ABSTRACT

DELISIO, Mary J. Comparison of hydrostatic weighing at residual volume and total lung capacity in boys. M.S. in Adult Fitness/Cardiac Rehabilitation, 1982, 55 pp. (Dr. Nancy K. Butts)

This study was designed to determine if hydrostatic weighing (HW) at total lung capacity (TLC) yield the same results as HW at residual volume (RV). Forty-two boys ($\bar{x}$ = 10.4 yr) from the La Crosse, WI, area were given a spirometry test to determine their vital capacity (VC). Three trials were performed and the highest reading was used as the measure of VC. The RV was determined on land utilizing the closed-circuit oxygen dilution technique. This value was added to the VC measurement and represented the SS' TLC. SS were instructed to perform HW at RV and TLC. The RV method consisted of a full expiration prior to submersion, and was performed until 3 identical readings were attained. The TLC consisted of a full inspiration prior to submersion, and was performed until 3 identical readings were reached. A dependent t-test was performed on these data at the .05 level. Small but statistical diff ($p < .05$) in body density and % fat values were observed. RV produced 1.0629 g/ml vs TLC 1.0640 g/ml. The TLC method resulted in a 0.4% lower % fat than the RV method. Although the diff between body composition parameters determined by HW at RV and TLC were statistically sig they were within the $\mp$ 4% error estimated in achieving body density through HW (Siri, 1961). HW at TLC is a possible method for children who are uncomfortable in the water and are unable to perform the RV method of a maximal expiration.

# COMPARISON OF HYDROSTATIC WEIGHING
# AT RESIDUAL VOLUME AND TOTAL LUNG CAPACITY IN BOYS

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A Thesis Presented

to

The Graduate Faculty

University of Wisconsin-La Crosse

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by

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# CHAPTER I

# INTRODUCTION

There are many techniques available for determining body density in order to estimate percent body fat. Hydrostatic weighing has been accepted as the standard procedure for determining density. This procedure involves the Archimede's Principle which states that an object immersed in a fluid loses an amount of weight equivalent to the weight of the fluid which is displaced (Behnke, Feen, & Welham, 1942). Fat is the only substance in the human body which is less dense than water. Therefore, the measurement of body density, as done in hydrostatic weighing, can be employed to estimate the percent body fat.

In order to obtain an accurate estimation of body density by means of hydrostatic weighing the volume of air in the lungs must be accounted for, due to the fact that air adds bouyancy. This in turn would decrease the weight of the body when submerged. Past hydrostatic weighing protocols have had a subject expire maximally before submerging under the water. The air that remained in the lungs after this maximal expiration is the residual volume (RV). A hydrostatic weighing technique which involves the measurement of the body weight while submerged at the time of a maximal expiration, is known as the residual volume technique. According to Katch (1969) many subjects have difficulty in performing the residual volume technique; therefore, he felt a learning process must take place.

Since many individuals have difficulty with the residual volume technique, ca.. another lung measurement or procedure be used in the calculation of body density? One such technique which accounts for the air in the body involves the measurement of total lung capacity (TLC). This technique of hydrostatic weighing involves a maximal inspiration prior to submersion. Recently, Weltman and Katch (1981) performed hydrostatic weighing on adults comparing RV and TLC. A high correlation (r = 0.95) between the two measures was found in determining body density. Weltman & Katch (1981) indicated that the subjects felt more comfortable and stable in performing the TLC technique compared to the RV.

Measurement of body density in children using hydrostatic weighing has been investigated by several researchers utilizing the RV technique. One known study conducted by Wells, Reynolds and Jessup (1982) compared RV and TLC in twenty prepubescent boys. They concluded that hydrostatic weighing may be enhanced with the TLC method with children who are uncomfortable in the water.

## Statement of the Problem

The problem of this study was to determine if there is a significant difference in the density calculated by the RV, compared to the TLC method during hydrostatic weighing of boys.

## Need for the Study

Many individuals feel uncomfortable in the procedures involved in hydrostatic weighing. The accuracy in determining body density and body fat by hydrostatic weighing is dependent on lung volume measurements. If subjects are unable to perform the RV technique, the measurement of body density will be inaccurate. Total lung capacity has been recently investigated in determining body density in hydrostatic weighing (Thomas & Etheridge, 1980; Weltman & Katch, 1981). These investigations were performed on adults, hence it was this researcher's opinion that TLC technique needed to be investigated in children. Recently Wells et al. (1982) compared RV and TLC in hydrostatic weighing with twenty males aged 9 to 12. Their results showed a linear correlation (r = 0.89) between the two body density measures.

## Purpose of the Study

The purpose of the study was to compare densities and percent fat obtained from RV and TLC techniques in hydrostatic weighing, in boys between 8-12 years.

## Hypothesis

The hypothesis of this study was stated in the null form.

There is no significant difference in body density between the methods utilizing RV as opposed to TLC in hydrostatic weighing of boys.

## Assumptions

The following were assumptions of the study.

It was assumed that all subjects expired maximally in the RV technique.

It was assumed that all subjects inspired maximally in the TLC method.

It was assumed all subjects fasted for the required period of time.

## Delimitations

The following were delimitations of the study.

The subjects were all volunteers from the La Crosse, Wisconsin, area.

All of the subjects were boys between the ages of 8 to 12 years.

All subjects were considered to be in good health.

All subjects felt comfortable in the water.

## Limitations

The following were limitations of the study.

The subjects chosen for the study were not selected randomly.

The number of trials for the RV technique was limited to 10.

The measurement of RV utilizing the oxygen dilution technique is an accurate measurement.

## Definition of Terms

The following terms have been defined according to McArdle, Katch, & Katch (1981).

Archimede's Principle - an object immersed in a fluid loses an amount of weight equivalent to the weight of the fluid which is displaced (Behnke, 1942).

Density - the mass per unit volume of body (D = M/V), expressed as gm/cc (Goldman & Buskirk, 1961).

Expiratory Reserve Volume - the amount of air that can still be expired after the end of a normal tidal expiration.

Functional Residual Capacity - equals the expiratory reserve volume plus the residual volume. The amount of air remaining in the lungs at the end of a normal expiration.

Hydrostatic Weighing - an indirect procedure to determine body density by the process of weighing a body under water. Percent body fat is computed from body density (ratio of body weight to body volume).

Inspiratory Capacity - equals the tidal volume plus the inspiratory reserve volume. The amount of air that a person can breathe beginning at the normal expiratory level and distending his lungs to the maximum amount.

Inspiratory Reserve Volume - the extra volume of air that can be inspired over and beyond the normal tidal volume.

Lean Body Mass (LBM) - a quantitative expression of lean body weight consisting of bones, muscle and organs, and it is usually expressed in kilograms (kg) or pounds (lbs).

Percent Body Fat - the percentage of total body weight that consists of storage fat found in adipose tissue and essential fat.

Residual Volume - the volume of air still remaining in the lungs after the most forceful expiration.

Spirometry - a method used for studying pulmonary ventilation. A spirometer records the volume movement of air into and out of the lungs.

Tidal Volume - the volume of air inspired or expired with each normal breath.

Total Lung Capacity - the maximum volume to which the lungs can be expanded with the greatest possible inspiratory effort.

Vital Capacity - equals the inspiratory reserve volume plus the tidal volume. The maximal amount of air that a person can expel from the lungs after a maximal insoiration.

# CHAPTER II

# REVIEW OF LITERATURE

## Introduction

The use of body density obtained from hydrostatic weighing for the prediction of the fat content is limited by both biological and technical sources of variation. As Katch (1968) has demonstrated, hydrostatic weighing at RV requires a series of learning trials to properly perform the standard hydrostatic weighing procedures as described by Goldman & Buskirk (1961). The alternative method of TLC could be utilized if it statistically yields the same results as the RV technique, especially with children who appear to experience difficulty with the RV technique.

Studies dealing with the development of formulas for determining body density and percent fat, the methods of hydrostatic weighing, lung volumes, body composition in children, and other pertinent topics are reviewed in this chapter.

## Development of the Formula to Predict Body Density and Percent Fat

Archimede was the first to state the significance of the relationship of weight to volume. Archimede's Principle states that a body immersed in a fluid loses an amount of weight equivalent to the weight of the fluid which is displaced (Behnke et al., 1942).

Body volume can be calculated through hydrostatic weighing by subtracting the body's underwater weight from the dry or land weight.

(Equation 1)

$$\text{Density (D)} = \frac{\text{weight in air } (M_A)}{\text{loss of weight in water } (M_A - M_W)}$$

(Goldman & Buskirk, 1961, p. 78)

In 1961, Goldman & Buskirk considered the density of the water during hydrostatic weighing procedures. A correction factor obtained from the temperature of the water was necessary to obtain the exact volume of the water displaced by the body. They recommended the temperature of the water in the underwater weighing tank to be at body temperature (35-36°C). The density of the water at this temperature is approximately 0.944 g/ml. The following equation was derived recording the water, temperature and applying the relating density value:

(Equation 2)

$$D = \frac{M_A}{\frac{M_A - M_W}{D_W}}$$

(Goldman & Buskirk, 1961, p. 79)

<u>Where</u>: DW = density of water

(at 35-36°C correction factor = 0.994 g/m).

Since gas adds buoyancy, the quantity of air in the gastrointestinal (GI) tract must be accounted for in determining an accurate body density value (Thomas & Etheridge 1980). The findings of Bedell, Marshall, DeBois, and Harris (1956) estimated the value of 100 ml to account for the air in the GI tract. The amount of air in the GI tract will vary in each individual, however one can reduce this by having subjects fast for twelve hours (Goldman & Buskirk, 1961).

Another gas that needs to be accounted for is the remaining air in the lungs after a maximal expiration. This volume is referred to as the Residual Volume (RV). A number of methods have been developed for determining RV and include: (1) the closed-circuit method, which involves a dilution followed by equilibrium of an inert gas, (2) open-circuit technique, involves breathing oxygen where nitrogen is "washed out", and (3) pneumatometric approach, a form of whole-body plethysmorgraph. In this study the closed-circuit oxygen dilution method described by Wilmore (1969) was utilized. The following formula was established taking into account the RV and air in the GI tract:

(Equation 3)

$$D = \frac{M_A}{\frac{M_A - M_W}{D_W}} - RV - .1 \text{ liter}$$

(Buskirk, 1961, p. 102)

Conversion of Body Density to Percent Fat

A number of formulas exist for predicting percent fat from the calculated body density. The formulas are slightly varied due to the inability of researchers to agree on the exact density of lean body mass. None of the equations have been derived from studies on children.

Rathburn & Pace (1945) studied the fat content of male and female guinea pigs. They determined 0.918 and 1.10 to be the specific gravity of fat and fat-free tissue, respectively. They derived the following formula for humans:

(Equation 4)

$$\% \text{ Fat} = \left(\frac{5.548}{\text{specific gravity}} - 5.044\right) \times 100$$

(Rathburn & Pace, 1945, p. 675)

Keys & Brozek (1953) criticized the findings of Rathburn and Pace (1945) in the derivation of the specific gravity or density. Keys & Brozek (1953) studied the density of fat in men and women and various animals. A density value of 0.90074 for human fat at a temperature of 36°C was reported. They derived the following formula:

(Equation 5)

$$\% \text{ Fat} = \left(\frac{4.201}{\text{body density}} - 3.813\right) \times 100$$

(Keys & Brozek, 1953, p. 280)

Siri (1961) felt that a fat-free body should be used in the development of a conversion formula. It was determined by Siri (1961) the values of 1.100 lean body mass and 0.900 fat should be used in the development of the formula:

(Equation 6)

$$\% \text{ Fat} = \left(\frac{4.95}{\text{body density}} - 4.50\right) \times 100$$

(Siri, 1961, p. 230)

Brozek, Grande, Anderson and Keys (1963) derived a formula estimating the chemical composition of the body. Dividing the body into compartments, chemical components, and analyzing each, a fat density of 0.915 was derived. The following formula was derived:

(Equation 7)

$$\% \text{ Fat} = \left(\frac{4.570}{\text{body density}} - 4.142\right) \times 100$$

(Brozek et al., 1963, p. 131)

Brozek et al. (1963) stated that this formula is thought to be the most valid, especially in individuals who do not experience a constant fluctuation in body weight. A study conducted by Wilmore & Behnke (1969) found a high correlation of 0.995-0.999 between the values obtained from the different formulas.

A standard deviation of ±4% represents error in the prediction of percent body fat by hydrostatic weighing (Siri, 1961). This error can be due to technical difficulties in the measurement of body density. Error may exist from the inability of the individual to perform the hydrostatic weighing procedures, and the RV used in the calculations. Even if no error existed in measuring density, the uncertainty in fat estimate would remain ±3.8% of body weight due to normal variability of body constituents, and the uncertainty in establishing the compositions of adipose tissue (Siri, 1961).

There has been some disagreement among researchers regarding the assessment of the appropriate volume of air in the lungs during hydrostatic weighing. Weltman & Katch (1981) studied hydrostatic weighing comparing RV and TLC. A small but statistical significant difference was found between hydrostatic weighing at RV and TLC.

## Methods of Hydrostatic Weighing

In addition to the RV and TLC methods, other methods of hydrostatic weighing have been researched. Underwater weighing subjects with the use of a snorkel was investigated by Katch (1969). The subject was instructed to breath through a snorkel while underwater. The underwater weight was taken following a maximal expiration, held for approximately 5 seconds. A progressive increase in weight between trials was observed, due to a practice effect. Katch (1969) concluded that the use of a snorkel reduced the fear or apprehension concerned with breath-holding underwater, followed by a maximal expiration.

Luft & Lim (1961) obtained the underwater weight and expiratory lung volume by a different method. In their study the subject was instructed to take 10 deep breaths followed by a maximal inspiration. The subject then exhaled into a spirometer. He then removed his mouthpiece and submerged underwater. The amount of air was recorded on a spirometer. The gas volume in the lungs was accounted for by subtracting the exhaled volume from the previously determined total lung capacity, which was calculated from adding VC and RV measurements.

Jensen (1979) underwater weighed children at the level of RV and one liter of air. The subject would attempt a maximal exhalation into a mouthpiece attached to a two-way breathing valve. A rubber bag comprising one liter of air was attached to the valve. After the subject completed his maximal expiration he would inhale the one liter of air and submerge, and the weight was obtained.

Thomas & Etheridge (1980) performed hydrostatic weighing at functional residual capacity (FRC) and RV using a specialized valve attached to a spirometer. The subject would submerge while breathing room air through a valve. To measure FRC the valve was turned into the attached spirometer and normal respirations were monitored, and weight was recorded. To obtain the RV, the subject was instructed to exhale maximally through the valve and the weight was recorded.

# Lung Volumes

## Residual Volume

It was indicated by Welch & Crisp (1958) that RV is least affected by hydrostatic pressure, and is the easiest lung volume to reproduce. Residual volume measures have been a standard practice due to the findings of Welch & Crisp (1958). However, when assessing hydrostatic weight, the use of RV in computation may be source of error. An investigation by Girandola, Wiswell, Mohler, Romero, & Barnes (1977) noted an increase of 6.7% in the RV when determined in the water. If the subject was unable to expire to the level of RV, the underwater weight would be inaccurate (Behnke & Wilmore, 1974). An increase in body volume without a weight change due to an increase in inspiration of air would cause density to decrease (Donoghue & Minnigerode, 1977).

An increase in pressure on the thorax when immersed in water causes significant fluctuations in lung volumes. A 10% reduction was found in the RV measured during immersion (Jarret, 1950; Hong, Ting, & Rahn, 1960).

It was noted by Sawka, Weber, & Knowlton (1978) that high density values were determined if RV was measured on land. It was shown by Jarrett(1965) that measuring RV immersed in the upright position caused the residual gas volume of the lungs to decrease. According to Christian, Lupi-H, & Anthonisen (1976) an influence by the loss of lung recoil resulted with immersion when measuring RV, which caused a decreased value. Leith & Mead (1967) pointed out that young subjects are more susceptible to alternations in RV as a result of hydrostatic pressures. Bondi, Young, Bennett, & Bradley (1976) concluded that at full expiration during immersion, airways both large and small are compressed. The smaller airways can be compressed to the point of collapse.

Robertson, Engle & Bradley (1978) demonstrated the RV to be less when measured by the dual inert gas dilution technique than measured by the plethysmographic method during immersion. The decrease in RV obtained by the dual inert gas dilution technique was attributed to gas trapping during immersion. Evidence from Collins, Cochrane, Davis, Benatar, & Clark (1973) has shown that increased thoracic fluid volume leads to increased airway closure, causing a decrease in RV when measured underwater. Significant differences in body density were identified when using RV measured on land and in water (Girandola et al., 1977). It was concluded that when obtaining body density values, RV should be measured concurrently while the subject is in the water. However, the following studies (Carey, Schaefer & Alvis, 1956; Craig & Ware, 1967; Prefaut, Lupi & Anthonisen, 1976) found no change when measuring RV during immersion.

Total Lung Capacity

Researchers differ regarding which lung volume to assess during hydrostatic weighing to achieve the most accurate estimation of body density and percent fat. Weltman & Katch (1981), comparing hydrostatic weighing at RV and TLC, concluded that hydrostatic weighing with TLC offers several practical advantages over hydrostatic weighing with RV. Having the lungs entirely filled can reduce the psychological effect of hydrostatic weighing (Brozek et al., 1963).

A recent study conducted by Wells et al. (1982) investigated the measurement of body density in children using hydrostatic weighing with both RV and TLC. A high linear correlation ($r = 0.89$)

between the two density measures was obtained. It was concluded that hydrostatic weighing with children who are uncomfortable in water may be enhanced if TLC is used. They indicated that further studies are needed.

Total lung capacity showed a slight decrease when measured in water, which has been attributed to a shift of blood to the chest and also the hydrostatic forces opposing the inspiratory muscles (Christian et al., 1976). Larger lung volumes in hydrostatic weighing may reduce air trapping which is a result of closure due to hydrostatic forces on the chest (Dahlback & Lundgren, 1972). Water immersion has been found to cause as much as 20 to 40% shift of blood volume in the thoracic area which produces marked decreases in pulmonary compliance (Arborelius, Baldwin, Lilji, & Lundgren, 1972; Begin, Epstein, Sackner, Levinson, Dougherty, & Duncan, 1976; Boundurant, Hickman, & Isley, 1957).

Immersion in water resulted in an increase in intrapulmonary pressure in relax:d, breath-holding subjects. Maintaining a relaxed position while holding one's breath throughout the maneuver of submerging in the water was shown to be difficult in a study conducted by Jarrett (1965). Due to hydrostatic pressure applied upon the chest, TLC and VC decreased when measured underwater (Agostoni et al., 1966; Carey et al., 1956; Craig et al., 1967; Hong et al., 1969; Prefaut et al., 1976).

## Body Composition in Children

Knowledge of body composition has major significance in disease, health, and care of children. However, little information with regard to chemical composition of the body and the components of body weight gain or loss during this growth is available (Macy & Kelly, 1956).

Factors such as growth, sexual maturation and physical activity affect body composition in children. Due to the growth stages of children, their changes in weight, statures, or chemical composition may be entirely different at one stage of development than another (Macy & Kelly, 1956).

An evaluation of body weight with specific reference to fat, fat-free mass, water, and mineral was investigated by Moulton (1923). Moulton discovered the concentration of water, protein, and ash of the fat-free mass became more or less stationary after appreciable changes occurred. He described this state of body composition as chemical maturity.

Maresh (1955) studied bone growth in children. His results showed the childhood patterns of long-bone growth were found to be stable and orderly at about the age of three or four, and continued in to the pre-pubescent years. In the newborn, bone is thought to be 3% of body weight and by childhood bone content comprises approximately 7% of body weight (Malina, 1969).

During maturation of children, the chemical composition of the body increases and moves closely toward adult values. The nitrogen, calcium, potassium, magnesium and phosphorus content will increase, while water, sodium, and chloride levels decrease (Forbes, 1962). When growth is rapid, the changes in the chemical composition are rapid and the changes are slow when the rate slows (Forbes, 1962).

Extensive studies have been made over the past 50 years of the physiology of body fluid in children, however few measurements of total body water have been reported. This lack of information can be attributed to a lack of a suitable method of measurement applicable to the living subject (Friis-Hansen, 1961). A rapid decrease in total body water and extracellular water was found during the first year of life. A small decrease of the volume of extracellular water occurs later in childhood (Friis-Hansen, 1961).

The largest component of the body is water, comprising 72 - 73% of fat-free body (Malina, 1969). Edelman, Haley, Schloberb, Sheldon, Friis-Hansen, Stoll & Moore (1952) determined total body water of both sexes throughout the life span by using the deuterium oxide dilution technique. This technique determines total body water by dilution of deuterium oxide. It may be 1 to 2% higher than actual water volume due to exchange of deuterium with labile hydrogen atoms in proteins and carbohydrates. Subjects between two days and 86 years were measured. The mean body water was lower in females studied than in males of the same age. Total body water determined for males one to nine years was 55.2 to 62.8% of body weight, and from 10-16, 51.8 to 63.2%. According to Edelman et al.(1952), 59% was the estimated total body water in childhood. It was concluded by Friis-Hansen, Holiday, Stapleton, & Wallace (1951) that changes in body water when expressed as a percentage of body weight were due to the differences in the amount of fat. If the percentage of water in the lean body is constant, total body fat can be calculated (Brook, 1971).

Body fat and lean body mass change considerably during growth. Body fat tends to accumulate during growth. In fetal life 0.3-1% of body weight is fat. Until the third trimester of pregnancy, this percentage slowly increases. At birth fat content is approximately 12-16% (Forbes, 1962). Fat content continues to increase during infancy and increases more gradually during childhood. The constant ratio of total body fat is formed by subcutaneous fat (Parizokova, 1961). This relationship changes during development and aging. There is a shift of fat from the subcutaneous layer to the body cavities, and from extremities to the trunk. In healthy children the greatest proportion of body fat is in the form of subcutaneous fat and the ratio of total body fat and subcutaneous fat approaches the ratio found in adults (Parizkova, 1961).

Parizkova (1961) noticed a turning point in development in boys aged 12-13. A temporary decline of body density occurred in boys between the ages of 10-12 years (average body density, 1.048 g/ml), and with the onset of puberty the body density increased considerably (average 1.063 g/ml). Parizkova (1968) conducted a longitudinal study of the development of body composition in 11 year olds, following them up until the age of 15. The group of boys was separated into groups from highest activity to lowest activity. At the age of 11 the average percent body fat of the highest activity group was 15.7% and 17.2% in the lowest activity group. At the age of 12, the average percent fat of the highest activity group was 14.1% and 19.1% in the lowest activity group. A decrease in percent fat was noticed in the highest activity group up until the age of 15, and a decrease in percent fat was also noticed in the lowest activity group. The only increase in percent fat occurred between the age of 11 to 12 in the lowest activity group.

Macy & Kelly (1956) studied body composition in children aged 4-12. In the group of 7-9 year old boys an average percent body fat of 24% was attained. It was estimated in the 10-12 year old boys an average percent fat of 28. In a study conducted by Slaughter, Lohman, & Misner (1977), a mean percent fat of 22.4% was attained in boys age 7-12. Forbes &

Amirhakimi (1970) studied body fat in boys between 8 and 12 years. Fat weight of 4.4 kg was seen in the 8 year olds and 13 kg was the average fat weight for the 12 year olds. Macy & Kelly (1956) found there was 3.5 - 12.2 kg of fat weight in boys aged 7-12.

Sady, Thompson, Savage & Petrates (1982) compared body composition data reported from wrestlers and a control group of boys 9 to 12 years. In their study, the average percent fat value achieved from the wrestlers was 13.3%, and 20% in the control group. The average fat weight of 7.4 kg was obtained from the control group and 4.2 kg was obtained from the wrestlers. In a study conducted by Cureton, Borleau & Lohman (1975), body density and thickness of subcutaneous fat in different age groups were looked at. In the 10-12 year old boys, a body density of 1.0628 g/ml was attained estimating 15.8% body fat. Wilmore & McNamara (1974) studied body composition of 95 boys between the ages of 8-12. The average body density value of 1.056 g/ml was attained, estimating 18.7% as the average percent fat for this age group.

According to Malina (1969) muscle weight of a newborn is comprised of approximately 25% of the total body weight. In the average adult male, muscle weight is thought to be 40% of body weight. Muscle weight in boys 5 years old increased from 42% to 50.3% at age 13. Following this increase to the age of 13, a slight decrease followed (Malina, 1969).

The results of a study conducted by Forbes (1972) showed LBM to rise from a mean value of 21 to 26 kg in the 8 to 9 year old boys. Maximum LBM values of 59 to 67 kg were seen in the 18 to 20 year olds. After this age a slow decline continues at a slow pace throughout adult life. Only a few "organs" in the body exhibit negative growth, adipose tissue is one in which this occurs (Forbes, 1972).

In children aged 7-12, lean body mass of 26.2 kg was derived by Slaughter et al., (1977). According to Forbes (1972) the average value for the LBM of 8 year old boys was 22-23 kg. This value then begins to rise rapidly after age 10 to a maximum of 62 kg in males. Sady et al., (1982) compared the body composition of wrestlers to a control group of 9 to 12 year olds. An average lean weight of 28.3 kg was found in the control group, and 27.5 kg in the wrestlers.

Conversion of Body Density to Percent Fat in Children

No systematic investigations have been made of the relationship of body fat and subcutaneous fat in children. The greatest proportion of body fat in normal healthy children is formed by subcutaneous fat, and during growth, the ratio of total body fat is probably very similar to adults (Parizkova, 1961). No specific research, however, has been conducted to convert density to percent body fat in children.

Moulton (1923) concluded that early in childhood fat-free protoplasm reaches a constant chemical composition with no substantial change. This does not imply, however, that the values of density for fat-free body mass in children agree with similar values for adults.

Due to the lack of knowledge of body composition in children, no specific equation exists for converting body density to percent fat in children (Durnin & Rahaman, 1967). It was concluded by Malina (1969) that a direct analysis of adipose tissue of children is needed to assess the relationship of converting density to percent fat. The cadaver studies upon which various formulas are based have not included children (Sady et al., 1982).

Siri (1961) estimated a standard deviation close to ± 3.4%. To approximate the uncertainty for estimating fat from density, it requires that all adult humans be identical in composition except for differences in their proportions of adipose tissue. According to Bakker & Struikenkamp (1977) a biological variation in lean body mass density corresponds to a 3.4% standard deviation when estimating fat content. In the general population, estimating biological variation of fat-free body and lean body mass yield similar results for estimating fat. However, for certain homogeneous populations (i.e., gymnasts, long distance runners, etc.), the reduction error in estimating fat may be considerable (Lohman, 1981).

Body densities are known to change from population to population. Taking into account age changes and sex differences Brozek (1961) pointed out quantitative corrections of the formula for predicting body fat. A value of 1.10 gm/cc was established for young sedentary adult males (Brozek, 1961). For children it would appear the fat-free body density is lower than 1.100 gm/cc, because of the differences in the chemical composition of water content, bone, and fat-free adipose tissue (Lohman, 1981).

There seems to be a wide range of normal percent fat for boys noticed by Sady et al., (1982). Wilmore & McNamara (1974) noted in their study that high relative fat values are most likely the result of using equations developed for mature adults. The reason for this inconsistency may be the result of assumed density of the lean tissue in the formulas used to convert body density to percent fat, which may be too high for younger boys. This can be due to the differences in total body water and density of bone between the immature boy and the man. Younger boys have higher total body water and lower bone density than a mature man. This may result in a lower value for the density of the lean tissue, which would lower calculated values for percent fat (Wilmore & McNamara, 1974).

## Conclusion

Hydrostatic weighing has been accepted as one method of determining body density in order to predict percent fat. However, differences exist concerning which lung volume to assess during the hydrostatic weighing, due to the apparent inconsistencies found by different researchers. Residual volume obtained on land or in the water was investigated by several researchers. The results of performing RV while being submerged or while on land were inconsistent. These results may be attributed to the individual's ability to perform the maneuver of a full expiration prior to submersion. Hydrostatic weighing with TLC has been shown to offer several practical advantages over RV. Reducing the psychological effect can enable the subject to feel comfortable and stable while submerged. Increasing the time the investigator had to obtain the underwater weight may enable a more accurate reading.

Further studies are needed concerning body composition in children. Changes that occur throughout a child's development need to be thoroughly investigated to obtain appropriate analysis of body composition. Although body density calculated from hydrostatic weighing has been investigated in children, no specific formula exists for converting the density to percent body fat.

## CHAPTER III

## METHODS

### Introduction

The methods and procedures used in this study are presented in the following sequence: Subject selection, general procedures, testing procedures and statistical treatment.

### Subject Selection

A total of 42 boys ranging from 8-12 years were subjects for the study. The subjects were volunteers obtained through announcements to faculty members and participants in the Adult Fitness and Cardiac Rehabilitation Programs at the University of Wisconsin-La Crosse. Interested parents received a letter of information explaining the procedures involved (see Appendix A). All procedures and potential risks were explained to the parent and subjects. A consent form to be read and signed accompanied the procedural letter (see Appendix B).

### General Procedures

Participation in the study involved two to three visits to the Human Performance Laboratory at the University of Wisconsin-La Crosse. The first visit was an orientation to the general procedures. All procedures and possible risks were again explained to the subject and their parents. During the first visit, the subject was introduced to the spirometry procedure, residual volume and underwater weighing procedures. Measurements of each procedure were taken during the first visit as a practice trial. The second visit to the laboratory involved a repetition of the same measurements. Data were collected during the second visit if the investigator felt confident that the performance of the child was maximal. If a child was unable to perform the procedures accurately in the researcher's opinion during the second visit, a third visit was scheduled.

## Instrumentation and Procedures

### Pilot Study

A pilot study (n = 7) was conducted to determine the test-retest reliability of the methods of RV and TLC. The procedures used for this pilot study were identical to those presented below. The subjects were boys between 8-12 years old. Results of this pilot study are included in Chapter IV.

## Spirometry-Measurement of Vital Capacity

### Introduction

Total lung capacity was determined by adding the measurements of Vital Capacity (VC) and RV. Vital Capacity is the total volume of air that can be expelled from the lungs after a maximal inspiration. This lung volume can be calculated directly from a spirometer. All gas volumes were measured at Ambient Temperature and Pressure Saturated (ATPS) and converted to Body Temperature and Pressure Saturated (BTPS).

### Equipment

The following equipment was used for measuring VC: A Collins 13.5 liter recording spirometer, nose clip, chart paper, chart pen, mouthpiece, and a metric ruler.

### Procedures

The subjects were instructed to sit comfortably facing the spirometer. All instructions were explained and demonstrated to the subjects before the trial. Following instructions, a nose clip was placed on the subject's nose to insure that all expired gas would pass through a rubber mouthpiece. The subjects were instructed to place their mouth over the entire mouthpiece. In each trial the subjects were instructed to inspire maximally, then expire as completely as possible. Three trials were performed with a few minutes between each trial to allow the subjects to relax. A vertical line was drawn by the spirometer indicating the volume of air inhaled and exhaled.

### Calculations

The vertical lines displaced by the spirometer drum represented the volume of air inhaled and exhaled. Each line was measured with a metric ruler, and the line measuring the greatest was the value used in the calculation of VC. This value was converted to milimeters (mm) and was multiplied by a conversion factor, which was obtained from the temperature of the spirometer from a conversion chart. This value was converted to liters and represented VC at BTPS.

## Residual Volume

### Introduction

The RV is the amount of air left in the lungs after a maximal expiration. The method used to measure RV was the closed-circuit oxygen dilution technique described by Wilmore (1969). Inspired and expired air was analyzed continuously by a Collins Nitrogen Analyzer (model number 21232).

Equipment

The equipment needed in the testing of RV included: A modified Collins 6 liter recording spirometer, A Collins Nitrogen Analyzer (model number 21232), oxygen (medical grade, dry), two-way breathing valve, corrugated plastic hose, nose clip, an adjustable valve holder assembly and stool.

Procedures

Calibration of the RV apparatus was conducted each day prior to testing. This involved the use of a six liter spirometer which measured the volume of oxygen used during the trials to determine RV. A total of ten sample volumes were entered into the spirometer for 4.5 seconds. The average of the 10 sample volumes was used as the amount of pure oxygen introduced into a five liter rubber breathing bag. The pure oxygen would enter into a five liter rubber breathing bag by opening a two-way valve. The bag was vacuumed free of air before the oxygen would pass through the valve. Flushing of pure oxygen and vacuuming gas contents were performed 2 to 3 times to assure a pure concentration of oxygen.

For the RV determination, the subjects were seated in front of the Nitrogen Analyzer which determines the percent of nitrogen in the inspired and expired air. The subjects were instructed to lean slightly forward in a position closely related to the position obtained in the underwater weighing tank.

The procedures were explained to the subjects prior to the measurement. A nose clip was fastened over each subject's nose and the subjects were instructed to place their mouth around the mouthpiece. The subjects were instructed to breath normally for a few seconds, and then instructed to inspire maximally followed by a maximal expiration. At the completion of the maximal expiration, the subjects were instructed to signal the investigator by tapping her on the hand. The initial alveolar nitrogen concentration ($AN_2$) was recorded for each subject. At that time the subjects were immediately connected to the bag of pure oxygen by closing the valve to room air. The subjects were then instructed to breath reasonably deeply and quickly. At this point the impurity of nitrogen in the original volume of oxygen was recorded ($IN_2$). Rebreathing continued until an equilibrium was reached between the oxygen in the bag and the air remaining in the lungs; this measurement was recorded ($EN_2$).

When the equilibrium was reached, the subjects were instructed to take a deep breath in, and then expire maximally. The subjects once again tapped the investigator when they expired all of their air. The final concentration was recorded ($FN_2$) and the subjects were instructed to remove their mouth from the mouthpiece. A second trial was performed with a few minutes of rest between trials. If a difference of 60 ml was observed between trials, a third trial was performed, and the average of the trials was used.

Calculations

Residual Volume was calculated by the following: (The data sheet used in the test is presented in Appendix C.)

$$RV = \frac{VO_2 \; (EN_2 - IN_2)}{(AN_2 - FN_2)} - DX \times \text{BTPS Factor}$$

Where:

$VO_2$ = the initial volume of oxygen in the spirometer system, including the dead space between the spirometer bell

$EN_2$ = decimal fraction of nitrogen at the point of equilibrium

$IN_2$ = decimal fraction of nitrogen initially in $VO_2$

$AN_2$ = decimal fraction of nitrogen in alveolar air initially when breathing room air

$FN_2$ = decimal fraction of nitrogen in alveolar air at the end of the test

DS = the dead space of the mouthpiece, sensing element of nitrogen analyzer, and a small portion of the breathing valve, which represented .05.

(Wilmore, 1969, p. 96)

## Hydrostatic Weighing

### Introduction

Hydrostatic weighing is thought to be the standard in the prediction of body density and is based on Archimede's Principle. This principle states that an object immersed in a fluid loses an amount of weight of the fluid which is displaced. Subjects were weighed by two different methods. One method used RV and the other used TLC for determination of body density and percent fat.

### Equipment

The equipment used for hydrostatic weighing included: A 4' x 4' x 4' water immersion tank (model number 09771), autopsy scale (Chatillion & Son, New York, N.Y., model number 8-2096 accurate to 25 grams), water thermometer, diving weights, submersible seat, nose clip, beam balance, and Continental Health-O-Meter Scale (model number 400 DLK).

### Procedures

Prior to the underwater weighing, the subjects were asked to fast for at least six hours. Before entering the tank, dry weight was obtained on a Continental Health-O-Meter scale, with the subjects dressed in their swim suits. The subjects were then instructed to shower to remove any dirt and oil from the skin. The subjects entered the tank and were instructed to sit comfortably on the chair. The chair was suspended from a 15 kg autopsy scale graduated in 25 gm increments, fastened to the ceiling. At this point the subjects were asked to draw a number out of a box to indicate which test would be performed first, either the RV or TLC technique. The subjects were then instructed to remove air trapped in their swimming apparel by rubbing their suits.

Residual Volume Method

The investigator explained the procedures of the specific test to each subject. A nose clip was securely placed on the subject's nose. The subjects were asked to move slowly when submerging under the water, holding on to the sides of the chair for support. The subjects were instructed to take a deep breath in, then submerge as they maximally exhaled. If any air remained in the lungs, the subjects were instructed to blow it all out under the water. Below the surface, the head was lowered and drawn toward their knees. While the subjects were completely submerged, the investigator obtained the weight from the autopsy scale. The investigator knocked on the tank to signal to the subjects to sit in the upright position, with their head out of the water. This procedure was repeated until three identical weights were recorded. Appropriate time was given between each trial to allow the subjects to relax.

Calculations. The weight of the chair was measured prior to testing and was subtracted from the observed weight. Body density was calculated according to the following formula: (The data sheet used in the testing is presented in Appendix D.)

$$DB = \frac{M_A}{\left(\dfrac{M_A - M_W}{D_W}\right) - RV - 0.1 \text{ liter}}$$

Where:

DB = body density

MA = mass in the air in kg

MW = mass in the water

DW = density of the water

0.1 liter = air in the gastro-intestinal tract

RV = residual volume determined by the closed-circuit oxygen dilution technique

(Buskirk, 1961, p. 102)

The body density value was calculated in the following formula to determine percent body fat:

$$\% \text{ Fat} = \left[\frac{4.570}{D_B} - 4.142\right] \times 100$$

(Brozek et al., 1963, p. 131)

Total Lung Capacity

Total Lung Capacity procedures were explained to the subjects. The procedures were similar to that of RV with the exception of asking the subjects to inhale maximally before submersion. The subjects would submerge themselves under the water similar to the RV method. Breath was held until the weight underwater was obtained. A knock on the tank was given to signal to the subjects to sit in the upright position, with their head out of the water. This procedure repeated until three identical weights were recorded. Appropriate time was given between each trial to allow the subject to relax.

Calculations. The percent fat (Brozek et al., 1963) and body density (Buskirk, 1961) were calculated from the standard formulas presented earlier with the exception of substracting the TLC measurement obtained by adding the RV (determined by the closed-circuit oxygen dilution technique) and VC (determined by the spirometer). The data sheet used in the testing is presented in Appendix E.

## Statistical Treatment

Standard descriptive techniques were used to describe the subjects. Dependent t-tests were used to analyze the data at the .05 level for significance for a two-tailed test. A Pearson Product Moment Correlation was used in the pilot study.

CHAPTER IV

# RESULTS AND DISCUSSION

## Introduction

The purpose of this study was to determine if there was a significant difference in the density and percent fat as a result of hydrostatic weighing techniques using RV and TLC in boys ages 8-12 years. This chapter includes a description of the subjects, the statistical analysis of the collected data obtained from the hydrostatic weighing techniques, and lung volume measurements.

## Subjects

The subjects involved in this study were 42 boys between 8-12 years old described in Table 1. The subjects were volunteers and residents of the La Crosse, Wisconsin, area. The subjects for this study were comparable in body composition to other 8 to 12 year old boys.

Table 1. Means and standard deviations of descriptive characteristics of subjects (n = 42)

| Variable | Mean | SD |
|---|---|---|
| Age (yr) | 10.4 | 1.32 |
| Height (cm) | 145.2 | 9.00 |
| Weight (kg) | 37.9 | 9.18 |

In this study the group of boys compared favorably in height and weight to boys of similar ages in other studies (Macy & Kelly, 1956;

Forbes & Amirhakine, 1970; Wilmore & McNamara, 1974; Lohman et al., 1979; Slaughter et al., 1977; Sady et al., 1982).

Reliability of the Measurements

A pilot study was conducted prior to actual data collection to establish the reliability of the measures. A total of 7 boys between 8-12 years old were subjects for this particular study. Measurements of VC, RV, body density and percent obtained from hydrostatic weighing at RV and TLC were obtained twice. A Pearson Product Moment Correlation was used to determine the test re-test reliability coefficients of RV, VC, body density and percent fat measurements. The reliability coefficients for all measurements ranged from 0.93 to 0.98 and are presented in Table 2. These high correlations indicated that the measurements were reliable.

Table 2. Reliability coefficients for pilot study measurements

| Variable | Correlation between $T_1$ and $T_2$ |
|---|---|
| Vital Capacity | .9875 |
| Residual Volume | .9459 |
| Body Density (Residual Volume) | .9538 |
| Body Density (Total Lung Capacity) | .9256 |

Lung Volume Measurements

The means and standard deviations of RV, VC, and TLC for all subjects are reported in Table 3. The lung volumes, VC, RV and TLC reported in the present study are in close agreement with the values reported by others for boys 8-12 (Wilmore & McNamara, 1974; Jensen, 1979; Ferris, Whittenberger & Gallagher, 1952). Residual volume was measured on land utilizing the closed-circuit oxygen dilution techniques as described by Wilmore (1969) and resulted in a mean of 0.624 liters. Residual volume measured on land has been found to be more accurate than underwater (Agostoni et al., 1966; Bondi et al., 1976; Robertson et al., 1978). Measurements taken underwater prevent a full expiration, due to collapsing airways. Measuring RV immersed may under estimate the body density value and percent fat due to the inability to completely exhale. Therefore, the RV was determined on land in this study.

Table 3. Means and standard deviations of lung volume measurements (N = 42)

| Variable | Mean | SD |
|---|---|---|
| Residual Volume (L) | 0.624 | 0.152 |
| Vital Capacity (L) | 2.591 | 0.551 |
| Total Lung Capacity (L) | 3.215 | 0.645 |

Vital capacity was measured on land with a spirometer. A value of 2.952 liters was attained as the average VC measurement. Total lung capacity was measured by adding the results of VC obtained from the spirometer, and the RV measurement obtained from the closed-circuit oxygen dilution technique. A value of 3.215 liters was the average TLC measurement. Since the measurements of VC and TLC were attained on land, differences in total body volume due to hydrostatic pressure may have resulted in a slight overestimation of TLC (Agostoni et al., 1966; Behnke et al., 1942; Brozek et al., 1976; Carey et al., 1956; Craig & Ware, 1967).

These studies indicate that VC and TLC decreased when measured while the subject is immersed in water. A decrease in TLC determined underwater may be due to hydrostatic pressure which inhibits the force of a full inspiration by compressing the chest. Lung compliance may be reduced due to a blood shift to the thorax attributed by the compression of water on the blood vessels of the extremities (Hamilton & Mayo, 1974; Agostoni et al., 1966; Dalback & Lundgren, 1972). These results indicate that VC and TLC measured on land may account for a higher lung volume value than actually performed in the underwater weighing.

## Body Density and Percent Fat Measurements

The subjects for this study were comparable in percent fat, body density, lean weight, and fat weight to those values reported for other 8 to 12 year old boys.

Table 4. Means and standard deviations of body composition parameters using hydrostatic weighing at RV and TLC (n = 42)

| Variable | Residual Volume Mean | ± SD | Total Lung Capacity Mean | ± SD |
|---|---|---|---|---|
| Body Density ($D_b$) g/ml | 1.0629 | 0.0145 | 1.0640* | 0.0128 |
| Percent Fat | 15.8 | 5.76 | 15.4* | 5.22 |
| Fat Weight (kg) | 6.3 | 3.47 | 6.1** | 3.20 |
| Lean Weight (kg) | 31.5 | 6.50 | 31.8* | 6.99 |

* $p < .05$
**$p < .01$

Parizkova (1968) conducted a longitudinal study of the development of body composition in 11 year olds and followed up until the age of 15 comparing highest activity group to lowest. At the age of 11, the average percent body fat of the highest activity group was 15.7% and 17.2% in the lowest activity group. Macy & Kelly (1956) studied body composition in children. In the group of 7-9 year old boys, an average percent body fat of 24% was attained. An estimated 28% was determined as the average percent fat of the 10-12 year olds. A mean percent fat of 22.4 was attained in boys aged 7-12 in a study conducted by Slaughter et al. (1977). Sady et al. (1982) compared body composition in wrestlers and a control group. The average percent fat value achieved from the wrestlers was 13.3% and 20% in the control group. Wilmore & McNamara (1974) studied body composition of 95 boys between the ages of 8-12. The average percent fat value of 18.7% resulted.

There seems to be a wide range of percent body fat reported for boys in this age group. Sady et al. (1982) noted in their investigation of body composition in boys that a large range of percent body fat exists. Wilmore & McNamara (1974) noted in their study that high percent body fat values for children are most likely the result of using equations developed for mature adults. This inconsistency may be the result of assumed density of the lean tissue in the formulas used to convert body density to percent fat, which may be too high for younger boys. This can be due to the differences in total body water and density of bone between the immature boy and the mature man. Younger boys have higher total body water and lower bone density than a mature man, which may result in a lower value for the density of the lean tissue, which would lower calculated values for percent body fat.

Body density values, fat weight and lean weight of the boys in this study compared favorably to boys in other studies (Macy & Kelly, 1956; Forbes & Amirhakimi, 1970; Parizkova, 1961; Sady et al., 1982; Wilmore & McNamara, 1974).

The comparison of body composition parameters determined by hydrostatic weighing at RV and TLC were presented in Table 4. In order to determine any statistical significant difference, a dependent t-test was performed on these data at the .05 level. A comparison of the results of hydrostatic weighing at RV and TLC was tested to determine if TLC yield the same results statistically as RV.

The method of hydrostatic weighing at TLC resulted in a significantly ($p < .05$) higher body density value than at RV. A density value of 1.0640 g/ml was attained from the TLC method, whereas 1.0629 g/ml was attained from the RV method. Therefore, percent fat was found to be significantly ($p < .05$) lower with the TLC method than the RV method. A percent fat of 15.4% resulted from the TLC method and 15.8% was estimated from the RV method.

In the determination of lean weight, the TLC method resulted in a significantly ($p < .05$) higher value of 31.8 kg, while 31.5 kg was obtained from the RV method. The fat weight estimation was found to be significantly ($p < .01$) higher in the RV method (6.3 kg), compared to the TLC method (6.1 kg).

These results showed a small but statistically significant difference between the results of hydrostatic weighing techniques TLC and RV in boys. These results are in agreement with the study conducted by Weltman & Katch (1981), which demonstrated a small but significant difference of hydrostatic weighing at RV and TLC in adults. The observed mean differences for percent fat of 0.6% for men and 0.9% for women were noticed, compared to the 0.4% difference in the present study. Weltman & Katch (1981) concluded that the use of hydrostatic weighing at TLC has application to individuals who are unable to successfully perform the RV method of a maximal exhalation while submerged underwater.

The results obtained from Wells et al., (1982) showed a significant difference ($p < .05$) in body density determined by RV and TLC in boys. A mean difference of 0.012 g/ml resulted between the body density values in their study, which resulted in a 5% difference between percent fat values. A small difference of 0.0011 g/ml was found in the present study. Although a significant difference occurred, a simple linear correlation of $r = 0.89$ between the two body density measures resulted in the study conducted by Wells et al. (1982). With these results, it was concluded that hydrostatic weighing with children who are uncomfortable in the water may find TLC a comfortable and stable means of achieving body density underwater.

The results of this study indicate a small but significant difference between the results of hydrostatic weighing at RV and TLC in boys aged 8-12. While statistically different, it may not be of practical importance. This difference may be a result of the fact that the lung volume measurements were measured on land and an overestimation of TLC may have resulted. Also this small difference is within the error of measurement previously reported for hydrostatic weighing (Siri, 1961).

Total lung capacity offers several practical advantages over hydrostatic weighing at RV. Having the lungs entirely filled with air may reduce the psychological effect. Also the investigator had more time to obtain the underwater weight, which allowed a very stable reading. Therefore, hydrostatic weighing at TLC should be a choice in individuals who are unable to perform hydrostatic weighing at RV.

## CHAPTER V

## CONCLUSIONS

### Summary

The purpose of this study was to determine if hydrostatic weighing at RV and TLC statistically yield the same results in boys aged 8-12. Forty-two subjects were underwater weighed at RV and TLC to determine body density values. Percent fat was calculated from the attained body density values and lean weight and fat weight were determined from these measurements. A statistical analysis was assessed to determine the significance at the .05 level.

### Conclusions

The following conclusions resulted from this study:

1. Hydrostatic weighing at TLC produced a higher body density value than at RV, therefore a lower percent fat was estimated in the TLC method.

2. Hydrostatic weighing at RV produced a higher fat weight than TLC, therefore a lower lean weight was estimated in the RV method.

3. Hydrostatic weighing at TLC may offer practical application to individuals who are uncomfortable in the water.

4. Although a significant difference was estimated comparing hydrostatic weighing at RV and TLC, it resulted in a mean difference of 0.4%. This observation is within the ± 4% error associated with the measurement of body density obtained from hydrostatic weighing (Siri, 1961). Therefore, the use of hydrostatic weighing at TLC has

application where subjects are unable to successfully perform hydrostatic weighing at RV, performing a maximal expiration.

## Recommendations

The following are recommendations made in reference to future studies:

1. In this study, VC was measured on land. It would be interesting to perform VC in the water and compare the difference.

2. Research is needed in developing a formula to convert body density to percent fat in children, since no known formula exists.

3. Due to inconsistencies in the results of RV, VC, and TLC measured underwater, further research is needed.

## REFERENCES CITED


Agostoni, E., Gurtner, G., Torri, G. & Rahn, H. Respiratory mechanics during submersion and negative pressure breathing. Journal of Applied Physiology, 1966, 21, 251-258.

Arborelius, M., Balldin, U. I., Lilja, B. & Lundgren, C. E. Regional lung function in man during immersion with the head above water. Aerospace Medicine, 1972, 43, 701-707.

Bakker, H. K. & Struikenkamp, R. S. Biological variability and lean body mass estimates. Human Biology, 1977, 49, 187-202.

Bedell, G., Marshall, R., DeBois, A. & Harris, J. Measurement of the volume of gas in the gastro-intestinal tract. Values in normal subjects and ambulatory patients. Journal of Clinical Investigation, 1956, 35, 336-345.

Begin, R., Epstein, M., Sackner, M. A., Levinson, R., Dougherty, R. & Duncan, D. Effects of water immersion to the neck on pulmonary circulation and tissue volume in man. Journal of Applied Physiology, 1976, 40, 293-299.

Behnke, A. R., Feen, B. G., & Welham, W. C. The specific gravity of healthy men. Jama, 1942, 118, 495-498.

Behnke, A. R. Quantitative assessment of body build. Journal of Applied Physiology, 1961, 16, 960-968.

Behnke, A. R. & Wilmore, J. H. Evaluation and regulation of body build and composition. Englewood Cliffs, N. J.; Prentice-Hall, 1974.

Bondi, K. R., Young, J. M., Bennett, R. M. & Bradley, M. E. Closing volumes in man immersed to the neck in water. Journal of Applied Physiology, 1976, 40(5), 736-740.

Bondurant, S., Hickam, J. B. & Isley, J. K. Pulmonary and circulatory effects of acute pulmonary vascular engorgement in normal subjects. Journal of Clinical Investigation, 1957, 36, 59-66.

Brook, C. G. D. Determination of body composition of children from skinfold measurements. Archives of Disease in Childhood, 1971, 46, 182.

Brozek, J. The measurement of body composition, Historical perspective. In A. Montague (ed.), Introduction to physical anthropology, pp. 637-679, 1961.

Brozek, J., Grande, F., Anderson, J. T. & Keys, A. Densitometric analysis of body composition: Revision of some quantitative assumptions. Annals New York Academy of Sciences, 1963, 110, 113-140.

Buskirk, E. Underwater weighing and body density: a review of procedures. In J. Brozek & A. Henschel (eds.), Techniques for measuring body composition, pp. 90-107, Washington, D. C.: National Academy of Sciences - National Research Council, 1961.

Carey, C. R., Scheafer, K. E. & Alvis, H. J. Effect of skin diving on lung volume. Journal of Applied physiology, 1956, 8, 519-523.

Christian, P., Lupi-H, E. & Anthonisen, N. R. Human lung mechanics during water immersion. Journal of Applied Physiology, 1976, 40(3), 320-324.

Collins, J. V., Cochrane, G. M., Davis, J., Benatar, S. R. & Clark, T. J. Some aspects of pulmonary function after rapid saline infusion in healthy subjects. Clinical Science of Molecular Medicine, 1973, 45, 407-410.

Craig, A. B. & Ware, D. E. Effect of immersion in water on vital capacity and residual volume of the lungs. Journal of Applied Physiology, 1967, 23(4), 423-425.

Cureton, K. J., Boileau, R. A., & Lohman, T. G. A comparison of densitometric, potassium-40 and skinfold estimates of body composition in prepubescent boys. Human Biology, 1975, 47, 321-336.

Dahlback, G. O. & Lundgren, C. E. G. Pulmonary air-trapping induced by water immersion. Aerospace Medicine, 1972, 43(7), 768-771.

Donoghue, E. R. & Minnigerode, S. C. Human body buoyancy. Journal of the Forensic Sciences Society, 1977, 22(3), 573-579.

Durnin, J. V. & Rahaman, M. M. The assessment of the amount of fat in the human body from the measurements of skinfold thickness. British Journal of Nutrition, 1967, 21, 681.

Edelman, I. S., Haley, H. G., Schloerb, P. R., Sheldon, D. B., Trus-Hansen, B. J., Stoll, G. & Moore, F. D. Further observations on total body water. Normal values throughout the life span. Surgical Gynocology & Obstetrician, 1952, 95, 1-12.

Ferris, B. G., Whittenburg, J. L., & Gallagher, J. R. Maximum breathing capacity and vital capacity of male children and adolescents. Pediatrics, 1952, 6, 659-670.

Forbes, G. B. Methods for determination of composition of the human body. Pediatrics, March, 1962, 477-494.

Forbes, G. B. Growth of the lean body mass in man. Growth , 1972, 36, 325-338.

Forbes, G. B. & Amirhakimi, G. H. Skinfold thickness and body fat in children. Human Biology, 1970, 42, 401-418.

Friis-Hansen, B. J. Body water compartments in children: Changes during growth and related changes in body composition. Pediatrics, 1961, 28, 169-181.

Friis-Hansen, B. J., Holiday, M., Stapleton, B. M. & Wallace, W. M. Total body water in children. Pediatrics, 1951, 7, 321-327.

Girandola, R. N., Wiswell, R. A., Mohler, J. G., Romero, G. T. & Barnes, W. S. Effects of water immersion on lung volumes: implications for body composition analysis. Journal of Applied Physiology, 1977, 43(3), 276-279.

Goldman, R. & Buskirk, E. Body volume measurement by underwater weighing: description of a method. In J. Brozek & A. Henschel (eds.), Techniques for measuring body composition, pp. 78-89, Washington, D..: National Academy of Sciences - National Research Council, 1961.

Hamilton, W., & Mayo, J. Changes in vital capacity when the body is immersed in water. Journal of Applied Physiology, 1944, 141, 51-53.

Hong, S. K., Ting. E. Y. & Rahn, H. Lung volumes at different depths during submersion. Journal of Applied Physiology, 1960, 15, 550-553.

Jarrett, A. S. Effect of immersion on intrapulmonary pressure. Journal of Applied Physiology, 1965, 20(6), 1261-1266.

Jensen, D. G. Determination of body density in prepubescent males, age 7-11. Unpublished master's thesis, University of WI-La Crosse, May, 1979.

Katch, F. I. Practice curves and errors of measurements in estimating underwater weight by hydrostatic weighing. Medicine and Science in Sports, 1969, 1(4), 212-216.

Katch, F. I. Apparent body density and variability during underwater weighing. Research Quarterly, 1968, 39, 993-999.

Keys, A. & Brozek, J. Body fat in adult man. Physiological Reviews, 1953, 33, 245-325.

Leith, D. E. & Mead, J. Mechanisms determining residual volume of the lungs in normal subjects. Journal of Applied Physiology, 1967, 21, 221-227.

Lohman, T. G. Skinfolds and body density and their relation to body fatness: a review. Human Biology, 1981, 53, 181-255.

Luft, U. C. & Lim, T.P.K. Modified procedure for determination of body volume by hydrostatic weighing. In J. Brozek & A. Henschel (eds.), Techniques for measuring body composition, p. 107, Washington, D.C.: National Academy of Sciences - National Research Council, 1961.

Macy, I. G. & Kelly, J. J. Body composition in childhood with reference to "in vivo" chemical analysis of water, fat, and protoplasmic mass. Human Biology, 1956, 28(3), 289-308.

Malina, R. M. Quantification of fat, muscle, and bone in man. Clinical Orthopaedics and Related Research, 1969, 65, 9-38.

Maresh, M. M. Linear growth of long bones of extremities from infancy through adolescence. American Journal of Disease in Children, 1955, 89, 725-742.

McArdle, W. D., Katch, F. I., Katch, V. L. (eds.), Exercise Physiology, Energy, Nutrition and Human Performance. Philadelphia: Lea & Febeger, 1981.

Moulton, C. R. Age and chemical development in mammals. Journal of Biological Chemistry, 1923, 57, 79-97, (Pediatrics, 1962, 477-494).

Parizkova, J. Total body fat and skinfold thickness in children. Metabolism, 1961, 10, 794-806.

Parizkova, J. Longitudinal study of the development of body composition and body build in boys of various physical activity. Human Biology, 1968, 40, 212-225.

Prefaut, C., Lupi, E. & Anthonisen, N. R. Human lung mechanics during water immersion. Journal of Applied Physiology, 1976, 40, 320-325.

Rathburn, E. & Pace, N. Studies on body composition. I. The determination of total body fat by means of the body specific gravity. Journal of Biological Chemistry, 1945, 158, 667-676.

Robertson, C. H., Jr., Engle, C. M. & Bradley, M. E. Lung volumes in man immersed to the neck: dilution and plethysmographic techniques. Journal of Applied Physiology, 1978, 44(5), 679-682.

Sady, S. P., Thompson, W. H., Savage, M. & Petratos, M. The body composition and physical dimensions of 9 to 12 year old experienced wrestlers. Medicine and Science in Sports and Exercise, 1982, 14(3), 244-248.

Sawka, M. N., Weber, H. & Knowlton, R. G. The effect of total body submersion on residual lung volume and body density measurements in man. Ergonomics, 1978, 21(2), 89-94.

Siri, W. Body composition for fluid spaces and density: analysis of methods. In J. Brozek & A. Henschel (eds.), Techniques for measuring body composition, pp. 223-244, Washington, D.C.: National Academy of Sciences - National Research Council, 1961.

Slaughter, M. H., Lohman, T. G. & Misner, J. E. Relationship of somatotype and body composition to physical performance in 7 to 12 year old boys. The Research Quarterly, 1977, 48(1), 159-167.

Thomas, T. R. & Etheridge, G. L. Hydrostatic weighing at residual volume and functional residual capacity. Journal of Applied Physiology, 1980, 49(1), 157-159.

Welch, B. E. & Crisp, C. E. Effect of the level of expiration on body density measurement. Journal of Applied Physiology, 1958, 12(3), 399-402.

Wells, T., Reynolds, C. & Jessup, G. T. A comparison of hydrostatic weighing at residual volume and total lung capacity in children. Abstract - Presented at the American Alliance for Health, Physical Education, Recreation, and Dance, 1982.

Weltman, A. & Katch, V. Comparison of hydrostatic weighing at residual volume and total lung capacity. Medicine and Science in Sports and Exercise, 1981, 13(3), 210-213.

Wilmore, J. H. A simplified method for determination of residual lung volumes. Journal of Applied Physiology, 1969, 27(1), 96-100.

Wilmore, J. H. & Behnke, A. R. Predictability of lean body weight through anthropometric assessment in college men. Journal of Applied Physiology, 1969, 27, 349-355.

Wilmore, J. H. & McNamara, J. J. Prevalence of coronary heart disease risk factors in boys 8 to 12 years of age. Journal of Pediatrics, 1974, 84, 527-533.

APPENDIX A

# Appendix A

Dear Parent/Guardian:

Most studies of body composition and physical fitness of children occur only at one point in time and few have studied the same child over a period of years. What are the normal body composition changes that occur in the young boy as he grows into his teens? Obviously he becomes stronger and grows in both height and weight but what specific alterations occur?

For the past few years we have been gathering longitudinal data on a group of girls between the ages of 7 and 11 years of age to help identify these changes in girls. This year we would like to expand this study to include boys in this same age range and would like to extend an invitation to you and your son to participate.

Participation in this study would involve two, one-hour visits to the Human Performance Laboratory (225 Mitchell Hall) on the University of Wisconsin-La Crosse campus at your convenience. During these visits we would determine your son's percent body fat through an underwater weighing procedure. The underwater weighing requires the boy to be submerged underwater for a period of 4-6 seconds, therefore it is necessary that your son be comfortable in the water. The specifics of the test are explained on the enclosed sheet. At the conclusion of all data collection you will be sent your son's individual data as well as a summary of the total results for comparison purposes.

Please read the enclosed materials and if, after discussing this with your son, you are willing to have him participate, please indicate your willingness on the enclosed sheet and return in the self-addressed, stamped envelope.

Sincerely,

Nancy Kay Butts, Ph.D.
Associate Professor
Director Research Unit

APPENDIX B

# Appendix B

## PARENTAL INFORMED CONSENT FOR BODY COMPOSITION TEST

I, the parent/guardian of ______________________________, give my permission for my son to participate in the body composition study being conducted in the Human Performance Laboratory at the University of Wisconsin-La Crosse. I understand that participation in this study will involve two visits to the Human Performance Laboratory and that each visit my son will have anthropometric measurements taken, residual volume determined and be underwater weighed. I also understand that I may withdraw my son from the study at any time.

In any type of testing situation some potential risk is involved. In working in a water environment these risks include infection, accident and possible drowning. Howerver, there has never been an acident reported of infection as a result of the hydrostatic weighing procedure at the Human Performance Laboratory.

The actual testing will be conducted by Mary DeLisio, a graduate student in the Adult Fitness/Cardiac Rehabilitation program at the University of Wisconsin-La Crosse. She will be under the supervision of Nancy Kay Buttts, Ph.D.

I, ______________________________________________parent/guardian of

______________________________________________, approve the participation of my son in the body composition test at the Human Performance Laboratory at the University of Wisconsin-La Crosse. I have read the foregoing and I understand it, and any question which may have occurred to me have been fully answered to my satisfaction. The potential risks have been explained to me and I fully understand their implications. I hereby acknowledge that no representations, warranties, guarantees, or assurances of any kind pertaining to the procedures have been made to me by the University of Wisconsin-La Crosse, the officers, administrators, employees, or by anyone acting on behalf of any of them.

Signed: ____________________________________________ Date: __________
(parent/guardian)

Address: ___________________________________________ Phone: _________

Witness: ___________________________________________ Date: __________

APPENDIX C

# Appendix C

## Residual Volume Data Sheet

Name ______________________________ Age: __________
First Last

| | Trial 1. | Trial 2. |
|---|---|---|
| Initial Volume of $O_2$ ($VO_2$): | ________ | ________ |
| $\%N_2$ (Impurity) ($IN_2$): | ________ | ________ |
| $\%N_2$ (Alveolar) ($AN_2$): | ________ | ________ |
| $\%N_2$ (Equilibrium) Range: | ________ | ________ |
| $\%N_2$ (Equilibrium) ($EN_2$): | ________ | ________ |
| $\%N_2$ (Final) ($FN_2$): | ________ | ________ |
| Dead Space (DS): | ________ | ________ |

$$\text{Residual Volume} = \frac{VO_2\ (EN_2 - IN_2)}{(AN_2 - FN_2)} - DS \times BTPS$$

= ________________ L.

Wilmore, J. H. (1969)

# APPENDIX D

Appendix D

Underwater Weighing- RV Data Sheet

Name______________________ Date of Birth__________ Date________

Height__________ft. ________inches Weight________Lbs. ________kgs.

Immersion Tank Temp.______________C. Density of Water ($D_W$) O.________

Residual Volume______________L.

Trial #1 ________
2________
3________
4________
5________
6________
7________
8________
9________
10________

Mass in Air ($M_A$)____________________kg.

Mass in Water ($M_X$)__________________kg.

Mass of Weighing Apparatus__________kg.
(in water)

Mass of Water ($M_W$) = $M_X$ - $M_Y$ =________kg.

Air in GI Tract= 100ml. = 0.1L.

$$\text{Body Density } (D_B) = \frac{M_A}{\left(\frac{M_A - M_W}{D_W}\right) - RV - 0.1L.}$$

$$\% \text{ Fat} = \left[\frac{4.570}{D_B} - 4.142\right] \times 100$$

Brozek et al. (1963)

# APPENDIX E

# Appendix E

## Underwater Weighing - TLC Data Sheet

Name________________________________ Date of Birth________ Date________

Height________________ft. ________inches Weight_______lbs. _______kgs.

Vital Capacity_____________

Residual Volume____________

Total Lung Capacity________ VC + RV =TLC

Immersion Tank Temp.______________C. Density of Water ($D_W$) 0.___________

Total Lung Capacity________________L.

Mass in Air ($M_A$)____________________kg.

Mass of Water ($M_X$)___________________kg.

Mass of Weighing Apparatus ($M_Y$)_____kg.
(in water)

Mass of Water ($M_W$) = $M_X - M_Y$ =_______kg.

Air in GI Tract= 100ml. = 0.1L._____

Trial #1________
2________
3________
4________
5________
6________
7________
8________
9________
10________

$$\text{Body Density } (D_B) = \frac{M_A}{\left(\frac{M_A - M_W}{D_W}\right) - TLC - 0.1L.}$$

$$\% \text{ Fat} = \left[\frac{4.570}{D_B} - 4.142\right] \times 100$$

Brozek et al. (1963)