped someday that a method would be developed to help measure and monitor organic change (Spivak, 1915).

The density of an object or substance will not change as the temperature of the water changes. However, specific gravity being the ratio of the weight of an object to the weight of an equal volume of water changes in water temperature and density will result in changes in specific gravity. For example, the specific gravity of a 70-kg man will change from 1.0789 at 20°C water temperature to 1.0838 at 36°C. When taking into account the density of water, both specific gravity measurements differ from the true density of 1.077 gm/cc. (Keys & Brozek, 1953).

Spivak (1915) using a volumeter determined specific gravity of four adults and ten boys ranging in age from 8 to 53 years. The specific gravity of the whole body ranged from 0.976 to 1.049 with the average of 1.003 for adults and 1.006 for boys. The average specific gravity of the entire group was 1.005. The emphasis of the study focused on the distribution of fat over and throughout the body with weight gain. Spivak compared specific gravity measurements before and after a ten-pound weight gain. The specific gravity before was 1.006 and after gaining ten pounds was 0.099. Since the specific gravity of fat is less than water the increase in weight had to be an increase in excess fat. Spivak then attempted to locate the gain in fat weight by measuring the specific gravity of body segments. This attempt was difficult due to the fact that the weight of various parts of the body could not be accurately determined.

Spivak compared his results against others preceding him and found Robertson (0.8706), Suetzer (0.970) and Herman (0.920) to be too low and Krause (1.055), Ziegelroth (1.055), Miess (1.012) and Meeh (1.012) to be too high. Spivak defended his results based on greater accuracy of his volumeter.

Boyd (1933) reviewed the measurement of specific gravity of humans up to the year 1933. She reviewed 787 measurements of specific gravity on subjects varying in age from 2 months to 60 years of which 205 were cadavers. Of the methods used 598 were conducted using the water displacement method while the remaining 189 utilized the underwater

weighing method. Boyd (1933) based on the evidence from the data concluded that an increase in fat will tend to decrease specific gravity. Unfortunately, the early measurements reviewed by Boyd were deemed inaccurate because of the lack of standardization and failure to correct for residual and gastrointestinal volumes (Behnke, Feen, Welham, 1942; Brozek & Keys, 1950).

Specific gravity may accurately predict the fat content of the human body provided a correction is made for residual volume at the time of weighing and the proportion of body water, muscle and bone remain relatively constant (Brozek & Keys, 1950).

Over the years several methods and devices have been developed for the measurement of body volume. Early studies utilized a volumometer to measure body volume by water displacement (Spivak, 1915; Boyd, 1933). A cylindrical steel tank containing a certain amount of water measured by an attached burette was used to determine body volume. The subject submerged himself in complete exhalation and the difference in the height of the water before and after submersion was recorded.

Early volumometers used by Spivak and others used a ruler or burette attached to the side of the tank to measure changes in water levels. This made accurate readings more difficult due to the movement of the water upon entering the tank. Garn & Nolan (1963) using a similar system found accuracy readings below the desired levels, with a one-millimeter change in water level resulting in a 263-cc. change in body volume. They overcame

this problem by installing an external measuring device. This allowed for more precise readings, better than ± 92 cc and decreased the time to 30 seconds for each reading. Garn & Nolan (1963) concluded that greater accuracy could be obtained when the volume of the tank approximates the subject volume.

When comparing the volumometer with the underwater weighing method, Von Dobeln (1956) preferred the underwater weighing method. Krzywicki & Chen (1967) found comparable results when between the volumometer and underwater weighing when estimating body density. The volumometer provides favorable results when determining the volumes of segmental body parts however, the underwater weighing method measures volume changes more precisely and provides greater accuracy when measuring body density (Behnke & Wilmore, 1974).

Many devices and procedures have been developed to measure body volume. Early measurements were conducted in large swimming pools. The subject was suspended from a diving board and lowered into the water by adding lead sinkers. Upon complete submersion the underwater weight was recorded. Problems with this method was the large fluctuations in scale readings due to water movement and the relatively cool temperatures of the water making it uncomfortable for the subject.

Eventually underwater weighing tanks were developed and placed in the laboratory. These tanks offered less water movement making scale readings much more precise and offered more control of water temperature.

Underwater weighing systems can be categorized as either suspension or platform systems. Suspension systems lowered subjects into the tank by means of a hoist. The subjects sat in a sling or chair connected to a Chatlin scale suspended from above. One concern that arose with this system was the water movement that occurred by lowering the chair or cot into the tank. The lowering effect can cause scale oscillations, which could exceed the recommended stability of 20 gm. The platform system consists of a stainless steel chair connected to a large Toledo platform scale, an aluminum tank and a system to measure residual volume. The subject sits in the chair leaning forward to fully submerge them into the water. Again care must be taken to avoid water movement and scale oscillations (Goldman & Buskirk, 1961).

Behnke et, al. (1942) was the first valid study measuring body volume by underwater weighing. In their study subjects were suspended below the water from a line attached to a spring scale graduated in ounces. Each subject wore a weight belt to assure negative buoyancy. Two weights were taken in the water to assume the accuracy of the procedure. One weight was taken at the end of maximum expiration and one at the end of maximum inspiration. The difference between weights offered a measure of vital capacity.

Brozek et, al. (1949) using a suspension type apparatus attached a stainless steel chair to a scale. The subject sat in the chair, which was lowered into the water by an electric hoist. Underwater weight was taken after complete expiration.

Von Dobeln (1956) utilized a system that consisted of a water tank and pendulum balance in which a chair was attached by a system of levers. The system had a built in adjustable dampening and tarring device. The pendulum balance had a maximal capacity of 20 kg. The tank had a brim outlet around the top to reduce water movement and to help keep water level constant. The chair was adjustable to keep the water at neck level.

Gnaedinger et, al. (1963) measured underwater weight using the method performed by Behnke et, al. (1942). The underwater weighing device consisted of a chair suspended from a weight sensitive load cell, which was connected, to a strain gauge amplifier and recorder. The subject sat in the chair and was lowered into a swimming pool at a water temperature of 80°F. The subject breathed through a snorkel type device while submerged, and weights were taken during normal breathing and at the end of maximal expiration. Lung volume was determined by the standard value of 1.45 liters.

Katch et, al. (1967) measured underwater weight in the shallow end of a swimming pool. Katch and his colleagues designed a wooden shell that was placed around the subject during weighing. The wooden shell minimized water turbulence and allowed for more stable readings. The subjects lay face down on a metal frame suspended from an autopsy scale with a capacity of 9 kg.

As stated earlier, underwater weighing systems can be categorized as either suspension or platform systems. Suspension systems utilizing autopsy scales have been the most common system used. However, water

movement causing scale oscillations make stable scale readings difficult. This led to systems that utilize load cells or strain gauges attached to a recording device. This made the recording of stable weights much easier.

Fahey & Schroeder (1978) studied the accuracy of the load cell system against the autopsy scale. 30 subjects were weighed on two separate occasions and the average fluctuations of the load cell and autopsy scale were measured. The average fluctuation of the load cell was .05 ± .02 kg and the autopsy scale .18 ± .11 kg. The average difference between the two systems was .27 ± .59 kg with the load cell producing a test-retest correlation of .99. Based on these findings, the load cell demonstrated far better accuracy than the autopsy scale.

Currently most underwater weighing systems consist of a tank, with either a platform scale utilizing load cells or an autopsy scale in which the subject is suspended. The platform with load cells seems to be the more reliable and accurate system. It allows for less water turbulence, more stable readings and less weighing time than the suspension systems.

For any method to become valid, first the method must produce results that are reliable. To determine the reliability of underwater weighing, several measurements must be made on the same subject and the results of these measurements must be compared.

Keys & Brozek (1953) studied repeated measurements of density on 35 young men, one week apart. The caloric balance of the men was maintained so changes in body composition did not occur. The standard deviation

between the two measurements was 0.0015 gm/cm^3. In a separate study using male schizophrenic patients, Key & Brozek (1953) found a standard deviation of 0.0026 gm/cc^3 between two measurements taken one week apart.

Durnin & Taylor (1960) determined body density on 10 men maintaining caloric balance for two weeks. The standard error between one replicated measurement was 0.0023 density units. The standard error found in 90% of all replicable measurements was 0.004 gm/cc.

Goldman & Buskirk (1961) studied replicate measurements on 16 subjects who were underwater weighed five times during the course of a day. A one-factor component of variance was used to determine overall error associated with multiple measurements. Goldman & Buskirk (1961) found an overall error of 0.0043 gm/cc density units.

Buskirk (1961) compared the standard deviation of replicate measurements of several investigators. Three hundred sixty one measurements were compared with some investigators finding much smaller errors than others. The standard deviation of replicate measurements of density range from 0.004 gm/cc to 0.0043 gm/cc. Most values fall below or equal the value of 0.0025 gm/cc found by Siri (1956). This value was considered as an acceptable error in terms of usefulness in the calculation of body composition and especially fat content.

The reliability of underwater weighing is dependent on the accuracy of equipment, standardization of procedures, subject training and personnel expertise.

Since the early 1940s attempts have been made to define the relationship between density or specific gravity and percent fat. In 1942, Behnke and his colleagues conducted the first valid study measuring specific gravity by underwater weighing. The significance of their study was the measurement of residual volume at the time of underwater weighing. Behnke et, al. concluded that low specific gravity values were due to an increase in body fat and that specific gravity can be used to measure obesity.

Behnke et, al. (1942) studied the measurements of specific gravity of 99 naval men ranging in age from 20 to 40 years. Their purpose was to classify individuals as overweight based on fat and fat-free weight. Also to replace the standard height-weight tables that lead to an estimation of overweight in more muscular men. Values for specific gravity ranged from 1.021 to 1.097 with low values reflecting obesity and high values reflecting leanness. Also with a loss of weight experienced through exercise and diet, values for specific gravity increased. Behnke and his colleagues concluded that the value of specific gravity of the whole body was an index of obesity.

In the same year Welham & Behnke (1942) speculated that if fat not body weight was the major factor producing low values for specific gravity, then heavy men comprised of larger muscles would produce high values for specific gravity. Twenty-five professional football players with an average

weight of 200 pounds produced values 1.080 for specific gravity. For a comparison, additional 75 naval men were measured and average specific gravity values of 1.081 and 1.086 were found for body weights of 149 and 157 pounds. The results found in this study support that fat not body weight in the determining factor influencing specific gravity.

In 1945, Rathbun and Pace conducted the first study investigating the relationship between specific gravity and body fat using 50 guinea pigs. Underwater weighing was used to determine specific gravity and petroleum ether was used to measure the absolute fat content of the guinea pigs. The values for specific gravity ranged from 1.021 to 1.096 which correspond with the values found by Behnke et, al. (1942). The calculated percent fat ranged from 1.5 to 35.8%. The correlation coefficient between specific gravity and percent fat was –0.972 with a standard error of 1.87 percent fat. Base on density values of .918 gm/cc for fat and 1.100 gm/cc for lean tissue, the following equation has been developed for humans:

Equation (5) $$\%Fat = 100 \times \left(\frac{5.548}{SG} - 5.044\right)$$

Where: SG = Specific Gravity

The calculation of percent fat from the measurement of body density is based on the assumption that the human body is comprised of two compartments, fat mass and fat-free or lean body mass. The calculation is dependent on the densities of the two compartments being relatively constant among individuals (Keys & Brozek, 1953; Siri, 1956a; 1961b; Lim &

Luft, 1961; Behnke, 1961a; Brozek et, al. 1963; Behnke & Wilmore, 1974; Katch & McArdle, 1977).

Assuming the whole body can be divided into two compartments, the estimation of body fat and fat-free mass can be made from body density. If a system is comprised of two components of different densities, then the proportion of the two components can estimate the density of the whole system. This leads to the following definition (Keys & Brozek, 1953; Behnke & Wilmore, 1974).

Equation (6)
$$D = \frac{A + B}{A/a + B/b}$$

Where: A = Fat-free mass
B = Fat mass
A/a = Fat-free density
B/b = Fat density

When the body consists of two masses A and B with different densities, and the whole body equals one, the proportional contribution of B is as follows:

Equation (7)
$$B = \frac{1}{D} \times \frac{ab}{(a - b)} - \frac{a}{(a - b)}$$

Based on the assumption that a and b are constants, then the previous equation can be simplified to:

Equation (8)
$$BF = \frac{X}{D} - Y$$

Where: X = density of fat mass
Y = density of fat-free mass
D = density of whole body

Based on equation 8 the following prediction equations have been developed, converting body density to percent body fat. All equations are very similar, except that different density values were found for fat and fat-free mass. Rathbun & Pace (1945) developed the following equation assuming the density of fat to be 0.918 gm/cc and fat-free mass to be 1.100 gm/cc.

$$\%BF = \left(\frac{5.548}{SG} - 5.044 \right)$$

Brozek, Grande, Anderson and Keys (1963) estimated the density of fat-free mass to be 1.100 gm/cc and fat mass to be 0.9007 gm/cc at 36°C and derived the following equation.

$$\%BF = \left(\frac{4.57}{D} - 4.142 \right)$$

Another popular equation developed by Siri (1956a) assumes the density of fat to be 0.90 gm/cc and fat-free mass to be 1.100 gm/cc.

$$\%BF = \left(\frac{4.950}{D} - 4.500 \right)$$

Other equations that have not received as much attention are:

Keys & Brozek (1953) based on the density of fat 0.9007 gm/cc and fat-free mass 1.102 gm/cc developed the following equation.

$$\%BF = \left(\frac{4.201}{D} - 3.813 \right)$$

A second equation was developed based on 14% body fat of reference man and the density of fat to be 0.9007 and fat-free mass to be 1.063 gm/cc.

$$\%BF = \left(\frac{5.427}{D} - 5.106\right)$$

Grande (1953) developed an equation based on fat weight representing 17.8% of total body weight, cited in Behnke (1961a).

$$\%BF = \left(\frac{4.0439}{D} - 3.6266\right)$$

Behnke (1959) developed an equation based on a fat density of 0.90 gm/cc and fat-free mass of 1.095 gm/cc, cited in Behnke (1961a).

$$\%BF = \left(\frac{5.053}{D} - 4.614\right)$$

At the time of underwater weighing, the volume of air left in the lungs must be accounted for to obtain valid measurements of body density. Residual volume (RV) is defined as the volume of air left in the lungs after maximum expiration (Lundsgaard & Van Slyke, 1918). Early studies utilized estimates of RV in the estimation of body density. Brozek & Keys (1951; 1953) used a value of 1.5 liters for young men and 2.2 liters for older men. Behnke et, al. (1942) and Gnaedinger (1963) used values of 1.45 liters for RV.

When RV is determined from assumed estimates errors in body volume maybe as large as 500 ml (Brozek & Keys, 1953; Buskirk, 1961). Brozek & Keys (1953) approximated that an error of 500 ml will correspond to an error of ± 4% body fat estimates. When assumed estimates of RV are used the effect of age, gender and posture must be taken into account. RV seems to be smaller in females than males and increases with age in both sexes

(Buskirk, 1961). Brozek & Keys (1953) found values of 1600 ml for mean aged 25 years compared to values of 2200 ml for men aged 50 years. Females produced similar results, increasing from 1250 ml to 1800 ml. Brozek (1960) studied the effect of age on RV and VC. RV values in young men versus older men ranged from 0.97 to 2.45 liters and 1.52 to 3.31 liters. Significantly larger RV values were found in older subjects in both males and females.

Posture also effects values of RV. RV seems to be less in the supine position compared to the sitting position when measured out of water. When RV measurements are compared in and out of the water, smaller values are found while the subject is submerged. When RV measurements are compared in and out of the water smaller values are found while the subject is submerged. When using volumes other than RV results in additional error and the need for correction factors (Welch & Crisp, 1958).

Residual volume as defined by Davy (1800) is the air left in the lungs following maximum expiration (Lundsgaard & Van Slyke, 1918). There are many methods that have been designed over the years to measure RV. The majority of methods can be categorized either as the pneumatometric, closed circuit and open-circuit approaches.

The pneumatometric method is based on Boyle's Law which states that the volume of gas varies in inverse proportion to the pressure to which it is subjected (Christie,1932). In this method the subject is placed in an air tight chamber breathing through a mouthpiece connected to an opening in the

chamber. The subject is then instructed to make an expiratory and inspiratory breath against a resistance. The positive and negative pressure is measured by a mercury manometer and from the relationship of volume change to pressure change the volume of air in the lungs can be determined (Christie, 1932). Many drawbacks are apparent when using the pneumatometric method. One drawback is that the gas in the gastro-intestinal tract is measured along with residual volume. Also the slightest leak around the mouthpiece during forced expiration will result in error and the apparatus is very cumbersome and possess technical difficulties (Christie, 1932).

A second method used to measure RV is the gas dilution with forced breathing or closed circuit method. This method is based on the dilution of a known volume of inert tracer gas such as hydrogen, oxygen, nitrogen or helium. After a forced expiration the subject takes 5 to 7 deep quick breaths from an anesthesia bag or spirometer containing a known volume of gas. Equilibrium between the bag and lungs is reached by the seventh breath and a sample of gas is analyzed to determine the degree of dilution. Based on the degree of dilution RV can be calculated (Lundsgaard & Van Slyke, 1918; Christie, 1932; Wilmore, 1969).

The third method used to measure RV is the Open-circuit or nitrogen washout method. This method is based on the mixing of a known volume of hydrogen with the nitrogen present in the lungs. This mixing is achieved by quiet respirations for 5 to 7 minutes. The volume of air in the lungs is

calculated from the quantity of hydrogen present in the spirometer and the beginning of breathing and the percentage of hydrogen upon completion of mixing.

Early studies measuring residual volume were mainly conducted using the closed-circuit method. One of the first studies measuring residual volume, was conducted by Lundsgaard & Van Slyke in 1918. In their study, a subject was connected to a 4 liter bag containing 2 to 3 liters of pure oxygen. After a maximal expiration the subject took 4 to 5 deep breaths to thoroughly mix the air in the bag with the air left in the lungs. The major problem that arose was the difficulty in achieving a homogeneous mixture of air between the bag and the lungs. Lundsgaard & Van Slyke found RV estimates ranging from .97 to 2.48 liters in eighteen subjects.

Christie (1932) using the oxygen dilution method of Lundsgaard & Van Slyke (1918) performed a series of fifteen estimations of RV on one subject. RV estimates ranged from 2008 to 2363 cc. Christie criticized this method due to inadequate mixing of air between the bag and lungs, inconstancy of the percentage of nitrogen in alveolar air and the absorption and excretion of gases by the blood.

In 1932, Christie developed a closed-circuit system using a spirometer and oxygen. In this method a known volume of oxygen was added to the spirometer. The subject was connected to the spirometer by a mouthpiece and a three-way valve. The subject breathed room air for 2 minutes and then breathed quiet respirations from the spirometer for seven minutes. The air

present in the spirometer at the end of breathing period was then analyzed. The seven minute breathing period is in agreement with other investigators (Campbell & Hill, 1931) as the length of time needed for adequate mixing of gases. Christie subtracted 80 cc. from all functional residual volume estimates to account for the error due to nitrogen excretion.

One problem with the early closed-circuit methods was that an equal mixture of an inert gas could not exist in a system that involved progressively decreasing inspired oxygen. This was due to the "oxygen storage effect" in which the expired nitrogen concentration is less than the inspired nitrogen concentration (Lassen et, al. 1937). This is due because the inspiratory gas mixture is always changing, causing no equilibrium between the spirometer and lungs.

The oxygen storage effect was overcome by the method of Herrald & McMichael (1939). They modified the Christie method by adding a constant flow of oxygen to the spirometer. The estimations of functional residual volume on ten subjects were compared using the Christie (1932) and the modified method. The mean values for the Christie method was 2.92 liters compared to the modified method of 2.79 liters. This kept the percentage of nitrogen in inspired air constant, reducing the error caused by the oxygen storage effect.

McMichael (1939) further modified the method of Herrald & McMichael by adding a fixed volume of hydrogen to the oxygen filled spirometer. The hydrogen acted as a diluent and was added to the spirometer to replace the

hydrogen being absorbed. In twenty-five paired measurement the standard error of a single measurement was .09 liters compared to .183 liters found by Herrald & McMichael (1939).

Darling et al. (1940a) proposed the use of correction factors to account for the excretion of nitrogen from the body. Darling and colleagues made repeated measures of nitrogen excretion under basal and non-basal conditions. The average nitrogen excretion was 195 cc. under basal conditions and 300 cc. under non-basal conditions. The average figure of 195 cc. is in agreement with similar studies (Campbell & Hill, 1937; Behnke et, al. 1935). The same method was used to measure nitrogen excretion in a patient with advanced pulmonary emphysema. The value for the emphysema patient was much higher compared to normal subjects. This was due to the fact that after four deep breaths of oxygen the alveolar nitrogen was over 20% compared to 3 to 8% for normal subjects. The emphysema patient was unable to rapidly wash out the nitrogen from the lungs. Darling et al. concluded that after 7 minutes of pure oxygen breathing the nitrogen excretion ranged from 115 cc. to 235 cc. under basal conditions. However under non-basal conditions the nitrogen excretion was much greater.

Cournand et al. (1940a) evaluated the use of closed-circuit methods for the determination of residual volume. Most of the early work using these methods assumed that at the end of five or more minutes of quiet breathing the gas in the lungs and spirometer was uniform, except for an excess

amount of inert gases in the lungs. Cournand et al. evaluated the original and modified methods for measuring RV in 6 normal subjects and 10 subjects with emphysema. The results by all methods were in agreement in 4 normal subjects, three of them whom had small residual volumes. In the remainder of subjects both normal and with emphysema wide discrepancies occurred by the different methods.

To help alleviate the problems with the closed-circuit method, Darling et al. (1940b) developed an open-circuit method. In the open-circuit approach, the subject is required to wash nitrogen out of the lungs by breathing pure oxygen. This allows the inspiratory gas to be uniform throughout the entire breathing period. During the breathing period all expired gases are collected and then analyzed for nitrogen. The only error that occurred in this method was due to the failure of the alveolar measurements to represent the mean value of residual air nitrogen. Darling et al. concluded that the open-circuit method used for measuring RV offers a better means of avoiding error due to the maldistribution of pulmonary gases.

Both the closed-circuit and open-circuit have been used to determine RV. Both methods are in close agreement producing standard errors of 186 cc. for the open-circuit method and 164 cc. for the closed-circuit method. Both methods have been criticized, however with modifications both have been accepted as valid and reliable. The main limitation of both methods thus far is the time required to complete one measurement.

Wilmore (1969) modified the closed-circuit oxygen dilution method of Lundsgaard & Van Slyke (1918), allowing for a more rapid determination of RV. Wilmore used a 9 liter spirometer instead of a rebreathing bag and a continuous electronic gas analyzer to determine the nitrogen content of inspired and expired air. This was achieved after 5 to 8 breaths. Wilmore compared his method with the open-circuit methods of Darling et al. (1940b) and Cournand et al. (1940b). The measurement of RV by each method on 20 normal subjects produced a intercorrelation of .958 and a mean difference of 26 ml. Using 195 males and 120 females, the Wilmore method produced a test-retest correlation of .993 SEE 26 ml for males and .987 SEE 30 ml for females. This method provided an estimate of RV within 8 to 10 minutes representing a two to sixfold reduction in testing time compared with existing methods.

To further simplify this method Wilmore et al. (1980) utilized standard oxygen and carbon dioxide analyzers to determine the percentage of nitrogen after equilibration and a 5 liter anesthesia bag for rebreathing eliminating the need for a spirometer. They also assumed an initial alveolar nitrogen value of 80%. The subject was connected to a rebreathing bag containing 100% pure oxygen. The subject breathed room air and then was instructed to perform an maximal expiration. After a maximal expiration, the subject took 5 to 7 breaths from the rebreathing bag. The rate and depth of the breaths are critical in achieving equilibrium between the bag and lungs. Following 5 to 7 breaths the subject then exhaled to maximal expiration. The

bag is then analyzed for oxygen and carbon dioxide content. Residual volume is calculated from the following formulae:

$$RV = \frac{VO_2\ (b - a)}{c - d}$$

Where: VO_2 = volume of oxygen in the bag at the beginning of the procedure

a = nitrogen impurity of pure oxygen

b = percent of nitrogen in the bag at equilibrium (100% - (O_2 + CO_2)

c = percent nitrogen in the alveolar air at the beginning of test (assumed to be 80%).

d = percentage of nitrogen in the alveolar air during the last maximal breath. (assumed to be 0.2% N_2 higher than the equilibration percentage, i.e., b + 0.2 N_2)

Simplified:

$$RV = \frac{5.0 \times b}{80.0 - (b + 0.2)} \quad \text{or} \quad \frac{5.0 \times b}{79.8 - b}$$

The modified method differed from the criterion method of Wilmore (1969) in several ways. First, the new method used an inexpensive rebreathing bag compared to an expensive spirometer. Second, the modified method used O_2 and CO_2 analyzers eliminating the need for a special N_2analyzer. Last, the modified method takes less than two minutes per test, or less than five minutes for duplicate tests.

This method was validated against the criterion method of Wilmore (1969). Sixty three subjects, 39 males and 24 females were studied to determine the validity of the new method. The mean difference between test 1 and test 2 was 3 ml compared to the criterion method of 30 ml. The test-retest reliability coefficient was higher for the criterion method (.96) compared to (.81) found by the new method. The intercorrelation between the criterion method and the modified method was .91 indicating a common variance of 82.8%. The modified method estimated RV within ±125 ml in 66.8% of subjects and within ± 175 ml in 84.2% of subjects. Considering that both methods produce similar error in measurement, assuming that nitrogen equilibrium had been established and alveolar nitrogen concentrations were assumed, the agreement between methods was considerably close. The modified method of Wilmore et al. (1980) is a simple and time efficient method that has produced accurate and reproducible results in comparison to previously established methods.

Air in the Gastrointestinal Tract

One last volume that needs to be considered is the amount of air in the gastrointestinal tract (GIA). GIA has the same effect on body density measurements as RV, however the magnitude is not as great (Keys & Brozek, 1953). The problem with determining the volume of air in the GIA is the difficulty of measurement. Many early attempts were made on GIA

volumes but most failed to produce acceptable and uquivocal results (Buskirk, 1961).

Blair et al. (1947) estimated the volume of the GIA to be 1330 cc. in males using a phlethysmographic technique. Keys & Brozek (1953) felt that this value was much too high and blamed the inaccuracies in the plethysmographic technique. Keys & Brozek (1953) measured the GIA volume in 21 young men using a radiological screening approach. They found a maximum value of 49 ml.

The best values for GIA volume have been obtained from total body plethysmographic technique and an intra-gastric balloon. Bedell et al. (1956) used this method to measure GIA volume on 13 normal subjects. The mean value for GIA was 115 ml with a standard error of ± 127 ml. However the GIA volume can range from 0 – 500 ml. Based on the findings of Bedell et al. (1956) it is proposed that a value of 100 ml (BTPS) be used in the body density equation. The density equation now becomes:

$$\text{Density} = \frac{Wa}{\frac{(Ww - Wa)}{Dw} - (RV + 100\text{ ml})}$$

The error due to GIA volumes is rather small and results in an error of only 1 to 2 density units. Due to the smallness of this error, GIA is usually neglected in most studies.

CHAPTER 3

METHODOLOGY & PROCEDURES

This chapter presents a detailed description of the equipment, testing protocols and the statistical design of the study. Prior to measurement, subjects read and signed an informed consent form and were passed by the Institutional Review Board involving human subjects. Since subjects were tested individually the study spanned eleven months. The testing protocol for each subject was identical.

Each subject reported only once to the laboratory for testing. However, as part of another study twenty subjects were asked to return for a second testing. These subjects were used to determine the test-retest reliability of bioelectrical impedance and infrared interactance (Burns, J.L. & Golding, L.A. 1995). The following is a detailed explanation of each test and measurement used.

Subjects

Subjects consisted of 54 women and 57 men of apparent good health and between the ages of 18 and 55 years of age. Table 1 presents physical characteristics of subjects.

Height and Weight

Each subjects height was measured with an anthropomometer to the nearest .25 of an inch. Each subject was measured in a swimsuit, with no shoes, standing as tall as possible and looking straight ahead. Weight was measured immediately after height on a Toledo physician balanced platform scale to the nearest .25 of a pound.

Near- Infrared

The Futrex 5000 consists of three main parts, the main body, an optical standard and a light wand with a light shield. The main body consists of a keypad to enter subject data, a LCD digital display window, and printer to print results. The optical standard is a teflon block used to calibrate the light wand prior to measurement. The light wand is the part that is placed on the site to be measured. The light wand houses the light emitting ring and the sensor window. The light emitting ring introduces the light beam into the biceps, and the sensor window measures the reflected light.

The procedures used to measure percent body fat using the Futrex 5000 is as follows. The subject sat with forearm of the dominant arm resting on a table. The following data was entered into the instrument: height, weight, gender, frame size, and exercise level. Height and weight were taken from previous measurements. Frame size was measured using the following techniques and guidelines: Place thumb and middle finger around dominant wrist. The following scale is used to determine frame size.

Small frame – fingers overlap

Medium frame – ends of fingers touch.

Large frame – fingers do not touch.

Exercise level is given as none, light, moderate and heavy. This is determined by the following subject prompts.

No exercise – none

1 to 2 times per week – light

3 to 4 times per week – moderate

5 to 6 times per week – heavy

The site of measurement was determined by measuring the length between the axillary fold and the anticubital fossa and finding the midpoint on the biceps brachii muscle. The light wand was then placed into the light shield to assure that no outside light penetrates the site where the measurement is being made. The light wand was placed on the measured site holding flaps of the light shield against arm. The enter button, on the main body, was then depressed and the light wand emitted a low level electromagnetic light beam that penetrates the site. Through a series of equations contained in the instrument percent fat is predicted and displayed. The actual equations are not supplied by the manufacturer.

Bioelectrical Impedance

The bioelectrical impedance method is based on the principle that lean tissue consists mainly of water and electrolytes, and offers a different

resistance to electricity than fat tissue, which contains little water (Kushner, & Scholler, 1986). Impedance of a geometrical conductor such as segments of the human body, is related to its length, configuration, cross-sectional area and also to the applied signal frequency (Kushner, 1992). The signal frequency of either 500 or 800 micro amps at 50 KHz is introduced into the body. This allows for the measurement of extracellular water and does not penetrate intracellular water. Resistance is based on the principle of Ohm's law which states that the resistance of a substance is related to the voltage drop of an applied current as it passes through that substance.

There are several commercially available bioelectrical impedance instruments. The one used in this study was a Bio-Analogics ELG II. A right sided electrode placement technique was used which means electrodes were placed on the right hand and foot. The impedance analyzer delivers a constant 800 micro amps of alternating current at 50 KHz through a distal or source electrode and the voltage drop or resistance of the current is measured through proximal or sense electrode. The resistance is measured in ohms which is placed into a multiple regression equation and the result is presented as percent body fat. (The actual equation was not supplied by the manufacturer).

The following is a detailed description of the procedures used when using the Bio-Analogics ELG II. Each subject was measured while lying in a supine position with arms and legs slightly abducted away from the body. Electrodes were then placed on the right foot and hand. Before the

electrodes were placed, each electrode site was thoroughly cleaned with an alcohol swab. The source electrodes were placed between the first and second metacarpal of the hand and the first and second metatarsal of the foot. The sense electrodes were placed between the styloid processes of the radius and ulna of the wrist, on the anterior surface of the forearm and between the lateral and medial malleoli of the dorsal surface of the ankle.

The impedance analyzer was calibrated by depressing both the calibration button and the operate button. Once zero was displayed the calibration button was released and ohms of resistance were displayed. The ohms reading was then entered into the ELG software containing the necessary equations and the percent body fat was printed out.

Skinfolds

Skinfold measurements are based on the principle that subcutaneous fat is related to total body fat. The skinfold measurements were taken with a Harpenden skinfold caliper, which meets the National Research Board, standard for jaw surface size and pressure of 90 gm/mm^2. The measurement is actually a fold consisting of two layers of skin and underlying subcutaneous fat. Skinfold measurements are measured where the greatest fat depots are usually located. Normally 7 to 8 skinfolds are taken and the results are millimeters of fat in each location. The subject is able to compare the measurements for each site with national norms those of the same age and gender.

The literature has reported several prediction equations based on skinfolds, to estimate percent total body fat. This has been accomplished by relating the measurements to hydrostatic weighing. This study used the equation developed by Jackson and Pollock based on the sum of four skinfolds. Jackson and Pollock developed generalized equations for men and women that were not population specific. These equations were developed on large heterogeneous samples with a wide range of ages and body fats. Equations using the sum of 3, 4, 5 and 7skinfolds were developed and they produce over .95 correlation with underwater weighing. The particular equation used in this study was based on the sum of 4 skinfolds, developed by Jackson and Pollock for the Y's Way to Physical Fitness. This equation produced a correlation of .96 with underwater weighing.

The following sites were measured according to the techniques described by Golding et, al. (1989). Each site was measured with the subject standing in a relaxed position and measured on the right side. Using a two handed technique, the fold was located and the thumb and four fingers of each hand was placed to the left and right of the site. The fold was then lifted two to three times to be certain no muscle was included. Then continuing to hold the skinfold with left hand, the right hand was removed and the caliper jaws were placed next to the thumb and index finger of the gripping hand. The pressure between the caliper jaws was allowed to compress the fold. When the pointer on the dial of the caliper stopped, the skinfold thickness was read to the nearest one millimeter.

The following is a description of the skinfold sites.

1. Triceps: A vertical fold on the posterior upper arm midway between the acromion and olecranon processes.
2. Abdomen: A vertical fold 1 to 2 inches to the right of the umbilicus.
3. Ilium: A diagonal fold at the crest of the ilium on the mid-axillary line.
4. Thigh: A vertical fold on the anterior thigh, midway between the groin line and the top of the patella.

Waist-to-Hip Ratio

The waist to hip ratio or abdomen to gluteal ratio has been used in medical literature dealing with obesity and cardiovascular disease. Waist or abdomen circumference has been suggested as an indicator of deep adipose tissue (Borkan et, al. 1983) and tends to be related to the fat free mass (Jackson & Pollock, 1976). Hip or gluteal circumference reflects the muscle, fat and skeletal structure in this area. Waist-to-Hip ratio therefore reflects the subcutaneous fat patterning of adipose tissue in the lower trunk (Lohman et, al. 1988). The higher the ratio has been linked to a greater risk of cardiovascular disease, type II diabetes and obesity (Lohman et, al. 1988). The following circumference measurements were performed according to the procedure described by Lohman, Roche, & Martorell, 1988 and are described below.

Waist Circumference

The subject stood erect with the abdomen relaxed and the arms at the sides. The tape was placed horizontally around the subject. The measurement was taken at the narrowest portion of the trunk between the top of the iliac crest and the bottom of the rib cage. The measurement was taken at the end of a normal expiration. If the measurement was affected by breathing then the circumference was measured again while holding the expiration. The tape was tight on the skin without compressing the skin. The measurement was recorded to the nearest one half inch.

Hip Circumference

The subject stood erect with the arms at the sides. The measurement was taken from the side of the subject and the tape is placed around the largest portion of the buttocks without compressing the skin. The measurement was recorded to the nearest one half inch. The following is a scale depicting the desirable ratios for men and women. High ratios increase the risk of type II diabetes, cardiovascular disease and obesity.

Males desirable 0.8 – 0.9

Females desirable 0.7 – 0.75

Underwater Weighing

The underwater weighing method is considered the gold standard against which all other body composition methods are compared. This method

measures the density of a person and the density is converted to percent fat by various prediction equations. Since fat is lighter than bone and muscle, the heavier the weight underwater, the less body fat there is. A correction must be made for the air that is in the lungs at the time of weighing. The volume is determined and subtracted from underwater weight to determine true underwater weight.

The underwater weighing system in this laboratory uses a load cell platform scale for land weight and 3 load cells connected to a triangular plinth on which the subject sat to obtain underwater weight. The system was designed and constructed by Toledo Scale.

The following is a detailed description of the methods and procedures used for measuring density by underwater weighing. Each subject was weighed in a nylon swim suit. Prior to any testing the Cavitron Anarad model # PM-20R CO_2 analyzer and the Servomex Model# 570 A O_2 analyzer was warmed up and calibrated with a 75% oxygen and 5% carbon dioxide calibration gas. In the system used, an electronic solenoid opened for a set time to deliver exactly 5 liters of O_2 from the cylinder of medically pure oxygen which had greater than 2000 pounds per square inch. Prior to testing this delivery system was checked by delivering the oxygen into a 7 liter spirometer. The time the solenoid was open was adjusted until exactly 5 liters was being delivered. Three 5 liter rebreathing bags were evacuated and filled with 5 liters of pure oxygen.

The subject's land weight was taken and then instructed to shower and to thoroughly wet down the hair and suit. The subject entered the tank and straddled the plinth while a weight vest was fitted to counter act buoyancy. The subject sat cross-legged on the plinth connected to 3 load cells. The load cells allow for the underwater weight to be determined and printed electronically. The subject sat with legs crossed submerged to the chin. A mouthpiece, nose clip and breathing tube connected to a t-valve allows the subject to snorkel completely submerged until the water was still. An oxygen filled rebreathing bag was attached to one of the connections of the t-valve. The t-valve allowed the subject to either breath room air or to breath from the rebreathing bag.

The subject was instructed to bend forward until totally submerged. The subject then snorkeled through the breathing tube and t-valve until the water had settled and weight on the digital read out stabilized. The subject was then instructed to exhale a comfortable amount of air and hold the breath. At this time underwater weight was printed 5 to 6 times on the Toledo Model # 8806 electronic printer. After the weight was recorded the t-valve changed from the snorkel position to the breathing bag position. The subject then slowly raised the head out of the water and rebreathed from the bag for eight deep breaths. This allowed the air in the lungs and the oxygen in the bag to equilibrate. On the eighth breath the subject was instructed to exhale air to again fill the rebreathing bag. The rebreathing bags valve was closed.

The mixed air bags were then analyzed to determine the carbon dioxide and oxygen content which were used in a functional residual volume formula to determine the air left in the lungs at the time the subject was weighed underwater. Functional residual volume differs from residual volume in that the subject expires a comfortable amount of air at the time of weighing. To determine residual volume the subject must expire all the air in the lungs. Functional residual volume was estimated by the 100% oxygen dilution method (Wilmore et, al. 1980). Nitrogen was determined by adding oxygen and carbon dioxide and subtracting from 100 using the formula:

$$\frac{5 \times \%N_2}{79.8 - \%N_2}$$

The computational formula was:

$$FRV = \text{Volume of bag} \; \frac{(-\text{Post } O_2 - \text{Post } CO_2 + \text{Pre } O_2 + \text{Pre } CO_2)}{-20.2 + \text{Post } O_2 + \text{Post } CO_2}$$

Body density was determined using the following formula:

$$\frac{Wa}{Wa - \frac{(Ww - Sw)}{Dw} - RV}$$

Wa – Weight in air

Ww – Weight in water

Sw – Weight of the sinkers

Dw – Density of water

RV – The air left in the lungs at the time of weighing represented in millimeters.

Percent fat was calculated using the prediction equations of Siri and Rathbun & Pace.

Siri: $\left(\frac{4.95}{D} - 4.5\right) \times 100$

Rathbun & Pace: $\left(\frac{5.548}{D} - 5.044\right) \times 100$

Statistical Analysis

Statistical analysis was used to compare the percent body fat calculated from underwater weighing (UWW) to the percent body fat calculated from: skinfolds (SF), bio-electrical impedance (BIA) and near-infrared photospectometry (NIR) and body mass index (BMI). Pearson's correlation coefficients were obtained for percent body fat estimated by UWW, SF, BIA NIR and BMI for males and females and males, females combined. R^2 values were calculated explaining the variability between each method and UWW. Standard error of estimate (SEE) Total error (TE) was calculated to determine the difference between the predicted values of percent fat by each method to the actual values determined by UWW. A one-way repeated measures Anova with Tukey's post hoc test was used to determine if significant differences existed between the means of percent body fat values determined by each method and UWW.

CHAPTER 4

RESULTS & DISCUSSION

The purpose of this study was to determine the validity of percent body fat determined by the Jackson & Pollock skinfold equation (JPSF), near-infrared (NIR), bioelectrical impedance (BIA) and body mass index (BMI) compared to the criterion method of underwater weighing.

The statistical analysis used in this study consisted of Pearson's correlation coefficients (r), standard error of estimates (SEE); R^2, Total Error (TE) and a one-way repeated measures Anova. Pearson's correlation coefficients were calculated to determine if relationships existed between the various techniques and the criterion method. Standard error of estimates along with R^2 values were calculated to determine the amount of prediction error and the degree of explained variance. Total error reflects the difference between the actual and predicted percent fat values. A one-way repeated measures Anova was used to determine if significant differences in percent body fat estimates occurred between each method and the criterion method.

The descriptive characteristics: means, standard deviations and range of age, height and weight for males and females are located in Table 1. As might be expected males were taller (x= 66.56 in) and heavier (x=

179.98lbs) than females. Both males and females were similar in age, males (x=30.11yrs) females (x=33.77yrs). The range of ages for males was 18 to 55 and females 18 to 51 years. By design, no subjects over the age of 55 were studied due to a decrease in fat free mass (FFM) which seems to be apparent after the age of 55 (Lohman, 1981).

Table 2 presents the means, standard deviations and range of percent fat estimates for males and females by each method. The mean percent body fat for both males and females fall within the recommended fat ranges found in the Y's Way to Physical Fitness. The recommended range for males is 16 to 20% body fat and for females is 19 to 23% body fat. Forty two percent (24) of the male subjects were below 16% body fat and 42% (24) subjects were above 20 percent body fat. Only 16% (9) of the male subjects were between 16-20% body fat. Females tended to be on the higher side with 48% (26) above 23 percent body fat. Twenty seven percent (15) of the female subjects were below 19% and 25% (14) were were between 19-23% body fat.

A one-way repeated measures Anova with Tukey's post hoc test was used to detect if significant differences occurred between the percent body fat means of each method. There was no significant differences found for males or females between SF, BIA, NIR and UWW ($p < 0.05$). There was a significant difference between the BMI method and UWW for both males and females ($P < 0.05$). When comparing the average percent fat the JP, NIR

and BIA methods under-predicted body fat in all groups compared to UWW. The BMI method over-predicted body fat in all groups compared to UWW.

Pearson correlation coefficients, R^2, SEE and TE values between the various methods are presented in Table 3. The JPSF equation showed the strongest relationship with UWW with a correlation coefficient of .923 for males, .934 for females and .935. for males and females combined. The BMI method showed the poorest relationship with UWW with the lowest correlation for males (.470) followed by the NIR method (.797) and BIA (.808). In females the BMI method showed a stronger relationship with UWW with a correlation coefficient of (.710) which was very similar to the NIR method (.719). The correlation between UWW and the BIA method was slightly higher at (.823). When males and females were combined the BMI method produced the lowest correlation with UWW (.620) followed by NIR (.790) and BIA (.830).

The standard error of estimate (SEE), compares the prediction errors of percent fat estimates by each method compared to UWW. The JPSF equation had the lowest SEE for males 2.73%, females 2.27% and 2.58% for males and females combined when compared to UWW. The BMI method had the highest SEE for males (6.27%) compared to the NIR method (4.29%) and BIA (4.18%). In females the BMI and NIR method compared to UWW had the largest SEE at 4.48% and 4.18% respectively. The BIA method had a lower SEE at 3.61%. When males and females were combined the BMI

method produced the largest error at (5.70%) followed by NIR (4.39%) and BIA (3.97%).

The total error (TE) compares the difference between the predicted values by each method to the actual values found by UWW. The values for TE were similar to the values found for SEE with the JPSF equation producing the lowest TE values for males of 2.75% and females 2.72%. Again, the BMI method produced the highest TE for males (8.81%) compared to the NIR method (4.31%) and BIA (4.41%). In females, BMI produced the highest TE (5.60%) followed by NIR (4.78%) and BIA (3.69%).

R^2 is used to determine how much of the prediction of percent body fat by UWW is explained by each method. When comparing R^2 values, the JPSF equation accounted for the most variance in UWW, 85% with males, 87% for females and 87% for males and females combined. The BMI method had the lowest amount of variance with UWW for males (22%) followed by NIR (63.5%) and BIA (65%). In females the BMI and NIR methods produced similar results accounting for 50% and 52% of the variance respectively. The BIA method was higher than the other methods (68%). When males and females were combined the BMI method accounted for the smallest amount of variance (38%) followed by NIR (63.5%) and BIA (70%).

When determining the prediction accuracy of any method, it should give accurate predictions even at the extremes of the body fat continuum. The following section is looking at the lean subjects only, and comparing the lean subjects body fat to UWW. The results based for lean subjects are located

in Table 6. In the male subjects with less than 10% body fat, the JPSF equation had the strongest relationship with UWW with a correlation of .75 and lowest TE of 2.71%. The BMI method produced the poorest relationship with UWW with a correlation of -.17 and the highest TE of 15.8%. The NIR method had a lower correlation of .21 compared to the BIA method (.60) however the TE was lower for the NIR method (5.38%) compared to the BIA method (5.45%).

In the female subjects with less than 15% body fat, the JPSF equation produced a moderate to low correlation with UWW (.32) however, the TE was low at 1.86%. The BMI and BIA methods produced the strongest relationship with UWW in lean female subjects producing a correlation of -.75 and .-78 respectively. The NIR method had the weakest relationship with UWW with a correlation of .09. BMI produced the largest TE (10.4%) compared to the NIR method (3.27%) and BIA method (4.63%). When males and females were combined the JPSF equation produced the strongest relationship with UWW .83 followed by BIA (.67), NIR (.30) and BMI (-.14). The TE was the lowest for the JPSF equation 2.32% compared to NIR (4.45%), BIA (5.06%) and BMI (13.37%).

The following section is looking at the more fat subjects only, and comparing the fatter subjects body fat with UWW. The results for more fat subjects are presented in Table 7. In male subjects with greater than 25% body fat, the JPSF equation and BMI produced the strongest relationship with UWW .79. The BIA method produced a slightly lower correlation .77

followed by the NIR method .46. The TE was lower for the JPSF equation (2.56%) and BMI (3.31%) compared to NIR (5.92%) and BIA (6.33%). In the female subjects with greater than 28% body fat, the JPSF equation produced the highest correlation with UWW (.90). The BIA and BMI methods produced similar coefficients (.78) and (.77) respectively. The NIR method produced the lowest correlation (.59) with UWW. The JPSF equation produced the lowest TE (2.94%) followed by BIA (4.36%), BMI (4.81%) and NIR (5.99%). When males and females were combined similar coefficients were found for JPSF equation (.90) and NIR (.57) however, the correlation increased to (.85) for BIA and (.82) for BMI. The JPSF equation produced the lowest TE (2.77%) followed by BMI (4.16%), BIA (5.39%) and NIR (5.95%).

When determining the validity of any method or equation, the prediction accuracy of estimating body fat should be similar for both males and females. In the present study, the prediction accuracy of the JPSF equation was as strong for males as females. The correlation coefficients and TE were almost identical for males (.923) and (2.75%) and females (.934) and (2.72%).The BIA method also produced correlation coefficients similar for both males (.808) and females (.823). However the SEE and TE were less for females (3.61%) and (3.69%) than males (4.18%) and (4.41%). The NIR and BMI methods did not possess similar prediction accuracy for both males and females. The NIR method produced stronger prediction accuracy in males (.797 TE 4.31%) than females (.719 TE 4.78%). The BMI method found

better prediction accuracy in females (.71 TE 5.60%) than males (.47 TE 8.81%).

One criticism of the BIA method is the equation that is supplied by the manufacturer. Several investigators have produced more generalized and fat-specific equations that have increased the prediction accuracy of BIA (Segal et al. 1988, Gray et al. 1989, Lohman, 1992). The results based on these equations are located in table 8. When comparing the results in table 8 with the results found by the manufacturer's equation, the only equation that increased the prediction accuracy was the equation developed by Segal et al. (1988) for males. Segal et al. developed two separate equations one for males with less than 20% body fat and one for males with greater than 20% body fat. The fat-specific equations of Segal et al. increased the correlation coefficient in males from .81 to .89 and decreased the SEE and TE from 4.29% to 3.25% and from 4.41% to 3.64% respectively. In females, the generalized equations of Segal et al. (1988) and Gray et al. (1989) produced correlation coefficients .82, .84 and SEE's 3.59%, 3.45% which is similar to the manufacturer's equation , however, the TE was higher for both equations 4.54% and 4.33%.

Discussion

The purpose of this study was to evaluate the validity of percent fat estimates measured by Jackson & Pollock skinfold equation (JPSF), bioelectrical impedance (BIA), near-infrared (NIR) and body mass index

(BMI) compared to the criterion method underwaterweighing (UWW). UWW is considered the "Gold Standard" against which other methods are validated.

The results from the present study indicate that the JPSF equation estimated percent body fat better than the other three methods (BIA, NIR and BMI). This is based on high correlation coefficients and low SEE's and TE's for males, females and males and females combined.

The JPSF equation has been studied extensively in the literature and has been shown to be a very accurate equation for both males and females. Skinfold thickness, when measured by an experienced technician and applied to the JPSF equation was a better predictor of body composition when compared to the other methods. The correlation coefficients found by the JPSF equation were high and agree with coefficients found in previous studies (Jackson et al. 1988, Elia et al. 1989, Mclean & Skinner 1992, Eckerson et al. 1996). The low SEE's and TE found for the JPSF equation indicates the strength of prediction and is similar to the previous studies. When comparing percent fat estimates at the extremes of the body fat continuum, the JPSF equation was the only method that maintained its prediction accuracy. The TE for both males and females was below 3.0% body fat, which is considered excellent when compared to the common error of between 3 and 4 percent body fat. The prediction accuracy of the JPSF equation was just as strong for males as females based on similar r, SEE and TE values. Several studies have cross-validated the generalized skinfold

equations of Jackson and Pollock and have reported similar values found in the present study, which supports the consistency and validity of the JPSF equation.

The BIA method produced less accurate results when compared to the JPSF equation. The BIA method using the manufacturer's equation produced lower correlation coefficients than the JPSF equation, however, the r coefficients were higher compared to other studies using the manufacturer's equation. Several earlier studies have found correlation coefficients less than .80 for both males and females using the manufacturer's equation (Hodgdon & Lawton 1985, Segal et al. 1985, Keller & Katch 1986, Jackson et al. 1988, Eckerson et al. 1996). The SEE and TE found by the BIA method was higher for males than females indicating that the BIA method estimated percent body fat better for females than males. When comparing body fat estimates at the extremes of the body fat continuum, BIA underpredicted percent body fat in males >25% body fat and females >28% body fat compared to UWW. This prediction error increased as the percentage of body fat increased. The prediction error was less for females (TE=4.36%) compared to males (TE=6.33%). In males with <10% body fat and females with <15% body fat the BIA method overpredicted percent body fat compared to UWW. Again the prediction error was better for females (TE=4.63%) compared to males (TE=5.45%).

To help alleviate the poor prediction accuracy of the manufacturer's equation, several investigators have developed more generalized equations

which have seemed to decrease the prediction error found by the manufacturer's equations (Segal et al. 1988, Gray et al. 1989, Lohman, 1992). When these equations were used to predict percent body fat in the sample in the present study, the generalized equations of Lohman, Gray and Segal found smaller correlation coefficients and larger SEE's and TE in males. The fat-specific equation of Segal et al. for males less than 20% and greater than 20% body fat was the only equation that improved the prediction accuracy over the manufacturer's equation. The correlation then increased from .81 to .89 and the SEE and TE decreased from 4.18% to 3.25% and from 4.41% to 3.64% respectively. In females the generalized equations of Segal and Gray found similar correlation coefficients and SEE compared to the manufacturer's equation. However, the TE for both equations was significantly higher than the manufacturer's equation. It is evident from the results found in the present study that the more generalized equations did not improve the prediction accuracy of BIA.

In the present study the NIR method produced weaker results when compared to the JPSF and BIA methods. The correlation coefficients were lower than both the JPSF and BIA methods and this agrees with values found in previous studies (Elia et al. 1989, Israel et al. 1989, Mclean & Skinner 1992, Cassady et al. 1993, Clark et al. 1992, Nielson et al. 1992). However, these results contradict the findings of Conway et al. (1984), Davis et al. (1988) and Heyward et al. (1992) who found higher correlation coefficients and low SEE's indicating that body composition could be

assessed with good validity. The SEE and TE for NIR found in the present study are in agreement with previous studies and range from 4.0 to 5.0% body fat.

Although poor, the NIR method predicted percent body fat better for males than females which is agrees with the results found by Mclean & Skinner (1992), Cassady et al. (1993) and Elia et al. (1989). One explanation for the larger prediction errors in females might be due to the larger fat depot found at the biceps area in women. The NIR spectrum of infrared light that is emitted only penetrates the area of measurement up to 4 cm measuring both subcutaneous fat and intramuscular fat (Quatrochi et al. 1992). The larger layer of subcutaneous fat found at the biceps site for women compared to men might hamper the penetration of infrared light.

When comparing the estimates of percent body fat at the extremes of the body fat continuum, the NIR method underpredicted percent body fat in males greater than 25% body fat and females greater than 28% body fat. This underprediction of body fat increases as the proportion of fat increases. In females with less than 15% body fat the NIR method slightly overpredicted body fat. In males with less than 10% body fat this underprediction was larger.

The BMI method produced the weakest results of all the methods studied when compared to UWW. The BMI correlation coefficients were lower for males than females which supports the findings of Wormersley & Durnin (1977). In the present study the correlation coefficient found between BMI

and UWW for females (.71) is in agreement with previous studies, however the correlation found for males is substantially lower (Jackson et al. 1988, Elia et al. 1989, Mclean & Skinner 1992). When observing the extremes of body fat estimates the BMI method overpredicted percent body fat for lean males and females. The reason for this might be due to the fact that the BMI is generally used in epidemiological studies to determine if subjects are obese. Since this method is used to detect obesity and in essence too much body fat the BMI might have a tendency to overpredict body fat in very lean individuals. On the other end of the continuum, the prediction of percent fat by the BMI method greatly improves as the amount of fat increases. Based on the findings in the present study, the BMI method improves its prediction accuracy in males greater than 25% body fat .79 with a TE of 3.31% and females greater than 28% .77 with a TE of 4.81% as seen in table 7. The BMI values for males are better than the values found by BIA and NIR. In females the BMI values are better than the NIR method and are comparable to the BIA method.

In summary, the prediction accuracy of percent body fat was better for JPSF equation for all groups compared to the other methods. When comparing the results based on the statistics used in this study, the JPSF equation produced the best results in all categories. The prediction accuracy of the JPSF equation was just as strong for males as females. The BIA method showed promise as a method of body composition. The refinement of the prediction equation could make the BIA method an alternative method

to the SF method without the loss of much accuracy. The NIR and BMI methods were the most inaccurate methods when compared to UWW. The measurement accuracy of NIR is questionable especially at the extremes of the body fat continuum. The BMI method severely overpredicted percent fat in male subjects however in female subjects with higher percentages of body fat the results were similar to the results found by the NIR method.

Table 1

Physical Characteristics Of Subjects -- Females

	Mean	SD	Range
Age	30.1	7.9	18.0 –51.0
Height (in)	65.2	2.5	61.0-70.5
Weight (lbs)	136.1	24.8	104.0-229.0

Physical Characteristics Of Subjects -- Males

	Mean	SD	Range
Age	33.7	10.7	19.0-55.0
Height (in)	66.5	2.9	63.0-75.5
Weight (lbs)	179.9	24.2	128-241.5

Table 2

Percent Body Fat For Females And Males By Five Methods

	Mean	SD	Range
	Females		
SF①	21.57	6.09	11.30-38.80
NIR②	22.27	6.26	7.70-37.70
BIA③	22.24	5.51	12.80-40.70
BMI④	26.30	6.00	18.90-47.80
UWW⑤	23.05	6.36	10.70-40.70
	Males		
SF①	17.25	6.93	4.60-31.50
NIR②	17.21	6.22	5.70-34.40
BIA③	16.38	4.70	7.00-34.40
BMI④	23.56	4.25	17.40-35.90
UWW⑤	17.64	7.10	2.40-33.80

Note
①Skinfold
②Near-Infrared
③Bioelectrical Impedance
④Body Mass Index
⑤Underwater Weighing

Table 3

Pearson Correlation Coefficients, R^2, Standard Error Of Estimate And Total Error For Females, Males, Females/Males Combined

	R	r^2	SEE	TE
	Females			
SF	.934	.87	2.27	2.72
NIR	719	.52	4.41	4.78
BIA	.823	.68	3.61	3.69
BMI	.710	.50	4.48	5.60
	Males			
SF	.923	.85	2.73	2.75
NIR	.797	.63	4.29	4.31
BIA	.808	.65	4.18	4.41
BMI	.470	.22	6.28	8.81
	Females /Males Combined			
SF	.935	.874	2.58	2.74
NIR	.797	.635	4.39	4.55
BIA	.837	.701	3.97	4.05
BMI	.620	.384	5.70	7.21

Table 4

Percent Body Fat For Males <10% Body Fat And Females <15% Body Fat

	Mean	SD	Range
	Males		
SF	9.1	3.38	4.6-14.3
NIR	11.5	3.06	8.3-16.5
BIA	12.7	2.25	9.0-15.1
BMI	22.2	5.04	17.5-32.4
UWW	7.4	2.71	2.4-10.4
	Females		
SF	13.8	1.86	12.0-17.2
NIR	13.0	3.25	7.7-16.5
BIA	17.1	2.01	14.3-20.5
BMI	22.6	3.47	18.9-27.4
UWW	13.6	1.50	10.7-15.1

Table 5

Percent Body Fat For Males >25% Body Fat And Females >28% Body Fat

	Mean	SD	Range
	Males		
SF	26.0	2.85	22.3-31.5
NIR	24.7	5.95	13.2-34.4
BIA	22.8	5.66	16.7-34.4
BMI	27.4	5.02	20.6-35.9
UWW	28.0	2.44	24.7-33.8
	Females		
SF	29.7	4.62	24.3-38.8
NIR	27.7	5.17	19.4-37.7
BIA	29.1	5.56	21.7-40.3
BMI	33.2	7.14	26.1-47.8
UWW	31.9	3.78	28.2-40.7

Table 6

Pearson Correlation Coefficients And Total Errors For Males <10% Body Fat And Females <15% Body Fat

	R	TE
	Males	
SF	.75	2.71
NIR	.21	5.38
BIA	.60	5.45
BMI	-.17	15.8
	Females	
SF	.32	1.86
NIR	.09	3.27
BIA	-.78	4.63
BMI	-.75	10.4

Table 7

Pearson Correlation Coefficients And Total Errors For Males >25% Body Fat And Females >28% Body Fat

	R	TE
	Males	
SF	.79	2.56
NIR	.46	5.92
BIA	.77	6.33
BMI	.79	3.31
	Females	
SF	.90	2.94
NIR	.59	5.17
BIA	.78	4.36
BMI	.77	4.81

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study compared the validity of the Jackson & Pollock skinfold equation (JP), Bioelectrical Impedance (BIA), Near-Infrared (NIR) and Body Mass Index (BMI) for estimating percent body fat compared to the criterion method of Underwater Weighing (UWW). Measurements were made on 111 subjects, 57 males and 54 females between the ages of 18 and 55 years. The measurements included height, weight, 4 skinfolds, body resistance, light interactance and body density. Male and female subjects tended to fall within the recommended range for percent body fat according to the YMCA's recommended percentages of fat.

A repeated measures ANOVA was used to determine if significant differences occurred between each method and UWW. For both male and female subjects, the BMI method was the only method that was significantly different from underwater weighing.

Pearson correlation coefficients were calculated for each method and all methods were positively correlated with UWW. The JP equation produced the strongest relationship with UWW for all groups. BIA was a better

predictor of percent body fat than NIR and BMI. When comparing NIR and BMI, the NIR method produced a higher correlation for males however in females the BMI method was just as accurate. When comparing the validity of each method to predict percent body fat at the extremes of the body fat continuum, the SF was the only method that maintained its validity for both males and females. The BMI method produced stronger results in the more obese groups compared to the NIR and BIA methods. The BIA and NIR significantly underpredicted percent fat in the more obese subjects. In lean subjects the BIA and BMI significantly overpredicted percent fat. When prediction error was evaluated the SF method produced the lowest SEE's and TE's with UWW followed by the BIA, NIR and BMI methods.

Conclusions

1. The JPSF equation when compared to UWW was a better predictor of percent body fat for males, females and males, females combined.
2. The BMI method was significantly different than UWW for both males and females.
3. The JPSF equation predicted percent fat with equal accuracy for males and females. The BIA method was slightly better in females than males. The NIR method predicted percent body fat better for males than females and BMI was better in females than males.

4. The SF maintained its prediction accuracy at the extreme ends of the body fat continuum. BMI was the only other method that showed this tendency in the more obese groups.

Recommendations

The skinfold method has been well established in heterogeneous samples of causians between 10 and 40% body fat. Future research needs to be devoted to developing skinfold equations in relation to fat patterning differences that occur with age, ethnic background, fatness level and physical activity. New equations need to be developed based on the four compartment model to account for density changes of the fat-free body associated with a decrease in bone density with aging and the underdeveloped fat-free body in children.

The BIA method needs to be cross-validated on heterogeneous populations developing more specific equations that can be applied to large groups differing in age, gender, degree of body fatness and ethnic background.

The NIR method needs to be cross-validated on heterogeneous populations differing in age, gender and body fatness. More research is needed in the very fat population where the prediction error is the greatest. The variables that are entered into the prediction equation especially exercise level, need to be reevaluated to determine the strength that each contributes to the prediction accuracy of the equation.

One area that needs to be addressed in future research is the use of the BMI method to predict percent fat in lean individuals. Based on the findings from this study, the development of specific equations for this group is vital before further application can be made. The BMI method should be included in epidemiological and body composition studies. BMI should not be the only measure of body fat, however should be included with SF, BIA, NIR and other laboratory methods. The future research for all methods should consist of developing generalized equations that can be applied to different populations.

APPENDIX I

MEMORANDUM TO PARTICIPANTS

RECORDING FORM

CONSENT FORM

MEMORANDUM

DATE: November, 1994

TO: Subjects in Body Fat Study

FROM: Lawrence A. Golding & Jeff Burns

SUBJECT: Validation of the various methods of determining body composition. Results and explanation.

First, thank you for being a subject in this study, without your volunteering, studies like this would be impossible. Also our apologizes for not getting the results to you earlier.

TITLE: Validation of the various methods of detirmining body composition

The following is a brief description of what we're are doing; and your results

Underwater weighing is considered the Gold Standard against which are other body composition methods are compared. There are dozens of different methods to determine the amount of fat and lean body weight in the human. Some of these methods are well validated and others are not. Even Underwater Weighing has a degree of 'prediction' and different Underwater Weighing procedures have different accuracy's. In Underwater Weighing the measurement we use for data treatment is 'density' because that we know is accurate, However, when you convert density to percent body fat, the conversion is a prediction.

This study is comparing Bio-Impedance technology; Infra-red techniques; skinfold prediction equations; and Waist-to-Hip ratio measurement to Underwater Weighing.

1. Underwater Weighing: This is a physics principle: Density is Mass divided by Volume. Gold has a density, silver has a density, and every element has a density. So too, can the body have a density. The body is made up of muscle, bone and organ weight and this is called Lean Body Weight (LBW). The balance of the body's weight is fat. We know the density of LBW so we can calculate the density which is fat. From this we can determine the percent of body fat. A correction must be made for the air in your lungs which is why we measure that volume when we get your underwater weight.

2. Skinfolds: This is an excellent technique to show where fat is being carried and how much is at the various sites. Some of these skinfolds have been put into equations to predict percent body fat. Some equations are very valid. The formula we use correlates .96 with Underwater Weighing which is very good.

3. Waist-to-Hip Ratio (also called Abdominal to Gluteal ratio): is an easy to take measurement which is being used widely in the medical literature dealing with obesity and disease. Very little research has been done to validate this ratio.

4. Bio-Impedance: This is based on the principal that water offers resistance (impedance) to a low grade electric current. In this technique a small electric current passes between two electrodes, the body water offers the current resistance, which is measured in ohms. Since the amount of water in fat and LBW is known, a calculation from resistance to percent fat can be made. Considerable research has been done on this technique and it offers hope for an easy body composition determination in the future.

5. Infra-Red: Infra red technology has been around for a long time, but not in the measurement of body composition. A massive advertising campaign by the manufacturers of the equipment has pushed the Infra Red technique into health clubs and hospitals. It's attractive because it is fast and easy to do. Very little scientific research has been done on the technique. This present study will be one of the first to relate it to other measurements.

YOUR MEASUREMENTS

NAME:______________________________ **Date:**___________________________

1. Underwater weighing: ____________________
2. Skinfolds: ____________________
3. Waist-to-Hip ratio: ____________________
4. Bio-Impedance: ____________________
5. InfraRed: ____________________

NOTE:

A male should be between 16-20% fat
A female should be between 19 –25% fat
Athletes are often 10 – 15% fat
Percent fat above 36 % is considered fat
Percent fat above 40% is considered obese

Waist –to –Hip ratio:

Males	desirable 0.8 – 0.9
Females	desirable 0.7- 0.75

These ratios have a slight age trend and increase slightly with age. The ratio has been related to risk of pathogenesis of obesity, and high ratios means a great risk of obesity.

When the study is completed we will send you the results.

Recording Form

Subject Name: ______________________________

Age: ______________________________

Date: ______________________________

1. Height: ______________________________
2. Weight: ______________________________

3. Skinfolds: Sum of 4

Abdomen ____________________mm

Ilium ____________________mm

Tricep ____________________mm

Thigh ____________________mm

Total ____________________

% Body Fat ____________________

4. Infrared: Exercise Level ____________ Retest ____________

% Body Fat ____________

None

Light – 1 to 2 times per week

Moderate – 3 to 4 times per week

Heavy - 5 to 6 times per week

5. BIA: Ohms ______________ Retest ______________

% Body fat ____________

6. UWW: Sinker Weight ______________

Dry Weight ______________

Water Temp ______________

Trial #1 Avg. water weight __________________

%O2 __________________

%CO2 __________________

Trial #2 Avg. water weight __________________

%O2 __________________

%CO2 __________________

Trial #3 Avg water weight __________________

%O2 __________________

%CO2 __________________

7. Hip to Waist Ratio: Waist ___________ins

Hip ___________ins

Informed Consent

TITLE OF STUDY: To determine the validity and reliability of skinfolds, bio-impedance, and infrared for predicting percent body fat when compared to underwater weighing.

PURPOSE: You have been asked to volunteer to participate in a study, to compare skinfolds, bio-impedance, and infrared techniques to underwater weighing.

SUBJECTS: Men and women between the ages of 18 and 65.

PROCEDURES: The following methods for determining percent body fat will be performed.

-- skinfolds sum of 4 (abdomen, ilium, thigh, triceps)
–bio – impedance
-- infrared
-- underwater weighing

RISKS: The tests are non-stressful and have virtually no risks. The possibility of slipping and falling, climbing in or out of the underwater weighing tank is always possible, but care will be taken to prevent this form of risk.

BENEFITS: To determine what method or methods are reliable enough to be practiced for determining percent body fat and to inform subjects of their body composition.

CONFIDENTIALITY: All data collected shall remain confidential. Data will be coded and kept in locked files. When and if data is published no names will be used and only averages will be used.

RIGHT TO REFUSE OR WITHDRAW: You have the right to refuse to take part in any test or to withdraw from the study at any time.

QUESTIONS: You may ask questions or request further explanations or information about the study or any of the tests.

In signing this consent form you indicate that you have read the above and voluntarily agree to participate and that any questions you have, have been answered to your satisfaction.

______________________ Subject's Signature	______________ Date
______________________ Subject's Name (print)	
______________________ Witness's Signature	______________ Date
______________________ Witness's Name (print)	

APPENDIX II

RAW DATA

STATISTICS

Subject	Age	WT Kgs	WT lbs	HT cm	HT ins	SF Ab	SF Il	SF Tri	SF Th	SF Tot
m1	42	71	156	81	71.25	21	10	12	16	59
m2	24	81.1	180	190.5	75	29	28	15	15	87
m3	23	73.2	161	183	72	17	14	8	7.5	46.5
m4	48	89.4	196.7	183	72	25	21	15	17	78
m5	34	93.9	206.5	177.8	70	43	35.5	17	22	117
m6	52	71.8	158	173	68	30	26	13	14	83
m7	62	68.6	151	166	65.3	25	18	14.5	15	72.5
m8	55	94.5	208	175	69	23	24	7.5	8	62
m9	46	89.3	196.5	173	68.3	51	32	17	20	120
m10	54	80	176	178	70.3	35	25	15	12	87
m11	30	75.5	166	181	71.3	29	24	9	12	74
m12	26	92.7	204	181	71.3	19	23	8	12	62
m13	36	102	223	168	66.3	53	42	22	29	146
m14	27	94.1	207	192	75.5	21	16	11	9	57
m15	35	79.8	175.5	177	69.75	25	25	11	13	74
m16	23	75.5	166	174	68.5	21	24	9	19	73
m17	22	74	163	176.5	69.5	10.5	13	7	8	38.5
m18	38	68.2	150	176	69.25	13	11	6	8	38
m19	19	97.7	215	171.5	67.5	11	12	7	10	40
m20	22	76.8	169	185	72.75	17	18	10	13	58
m21	32	78.4	172.5	171.5	67.5	42	25	15	20	102
m22	23	64.5	142	168	66.25	12	11	7	7	37
m23	36	83.2	183	173	68	21	17	10	12	61
m24	31	82	180.5	180	70.75	22	19.5	11.5	17	70
m25	43	81.2	179	160	63	17	22.5	13	13.5	66
m26	23	76.4	168	175.3	69	13.5	10	6.5	10	40
m27	21	93.2	205	179	70.5	23	21	12	15	71
m27	48	85	187	183	72	19	16	7	10	52
m29	22	74.8	164.5	167.5	66	20	25	10.5	8	63.5
m30	34	101	222.5	191	75.25	40	27	12.5	23.5	103
m31	26	89.5	197	185.4	73	37	28	13	11	89
m32	53	89.5	197	171	67.25	32	30	19	19	98
m33	39	81	178	180	71	20	19	7.5	10	56.5
m34	31	81.1	180	173.4	68.25	17.5	23	10	14	64.5
m35	26	58.2	128	162.5	64	14	10	6.5	7	38
m36	22	70.6	155.5	173	68	17.5	21	12	13	63.5
m37	32	81.4	179	184	72.5	24.5	16	10.5	10.5	61.5
m38	41	78.4	173	179	70.5	6	5.5	5.5	9	26
m39	31	73.9	163	164	64.5	5.5	5	5	4.5	20
m40	33	88.6	195	184	72.5	43	25	16	20	104
m41	31	64.1	141	160	63	12.5	16	8	14	50.5
m42	22	74.4	164	181.5	71.5	13.5	13	8.5	8	43
m43	34	74.8	165	180	71	8	7	6	5.5	26.5
m44	50	67.4	148.5	168	66.25	19	13	7.5	9	48.5
m45	51	100	222	175	69	42	36	13	18	112
m46	38	80	176	181.5	71.5	13.5	11	9	14	47.5
m47	50	71.8	158	167	65.75	9	10	12	11	42
m48	27	94.9	209	186	73.25	31	28	12	15	86
m49	29	89.1	196	182	71.75	46	31	20	17	114
m50	30	87.5	193	176.5	69.5	33	30	14	15	92
m51	49	90.2	198.5	180	71	33	33	25	34	125

Subject	Age	WT Kgs	WT lbs	HT cm	HT ins	SF Ab	SF Il	SF Tri	SF Th	SF Tot
m52	46	110	241.5	180	71	39	27.5	19	10	95.5
m53	35	74.8	164.5	170	67	18.5	17	10.5	19	65
m54	27	65.2	143.5	174	68.5	6	7.5	5.5	5	24
m55	53	97.5	215	180	71	33	27	15	18	93
m56	28	81.1	178.5	171.5	67.5	42	37	16	18	113
m57	27	75.9	167	188	74	9	14	7	10.5	40.5

Subject	SF %fat	Exer level	Frame size	Infrared % fat	BIA ohms	BIA %fat	Density	UWW %fat
m1	16.3	hvy	med	10.5	455	12.2	1.066	14.2
m2	19.4	lt	sm	20.5	513	18.8	1.047	22.4
m3	10.3	mod	sm	11.3	473	14	1.084	7.7
m4	22.3	mod	med	19.8	424	17.9	1.040	25.5
m5	26.7	mod	lg	21.9	383	18.1	1.047	22.6
m6	23.4	mod	med	22.4	489	18.5	1.042	24.7
m7	21.8	mod	med	21.2	402	13	1.049	21.5
m8	18.7	mod	lg	24.4	365	17.6	1.045	22.9
m9	29.2	mod	med	24.9	415	21.2	1.036	27.5
m10	24.2	mod	sm	21.4	447	16.7	1.038	27.3
m11	18.1	mod	med	13	456	14.5	1.062	16.1
m12	13.9	mod	med	15	381	17.2	1.071	13.1
m13	31.5	mod	lg	28.9	402	34.4	4.022	33.8
m14	12.8	hvy	lg	10	402	14.6	1.079	9
m15	18.9	lt	med	22.6	407	14	1.053	19.8
m16	17.3	mod	med	14.4	463	17.7	1.061	16.3
m17	8.3	mod	sm	12.7	447	14.8	1.070	12.8
m18	11.5	mod	med	9.7	421	10.4	1.073	11.7
m19	8.3	hvy	lg	15.8	275	10.9	1.084	7
m20	13.1	lt	med	16.2	440	12.6	1.075	10.6
m21	23.2	hvy	med	16.6	482	21.9	1.045	23.2
m22	7.8	hvy	med	8.7	432	11.5	1.089	4.8
m23	15.5	hvy	lg	14.2	370	13.9	1.072	13.9
m24	17	hvy	med	11.6	397	13.2	1.057	18.1
m25	18.2	hvy	lg	18.3	330	15.2	1.047	22.6
m26	9.1	mod	med	12.6	402	12.9	1.070	12.6
m27	15.4	hvy	med	15.5	379	16.9	1.062	16.2
m28	15.5	hvy	med	14.9	435	16.2	1.066	14.1
m29	14.3	mod	med	16.5	402	15.1	1.076	10.4
m30	24.6	hvy	med	13.2	440	20.7	1.036	27.3
m31	20.4	mod	lg	19.1	463	19.4	1.043	24.1
m32	27.1	mod	lg	24.9	383	19.3	1.042	24.6
m33	15.1	mod	med	16.6	448	16.5	1.063	15.5
m34	15.9	mod	lg	19.7	396	15.3	1.071	12.2
m35	9.1	mod	med	12.8	464	12.6	1.074	10.8
m36	14.3	lt	med	22.7	452	15.1	1.060	16.8
m37	14.7	mod	med	15.5	479	17.6	1.058	17.6
m38	7.6	hvy	med	9.4	410	13	1.071	12
m39	14.6	hvy	med	10.8	345	11.4	1.097	2.4
m40	24.9	mod	med	21.5	428	16.6	1.050	21.7
m41	12.4	hvy	med	11.9	407	13.5	1.071	12.2
m42	9.6	hvy	sm	8.3	470	14.8	1.076	10.2
m43	6.8	hvy	med	5.7	401	10.6	1.073	11.3
m44	15.5	hvy	sm	11.8	455	15.5	1.051	20.1
m45	28.2	none	lg	34.4	337	26.4	1.034	28.1
m46	12.7	mod	med	12.4	426	13.9	1.073	11.9
m47	13.1	hvy	med	13.8	434	16.6	1.061	16.5
m48	19.4	mod	lg	19.4	399	16.7	1.056	18.5
m49	25.9	lt	med	26	463	21.5	1.032	28.9
m50	21.2	lt	med	23.8	435	20.9	1.049	21.2
m51	30.8	lt	med	25.5	429	19.8	1.040	25.4

Subject	SF	Exer	Frame	Infrared	BIA	BIA	Density	
		UWW						
	%fat	level	size	% fat	ohms	%fat		%fat
m52	24.6	lt	lg	30.3	377	29.7	1.032	28.8
m53	16.7	hvy	lg	12.7	397	13.7	1.057	18.1
m54	5.2	mod	med	10.4	419	9	1.082	7.7
m55	26.2	mod	lg	25.7	403	20.5	1.035	27.6
m56	25.6	mod	med	22.9	435	19.2	1.050	21.2
m57	9.1	hvy	med	4.8	391	8	1.077	9.5

Subject	Waist cm	Waist ins	Hip cm	Hip ins	W/H ratio	BMI	BMI %fat
m1	78	30.75	94	37	0.83	21.65	17.6
m2	87	34.25	107	42	0.82	22.42	18.6
m3	79	31	95.25	37.5	0.83	21.85	17.9
m4	94	37	106.7	42	0.88	26.69	24.1
m5	99	39	109	43	0.91	29.67	27.9
m6	91.5	36	104	41	0.88	23.99	20.6
m7	84	33	83.6	38	0.87	24.89	21.8
m8	103	40.5	104	41	0.99	30.86	29.4
m9	100	39.5	112	44	0.90	29.84	28.1
m10	94	37	100	39.5	0.94	25.25	22.2
m11	81.3	32	99	39	0.82	23.05	19.4
m12	90	35.5	112	44	0.81	28.39	26.2
m13	108	42.5	118	46.5	0.91	35.96	35.9
m14	85.7	33.75	104	41	0.82	25.53	22.6
m15	87.6	34.5	100	39.5	0.87	25.47	22.5
m16	83.8	33	99	39	0.85	24.94	21.8
m17	79	31.25	99	39	0.80	23.75	20.3
m18	78.7	31	93	36.5	0.85	22.02	18.1
m19	87.6	34.5	105.4	41.5	0.83	33.22	32.4
m20	82.6	32.5	100	39.5	0.82	22.44	18.6
m21	89	35	107	42	0.83	26.66	24.0
m22	75	29.5	91.5	36	0.82	22.85	19.1
m23	83.8	33	104	41	0.81	27.80	25.5
m24	85.1	33.5	99	39	0.86	25.31	22.3
m25	97.8	38.5	101.5	40	0.96	31.72	30.5
m26	81.3	32	99	39	0.82	29.95	28.2
m27	89	35	109	43	0.81	29.09	27.1
m28	83.8	33	99	39	0.85	25.38	22.4
m29	87.6	34.5	101.5	40	0.86	26.66	24.0
m30	103	40.5	109	43	0.94	27.69	25.3
m31	94	37	105.4	41.5	0.89	26.04	23.2
m32	100	39.5	106.7	42	0.94	30.42	28.8
m33	89	35	101.5	40	0.88	25.00	21.9
m34	87.6	34.5	103	40.5	0.85	27.21	34.5
m35	73.7	29	96.5	38	0.76	22.05	18.1
m36	78.7	31	101.5	40	0.78	23.59	20.1
m37	89	35	101.5	40	0.88	24.04	20.7
m38	82.6	32.5	100.3	39.5	0.82	24.47	21.2
m39	73.7	29	95	37.5	0.77	27.48	25.1
m40	93	36.5	105.4	41.5	0.88	26.17	23.4
m41	76	30	99.5	39	0.77	25.04	21.9
m42	78.7	31	99.5	39	0.79	22.58	18.8
m43	81	32	94	37	0.86	23.09	19.4
m44	82.5	32.5	93	36.5	0.89	23.88	20.5
m45	104	41	114	45	0.91	32.65	31.7
m46	84	33	104	41	0.80	24.28	21.0
m47	81	32	98	38.5	0.83	25.74	22.8
m48	90	35.5	109	43	0.83	27.43	25.0
m49	102	40	106.5	42	0.95	26.90	24.3
m50	95	37.5	104	41	0.91	28.09	25.9
m51	96.5	38	113	44.5	0.85	27.84	25.5
m52	117	46	119	47	0.98	33.95	33.4

Subject	Waist cm	Waist ins	Hip cm	Hip ins	W/H ratio	BMI	BMI %fat
m53	81	32	103	40.5	0.79	25.88	23.0
m54	75	29.5	98	38.5	0.77	21.54	17.5
m55	107	42	112	44	0.95	30.09	28.4
m56	93	36.5	105.5	41.5	0.88	27.57	25.2
m57	77.5	30.5	96.5	38	0.80	21.47	17.4

Subject	Age	WT Kgs	WT lbs	HT cm	HT ins	SF Ab	SF Il	SF Tri	SF Th	SF Tot
f1	21	57.3	126	164	64.5	22	24.5	16	24.5	87
f2	27	60	132	161	63.5	25	26	24	26	101
f3	29	69.5	153	157.5	62	35	30	23	31	119
f4	20	57.7	127	170	67	11	12	11	19	53
f5	18	54.5	120	171.5	67.5	9	11	11	18	49
f6	20	58.2	128	168	66.28	10	11.5	13	20	54.5
f7	22	84.1	185	174	68.5	20	18	18	22	78
f8	35	63.2	139	155	61	19	20	23	41	103
f9	27	74.8	164.5	179	70.5	14	18.5	16	24.5	73
f10	24	47.3	104	160	63	9	12	6	10	37
f11	22	53.1	112.5	162.5	64	17	12.5	12.5	22	64
f12	22	51.4	113	161	63.5	13	10	13	19	55
f13	36	57.7	127	170	67	9.5	7.5	12	20	49
f14	24	48.4	106	160	63	8	8	11	14	41
f15	27	55	121	170	67	15	13.5	17	26.5	72
f16	43	68.2	150	177	69.75	19	19	21.5	21	80.5
f17	37	64.5	142	167.6	66	10	9	10	10.5	39.5
f18	28	104	229	167.6	66	37	34	33	43	147
f19	38	73	161	168.3	66.25	25	20	16	32	93
f20	25	68.2	150	160	63	26.5	16.5	17	23	83
f21	51	78.2	172	177.2	69.75	30	22	22	31	105
f22	35	60	132	160.6	63.25	21	16.5	14.5	20	72
f23	30	97.7	204	165	65	49	36	37	37	159
f24	21	70.3	155	174	68.5	7	11	9	8	35
f25	43	72.3	159	162.5	64	23	21	22	37	103
f26	38	42.3	104	155	61	8	8	14	22	68
f27	35	58.2	128	162.5	64	11.5	11	15.5	22	60
f28	27	56.8	125	160.6	63.25	14	18	10	15	57
f29	25	66.3	146	162.5	64	27	32	15	19	93
f30	25	47.7	105	165	65	10	12	14	30	66
f31	21	59.1	130	172.7	68	24	17	16	19	76
f32	37	63.2	139	171.4	67.5	13	12	22	25	72
f33	48	69.5	153	165.7	65.25	36	19	25	34	114
f34	35	72	158	174	68.5	10.5	13	13	20	56.5
f35	31	54.1	119	162.5	64	14	12	14	20	60
f36	28	47.3	104	155	61	8	10	15	23	56
f37	30	50.9	112	155	61	12.5	18	14	25	69.5
f38	25	47.5	104.5	161	63.5	9	10	11	16	46
f39	39	56.8	125	159.4	62.75	23	24	18	26	91
f40	31	61.6	135.5	157.5	62	31	25	16.5	25.5	98
f41	24	55.9	123	162.5	64	12	15	10	22	59
f42	23	52.3	115	172.7	68	9	6.5	8	13.5	38
f43	42	60.9	134	172.7	68	16	16	16	29	77
f44	26	61.4	135	165	65	21	18	15	22	76
f45	27	53.6	118	170.2	67	11	10	12	21	44
f46	27	50.5	111	155	61	18	10	17	22	68
f47	43	64.1	141	165	65	20	14	21	30	85
f48	38	61	134.5	158	62.25	33	16	14	15	78
f49	28	61.6	136	172.7	68	11	11	17	21	60
f50	22	62.6	138	169	66.5	14	19	12	21	66

Subject	Age	WT Kgs	WT lbs	HT cm	HT ins	SF Ab	SF Il	SF Tri	SF Th	SF Tot
f51	22	63.6	140	167.6	66	25	23	16	27	91
f52	40	52.2	121.5	161.3	63.5	8	8	14	18	48
f53	30	63.6	140	170	67	29	20	15	15	79
f54	34	73.6	162	173.4	68.25	34	21	27	29	111

Subject	SF %fat	Exer level	Frame size	Infrared % fat	BIA ohms	BIA %fat	Density	UWW %fat
f1	23.6	mod	sm	21.5	527	19.5	1.057	18.1
f2	27.5	mod	med	25.7	507	21.9	1.039	25.9
f3	31.7	mod	med	29.1	516	32.9	1.024	32.5
f4	16.5	hvy	sm	13.1	661	24.1	1.049	21.4
f5	15.2	hvy	sm	14.4	612	15.8	1.069	13.1
f6	16.5	lt	sm	25.5	533	17.9	1.050	21.2
f7	22.5	hvy	lg	18.5	441	27.2	1.044	23.6
f8	28.9	hvy	med	23.5	485	28.7	1.032	29.0
f9	22	mod	med	21.5	504	24.0	1.043	24.1
f10	12	mod	med	12.4	569	17.0	1.062	15.1
f11	18.9	hvy	sm	15.9	618	20.6	1.055	18.7
f12	16.5	none	sm	28.8	494	12.8	1.052	20.7
f13	16.2	hvy	sm	16.8	589	20.1	1.054	19.4
f14	13.3	hvy	sm	13.1	575	16.6	1.067	13.8
f15	20.8	none	med	28.5	610	19.0	1.052	20.2
f16	23.7	mod	med	22.6	526	21.6	1.044	23.8
f17	13.7	hvy	med	16.5	458	19.2	1.070	12.4
f18	36.3	hvy	lg	28.9	388	40.3	1.018	35.3
f19	26.8	mod	sm	26.8	457	25.4	1.031	29.6
f20	24.3	lt	med	33	485	28.9	1.034	28.2
f21	29.3	mod	med	26.2	505	27.0	1.030	29.9
f22	21.1	mod	sm	26.5	514	22.8	1.041	24.8
f23	38.8	lt	lg	37.7	468	36.7	1.007	40.7
f24	11.3	hvy	sm	8.9	458	20.5	1.074	10.7
f25	29.2	mod	med	26.9	443	27	1.025	32.0
f26	21.2	mod	sm	24.7	569	18.2	1.049	21.3
f27	18.7	mod	sm	25.4	490	18.3	1.048	21.7
f28	17.2	hvy	med	16.2	459	15.6	1.066	14.3
f29	26.5	mod	med	26.5	459	26.1	1.035	27.4
f30	20.8	none	med	25.8	669	20.1	1.045	23.1
f31	21.3	none	sm	28.4	664	22.0	1.045	23.3
f32	21.1	mod	med	22.7	597	23.7	1.040	25.4
f33	31.3	lt	sm	30.9	522	29.0	1.021	33.8
f34	17.5	mod	sm	21.3	469	22.5	1.050	21.0
f35	18.7	lt	sm	23.7	582	21.2	1.050	21.0
f36	17.3	hvy	sm	19.3	552	17.6	1.058	17.5
f37	21	hvy	sm	19.1	608	24.7	1.041	24.7
f38	14.6	hvy	sm	15.0	587	17.5	1.066	14.6
f39	25.7	hvy	med	19.4	524	21.7	1.032	28.4
f40	27.7	mod	med	27.1	471	24.4	1.034	28.2
f41	13.9	mod	sm	19.7	505	17.4	1.062	16.1
f42	13.3	hvy	sm	7.7	604	14.3	1.064	15.0
f43	22.3	mod	med	20.7	603	21.6	1.037	26.8
f44	22.0	mod	med	24.6	522	21.7	1.044	23.4
f45	14.8	mod	med	17.2	574	15.3	1.055	18.8
f46	20.8	none	med	30.9	475	14.9	1.044	23.5
f47	24.9	hvy	med	21.2	518	25.0	1.026	31.5
f48	23.5	mod	med	26.2	494	25.3	1.047	22.5
f49	18.6	hvy	med	15.4	517	17.0	1.051	21.0
f50	18.9	none	med	31.6	587	24.2	1.051	21.0
f51	24.7	hvy	sm	19.0	584	27.2	1.043	24.5

Subject	SF %fat	Exer level	Frame size	Infrared % fat	BIA ohms	BIA %fat	Density	UWW %fat
f52	16.3	hvy	sm	18.0	491	16.5	1.059	17.0
f53	23.3	hvy	med	18.5	541	21.7	1.051	20.8
f54	29.9	mod	med	24.4	544	28.8	1.023	32.9

Subject	Waist cm	Waist ins	Hip cm	Hip ins	W/H ratio	BMI	BMI %fat
f1	70	27.5	94	37	0.74	21.3	24.5
f2	67	26.5	96.5	38	0.70	23.15	27.3
f3	80	31.5	110.5	43.5	0.72	28.02	34.5
f4	68.5	27.0	100	39.5	0.68	19.97	22.6
f5	67	26.5	89	35	0.76	18.53	20.4
f6	68.5	27.0	96.5	38	0.71	20.62	23.5
f7	81	32	105.5	41.5	0.77	27.78	34.1
f8	73.5	29.0	101.5	40	0.73	26.31	32.0
f9	77.5	30.5	103	40.5	0.75	23.35	27.6
f10	61	24	86.5	34	0.71	18.48	20.4
f11	59.5	23.5	90	35.5	0.66	20.11	22.8
f12	63.5	25	94	37	0.68	19.85	22.4
f13						19.96	22.5
f14	61	24	89	35	0.69	18.79	20.8
f15	66	26	94	37	0.70	19.03	21.2
f16	71	28	101.5	40	0.70	21.77	25.2
f17	75	29.5	96.5	38	0.78	22.99	27.0
f18	104	41	122	48	0.85	37.02	47.8
f19	80	31.5	106.7	42	0.75	25.77	31.1
f20	73.6	29.0	102.8	40.5	0.72	26.64	32.4
f21	85	33.5	113	44.5	0.75	24.90	29.9
f22	78.1	30.8	97.8	38.5	0.80	23.26	27.4
f23	97.8	38.5	119.4	47	0.82	35.89	46.0
f24	76.2	30	102.8	40.5	0.74	23.22	27.4
f25	76.2	30	114.3	45	0.67	23.38	27.6
f26	63.5	25	87.6	34.5	0.72	17.61	19.1
f27	69.9	27.5	96.5	38	0.72	22.04	25.6
f28	66	26	91.4	36	0.72	22.02	25.6
f29	77.5	30.5	99.1	39	0.78	25.1	30.1
f30	61	24	89	35	0.69	17.5	18.9
f31	71.1	28	92.7	36.5	0.77	19.8	22.3
f32	76.6	29	96.5	38	0.76	21.5	24.8
f33	85.1	33.5	104.1	41	0.82	25.31	30.5
f34	82.55	32.5	101.6	40	0.81	23.78	28.2
f35	67.3	26.5	95.25	37.5	0.71	20.48	23.3
f36	61.0	24	87.6	34.5	0.69	19.7	22.2
f37	68.6	27	91.4	36	0.75	21.19	24.4
f38	63.5	25	87.6	34.5	0.72	18.32	20.1
f39	72.4	28.5	97.8	38.5	0.74	22.38	26.1
f40	74.9	29.5	99.1	39	0.76	24.83	29.7
f41	66.7	26.3	89	35	0.75	21.17	24.3
f42	63.5	25	90.2	35.5	0.70	17.54	18.9
f43	67.3	26.5	97.8	38.5	0.69	20.42	23.2
f44	72.4	28.5	100.3	39.5	0.72	22.55	26.4
f45	64.8	25.5	91.4	36.0	0.71	18.43	20.3
f46	66.0	26.0	91.4	36.0	0.72	21.02	24.1
f47	71.1	28.0	100.3	39.5	0.71	23.54	27.8
f48	69.9	27.5	99.1	39.0	0.71	24.42	29.1
f49	66.0	26.0	97.8	38.5	0.68	20.64	23.5
f50	68.6	27.0	104	41.0	0.66	21.90	25.4

Subject	Waist cm	Waist ins	Hip cm	Hip ins	W/H ratio	BMI	BMI %fat
f51	75.0	29.5	103	40.5	0.73	22.53	26.3
f52	66.0	26.0	92.7	36.5	0.71	20.06	26.7
f53	75.0	29.5	96.5	38.0	0.78	22.08	25.7
f54						24.47	29.2

FEMALES

Analysis Variable : SCORE

------------------------------ SF ------------------------------

N	Mean	Std Dev	Std Error
54	21.7351852	5.9477016	0.8093797

------------------------------ NIR ------------------------------

N	Mean	Std Dev	Std Error
54	22.2759259	6.2597226	0.8518403

------------------------------ BIA ------------------------------

N	Mean	Std Dev	Std Error
54	22.2407407	5.5052811	0.7491739

------------------------------ UWW ------------------------------

N	Mean	Std Dev	Std Error
54	23.0555556	6.3505063	0.8641945

------------------------------ BMI ------------------------------

N	Mean	Std Dev	Std Error
54	26.3000000	5.6016170	0.7622835

Analysis of Variance Procedure
Class Level Information

Class	Levels	Values
SUBJ	54	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54
TRIAL	5	1 2 3 4 5

Number of observations in data set = 270

Analysis of Variance Procedure

Dependent Variable: SCORE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	269	10088.51540741	37.50377475	.	.
Error	0	.	.		
Corrected Total	269	10088.51540741			

R-Square	C.V.	Root MSE	SCORE Mean
1.000000	0	0	23.12148148

Source	DF	Anova SS	Mean Square	F Value	Pr > F
SUBJ	53	7345.14340741	138.58761146	.	.
TRIAL	4	730.06985185	182.51746296	.	.
SUBJ*TRIAL	212	2013.30214815	9.49670825	.	.

Tests of Hypotheses using the Anova MS for SUBJ*TRIAL as an error term

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRIAL	4	730.06985185	182.51746296	19.22	0.0001

Analysis of Variance Procedure

Tukey's Studentized Range (HSD) Test for variable: SCORE

NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 212 MSE= 9.496708
Critical Value of Studentized Range= 3.891
Minimum Significant Difference= 1.6318

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	TRIAL
A	26.3000	54	BMI
B	23.0556	54	UWW
B			
B	22.2759	54	NIR
B			
B	22.2407	54	BIA
B			
B	21.7352	54	SF

MALES

Analysis Variable : SCORE

------------------------------------ SF ------------------------------------

N	Mean	Std Dev	Std Error
57	17.2561404	6.9321976	0.9181920

--- NIR ---

N	Mean	Std Dev	Std Error
57	17.0982456	6.3987022	0.8475288

--- BIA ---

N	Mean	Std Dev	Std Error
57	16.3122807	4.7165389	0.6247208

--- UWW ---

N	Mean	Std Dev	Std Error
57	17.6245614	7.1201495	0.9430868

--- BMI ---

N	Mean	Std Dev	Std Error
57	23.7385965	4.5477920	0.6023698

Analysis of Variance Procedure
Class Level Information

Class	Levels	Values
SUBJ	57	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 2829 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
TRIAL	5	1 2 3 4 5

Number of observations in data set = 285

Analysis of Variance Procedure

Dependent Variable: SCORE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	284	12305.31985965	43.32859106	.	.
Error	0	.	.		
Corrected Total	284	12305.31985965			

R-Square	C.V.	Root MSE	SCORE Mean
1.000000	0	0	18.40596491

Source	DF	Anova SS	Mean Square	F Value	Pr > F
SUBJ	56	7838.76785965	139.97799749	.	.
TRIAL	4	2078.40757895	519.60189474	.	.
SUBJ*TRIAL	224	2388.14442105	10.66135902	.	.

Tests of Hypotheses using the Anova MS for SUBJ*TRIAL as an error term

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRIAL	4	2078.40757895	519.60189474	48.74	0.0001

Analysis of Variance Procedure

Tukey's Studentized Range (HSD) Test for variable: SCORE

NOTE: This test controls the type I experimentwise error rate, but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 224 MSE= 10.66136
Critical Value of Studentized Range= 3.889
Minimum Significant Difference= 1.682

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	TRIAL
A	23.7386	57	BMI
B	17.6246	57	UWW
B			
B	17.2561	57	SF
B			
B	17.0982	57	NIR
B			
B	16.3123	57	BIA

Correlation Analysis

5 'VAR' Variables: SF NIR BIA BMI UWW

Simple Statistics

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
SF	54	21.568519	6.093016	1164.700000	11.300000	38.800000
NIR	54	22.275926	6.259723	1202.900000	7.700000	37.700000
BIA	54	22.240741	5.505281	1201.000000	12.800000	40.300000
BMI	54	26.298148	5.602240	1420.100000	18.900000	47.800000
UWW	54	23.055556	6.350506	1245.000000	10.700000	40.700000

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 54

	SF	NIR	BIA	BMI	UWW
SF	1.00000 0.0	0.69662 0.0001	0.84935 0.0001	0.77350 0.0001	**0.93411** 0.0001
NIR	0.69662 0.0001	1.00000 0.0	0.52552 0.0001	0.51594 0.0001	**0.71990** 0.0001
BIA	0.84935 0.0001	0.52552 0.0001	1.00000 0.0	0.86370 0.0001	**0.82290** 0.0001
BMI	0.77350 0.0001	0.51594 0.0001	0.86370 0.0001	1.00000 0.0	**0.71051** 0.0001
UWW	0.93411 0.0001	0.71990 0.0001	0.82290 0.0001	0.71051 0.0001	1.00000 0.0

Correlation Analysis

5 'VAR' Variables: SF NIR BIA BMI UWW

Simple Statistics

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
SF	57	17.256140	6.932198	983.600000	4.600000	31.500000
NIR	57	17.043860	6.423062	971.500000	4.800000	34.400000
BIA	57	16.394737	4.671090	934.500000	8.000000	34.400000
BMI	57	23.738596	4.547792	1353.100000	17.400000	35.900000
UWW	57	17.624561	7.120149	1004.600000	2.400000	33.800000

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 57

	SF	NIR	BIA	BMI	UWW
SF	1.00000 0.0	0.83184 0.0001	0.79180 0.0001	0.50378 0.0001	**0.92364** 0.0001
NIR	0.83184 0.0001	1.00000 0.0	0.78594 0.0001	0.64249 0.0001	**0.80031** 0.0001
BIA	0.79180 0.0001	0.78594 0.0001	1.00000 0.0	0.62409 0.0001	**0.81242** 0.0001
BMI	0.50378 0.0001	0.64249 0.0001	0.62409 0.0001	1.00000 0.0	**0.47384** 0.0002
UWW	0.92364 0.0001	0.80031 0.0001	0.81242 0.0001	0.47384 0.0002	1.00000 0.0000

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