2017

Head above water weighing: A valid method to measure body fat storage?

Molly Lin Hussey
University of Northern Iowa

HEAD ABOVE WATER WEIGHING: A VALID METHOD

TO MEASURE BODY FAT STORAGE?

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Arts

Molly Lin Hussey

University of Northern Iowa

May 2017

ABSTRACT

Hydrostatic weighing using underwater weighing with full lung expiration has been established as a valid method to assess body composition; however, many people do not prefer to submerse their heads in water due to various reasons. Keeping the head above water as a method for hydrostatic weighing at full lung capacity has been tested but has not been accepted as an alternative method. **Purpose:** The main purpose of this study is to determine if hydrostatic weighing with the head above water at residual volume could provide valid estimates of total body fat. **Methods:** Fifty-eight subjects (F=29. M=29) participated in performing four different methods of underwater weighing: complete immersion with full lung expiration (UWW_{RV}), complete immersion with total lung capacity (UWW_{TLC}), partial immersion with the head above water at full lung expiration (HAW_{RV}), and partial immersion with the head above water at total lung capacity (HAW_{TLC}). Bland-Altman Plots were created and regression analyses were used to test for proportional bias across the range of means. **Results:** There was no significant difference between HAW_{RV} and UWW_{RV} for both males and females. However, a Bland-Altman plot indicated the range of error between these methods was >5% body fat for both genders. There was a significant difference between HAW_{TLC} versus HAW_{RV} in both males ($t = 4.616$, $df= 28$, $p <0.001$) and females ($t = -14.661$, $df=28$, $p< 0.001$). **Conclusion:** These results indicate that although the mean difference between HAW_{RV} and UWW_{RV} was not significantly different, the large range of error at 95th confidence levels suggests it might not be suitable as a substitute.

HEAD ABOVE WATER WEIGHING: A VALID METHOD TO MEASURE BODY FAT STORAGE?

A Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Arts

Molly Lin Hussey

University of Northern Iowa

May 2017

This Study by: Molly Lin Hussey

Entitled: Head above water weighing: A valid method to measure body fat storage?

has been approved as meeting the thesis requirement for the

Degree of Master of Arts

Date	Dr. Kevin Finn, Chair, Thesis Committee
Date	Dr. Forrest Dolgener, Thesis Committee Member
Date	Dr. Jacob Reed, Thesis Committee Member
Date	Dr. Kavita R. Dhanwada, Dean, Graduate College

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to Dr. Kevin Finn for his persistent guidance and help throughout this process. Thank you for sharing your expertise in exercise physiology, and for providing valuable insight, direction, and knowledge.

I would also like to thank my parents, Jim and Jean Lin Hussey, for their continuous support in furthering my education. Your encouragement and desire to provide the best opportunities for me do not go unnoticed. Thank you for your unconditional love, faith, and patience.

TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The human body can be divided into four chemical components: water, protein, bone mineral, and fat (Lukaski, 1987). The ratios of these components are vital to living a healthy life. Excess fat can cause health issues such as high blood pressure, high cholesterol and diabetes, which increase the risk for heart disease, stroke, and other health complications. More knowledge about one's body allows appropriate changes to be made to reduce these health risks. Body composition assessments are used to measure the percentage of fat versus fat-free mass in the body. One method to estimate body composition is from body density measurement, known as densitometry, with hydrostatic weighing being the most common technique (Heymsfield, Lohman, Wang, & Going, 2005). These assessments are becoming prevalent in health screening; therefore, it is important that body composition methods are convenient and easy to perform.

Underwater weighing has been established as a valid method to assess body composition by using the buoyancy of body fat and its effect on body weight in water. The complex procedures associated with underwater weighing, however, make it less suitable for working with persons who have difficulty in the water (Jackson, Pollock, Graves, & Mahar, 1988). The process of underwater weighing includes a total immersion of the body while exhaling as much air as possible, and then remaining still until a weight measurement is recorded. Many people find this standard method of underwater weighing to be uncomfortable and may be frightened as they remain under water long enough to get an accurate measurement after maximal exhalation. Underwater weighing is a cost-efficient method for measuring body composition compared to other clinical methods such as Dual-energy X-ray Absorptiometry (DXA) and air plethysmography (Bod Pod). Underwater weighing remains one of the most accurate and valid methods of measuring body composition and the weighing system can be easily placed in recreational areas that contain a pool for convenient accessibility for the general public. The cost for an underwater weighing measurement is substantially cheaper than that of a DXA scan, and underwater weighing can accommodate clients of all sizes where other methods such as Bod Pod and DXA scan have body size limits.

Hydrostatic weighing without head submersion was a method introduced to provide an option for those uncomfortable with the traditional method (Donnelly et al., 1988). To test this method, researchers used the subject's weight in water with the head above the water (See Figure 1) at total lung capacity to estimate body density, and thus body composition. Residual volume, or the volume of air in the lung after forced expiration, is the most common measurement of trapped body air used for underwater weighing because it is least affected by hydrostatic pressure (Heymsfield et al., 2005). The researchers (Donnelly et al., 1988) felt that hydrostatic weighing taken at total lung capacity may be advantageous because subjects would feel more comfortable and able to stay motionless longer. This would allow more time to steady the scale, allowing for an accurate measurement in water without the disturbance of buoyancy. If the weight in water with the head above water is taken after full expiration, either a measure or prediction of residual volume would improve the methodology. This method is rarely adopted due to concerns over errors in the assumptions regarding buoyancy with maximal air in the lungs.

There is current interest by managers of fitness facilities who have invested in water weighing systems to provide easier methods for underwater weighing. This can expand the number of people willing to have their body composition assessed. Head above water weighing at residual volume may be an alternative for those who prefer to keep their heads above water and to minimize errors associated with the amount of air in the lungs.

Statement of the Problem

The main purpose of this study was to determine if measuring body mass in water with the head above water could be a valid method to estimate body composition. The goal was to create a new method for hydrostatic weighing that would allow an accurate body composition measurement while maintaining the head above water. While we expect hydrostatic weighing with head above water to be heavier than underwater weighing (due to the buoyancy of the cranial cavity), if the differences between the two methods are similar in measure, an adjustment could be made in the equation for body density. The secondary purpose of this study was to compare hydrostatic weighing with the head above water at residual volume with Donnelly's method of head above water at total lung capacity, and evaluate preference for these methods by subjects. If the subjects' preference for the two lung volume methods (total lung capacity vs. residual volume) during hydrostatic weighing is equally selected, adjustments to body mass with head above water at residual volume or at total lung capacity could be included in future software development.

Research Questions

1. Is the water weight with the head above water of similar difference to the head below water weight in a group of young adults when asked to exhale as much air as possible?
2. Is the water weight with the head above water of similar difference in a group of young adults if the subjects exhale as much air as possible versus with full lung capacity?
3. What is the preferred method in a group of young adults for body position (head above water or submerged) and lung volume (full expiration or full inhalation) during hydrostatic weighing?

Hypotheses

It is hypothesized that using the mean differences in water weight between head above and head under water at residual volume when applied to estimates of body fat percentage will not be significantly different between subjects. Using a Bland-Altman plot, it is expected that the limits of agreement using the 95th confidence interval between body fat percentages for head above and head under water techniques will be within +/- 5% body fat.

It is hypothesized that the mean differences in head above water weight measured at total lung capacity versus residual volume when applied to estimates of body fat percentage will be significantly different between subjects. Using a Bland-Altman plot, it is expected that the limits of agreement using the 95th confidence interval between body fat percentage for the head above water technique at residual volume and total lung capacity will not be within +/-5% body fat.

Using a standard order for methods, it is hypothesized that subjects will prefer head above water to head submersion for the water weighing. In addition, it is expected more subjects will prefer having the weighing with a full inhalation as opposed to full expiration.

Limitations

Possible limitations of this study include:

1. Subjects who are unfamiliar with being underwater could be uncomfortable; therefore, they may not entirely exhale their air, a source of variance between measures. A number of repeat trials will be performed to establish a stable underwater weight.
2. Taller subjects may have to compress their torso in order to maintain proper position with their head above water. Positioning the height of the seat during the head above water weighing is not possible.
3. The measures of residual volume and vital capacity are taken out of the water due to the location of the instrumentation away from the water-weighing tank. These measures may be different if performed in water due to water pressure exerted against the chest cavity.

4. The order of the testing methods were the same for all subjects. Non-randomization of the order of methods may have affected the subjects' preference of method due to learning or fatigue throughout the testing process.

Delimitations

Our ability to generalize the results of this study is due to:

1. The call for recruitment of subjects was answered by people with exposure to hydrostatic weighing.
2. We used young adults for this study aged 18-50 years.
3. The measurement of water weight and residual volume used instrumentation that might not be available to those in a fitness facility.

Assumptions

1. When measuring with head above water, hair had minimal interference with weighing due to being kept above water with a hair-tie or swim-cap.
2. All subjects gave their best effort throughout the testing.
3. All subjects followed instructions prior to testing on food intake, physical exertion, and use of medications that might influence water retention in the body.
4. The order of the methods used will not have an effect on the performance of the hydrostatic weighing.

Definition of Terms

Bland-Altman plot: a method of data plotting used in analyzing the agreement between two measurement techniques and identifying the limits of agreement.

Body composition: measurement of fat, muscle, water and bone in the human body.

Densitometry: a procedure to estimate body composition from body density.

Fat-free mass: total amount of lean body mass in the body.

Fat mass: portion of the human body that is composed of fat.

Hydrodensitometry: weighing of a human body immersed in water and subsequent measurement of the water displaced in order to estimate body fat.

Hydrostatic weighing: a technique using displacement of water to measure the mass per unit volume of a living human body.

Residual volume: amount of air remaining in the lungs after maximal expiration.

Stadiometer: a device consisting of a vertical ruler with a sliding horizontal panel to measure height.

Spirometer: a device measuring air capacity of the lungs.

Total lung capacity: the inspiratory capacity plus the functional residual capacity

Underwater weighing: the body mass of the person while totally submersed in water

Vital capacity: greatest volume of air that can be exhaled from the lungs with the deepest possible breath.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Underwater weighing has been referred to as the "gold standard" for assessing body composition throughout the years and often used as a criterion in validating new methods of body composition (Heymsfield et al., 2005). Most in vivo research has simply separated body weight into fat and fat-free components (Spencer, 1997). Hydrodensitometry works because fat-free mass has a greater density than water, which makes one sink. Fat mass is less dense than water, increasing buoyancy. At 37 degrees Celsius, fat-free mass is assumed to be relatively consistent with a density of 1.100 g/cc, while fat mass has a density of .900 g/cc (Lukaski, 1987). Fat-free mass has a water content of 72-74% and a potassium content of 60-70 mmol/kg in men and 50-60 mmol/kg in women while fat mass is anhydrous and potassium free (Lukaski, 1987). Measuring body density with the principle of water displacement, mass is the weight of the body in air and volume is the difference between the weight in air and the weight of the body underwater (Katch, Michael, & Horvath, 1967). The ratio of the mass and volume will provide the density of the human body (Heymsfield et al., 2005). Finally, the percent fat can then be estimated using formulas such as the common Siri 1956 equation (495 / Body Density - 450) or the Brozek 1963 equation (457 / Body Density – 414.2).

Additional variables such as height, dry land weight, water temperature, and residual volume have to be measured to accurately determine body density. Residual volume can be measured using an oxygen dilution technique on land before underwater weighing or simultaneously with underwater weighing (Heymsfield et al., 2005). Measuring residual volume while submerged is the preferred method because it cannot be assumed that subjects are able to accurately match their maximal exhalations on land and in water; however the procedures (rebreathing oxygen from a bag) is problematic while in the water. In order to obtain an accurate measurement, underwater weight has to be measured when the person testing has minimal amount of air in their lungs. Although underwater weighing is a customary method of measuring body composition, it is not always the most comfortable method. Many people are hesitant to be fully submerged underwater while exhaling all their air. This fear may cause measurement errors and keep people from participating in underwater weighing procedures altogether.

There are biological variations that contribute to errors that occur with hydrostatic weighing including: residual volume, underwater weight, body weight, and water temperature. For example, with a variation of 0.0059g/ml of fat-free mass density in a specific population and a variation of 0.0020g/ml in technical error, the combined error is estimated to be 0.0062g/ml. This is the equivalent of about 2% fat. For every 100mL error in residual volume or 100g error in underwater weight, percent fat will be in error by approximately 0.7% fat units (Heymsfield et al., 2005).

This review will cover the standard method for hydrodensitometry and modifications of underwater weighing for the assessment of body composition. This knowledge will provide a foundation for evaluating the importance of considering alternative methods for estimating body fat percentage through underwater weighing while keeping the head above water.

Standard Method for Hydrodensitometry

Underwater weighing was first introduced as a method of measuring body composition in the early 1940s (Behnke, Feen, & Welham, 1942). In the study by Behnke et al., the weight in water was determined by suspending the subject underwater on a line leading up to an autopsy scale graduated in ounces. They took one weighing at completion of maximum inspiration and another after complete expiration. Vital capacity was determined by the difference in weight obtained by hydrostatic displacement. Behnke supported the concept that the comparatively low specific gravity of fat makes the measurement of the specific gravity of the body mass valid for estimation of fat content.

There are many challenges in using the method described by Behnke. There is a greater chance of error when using an autopsy scale due to the need for the subjects to remain motionless underwater. When residual volume is measured on land rather than simultaneously with underwater weighing, an error of 100-200ml, or 0.7-1.4% fat units can occur. When residual volume is estimated, an error of 300-400ml is likely to occur (Heymsfield, et al., 2005). Body weight in air and water temperature also attributes to measurement errors; however, the significance is not as great. Behnke's method became the "standard procedure" for almost 40 years before others considered alternative methods.

Hydrodensitometry with Head Above Water

The physical and emotional comfort of subjects while conducting underwater weighing can influence the results. In a study conducted by Donnelly et al. (1988), their goal was to minimize the psychological and physiological demands for subjects to assure an accurate measurement. Donnelly introduced a method of hydrostatic weighing at total lung capacity in which subjects were not required to submerge their heads underwater. Two separate pilot studies were conducted. Fifteen subjects participated in the first pilot study and forty subjects in the second. The subjects in his studies compared hydrostatic weighing at total lung capacity without head submersion (Figure 1) with the traditional head submersion at residual volume. The percentage of fat compared between the two methods from the two pilot studies resulted in a range of correlation coefficients of 0.92-0.98 (Donnelly et al., 1988). The subjects also verbally stated that hydrostatic weighing at total lung capacity while keeping their head above water reduced their anxiety considerably compared to being submerged.

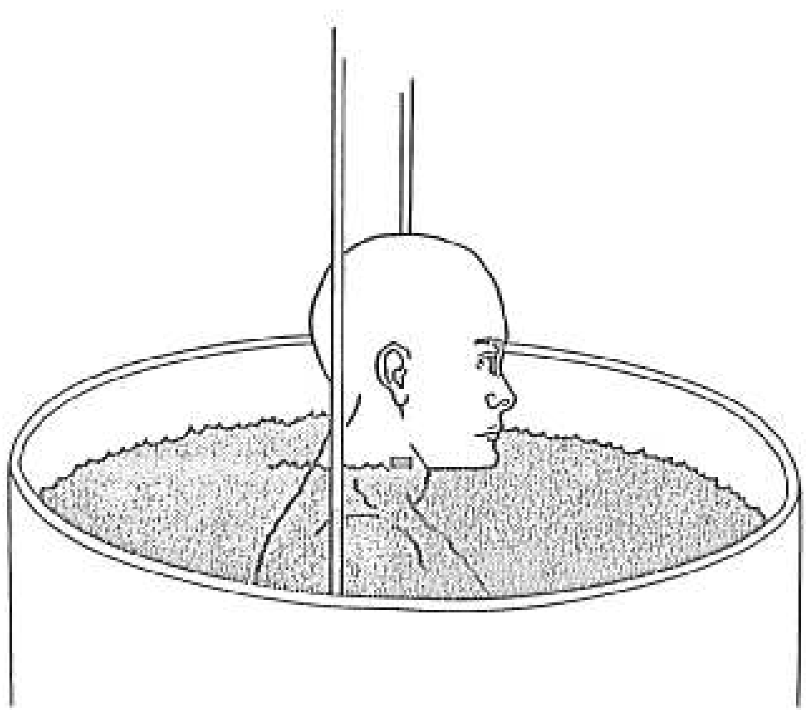

Figure 1. Head Above Water Position (as described by Donnelly et al., 1988)

Donnelly et al. (1988) expanded the pilot data with a larger sample and refined the techniques used to estimate body fat with hydrostatic weighing at total lung capacity. There were 95 males and 87 females in this follow-up study. All subjects were Caucasian volunteers from two testing sites and had no known pulmonary disease. Subjects were asked to abstain from eating and exercise for three hours prior to testing.

Vital capacity was measured using spirometry while the subjects were seated and submerged in water to their shoulders. Three measurements were taken and the average of the highest two were used for calculations. If the two highest measurements varied greater than 100ml, additional trials were administered. Residual volume was measured using the oxygen rebreathing method described by Wilmore, Vokak, Parr, Girandola, and Billing (1980) on land with the subject seated upright and slightly bent forward. The average for two trials of residual volume measurements was used for calculation. If there was a difference greater than 200ml between the two measurements, additional trials were collected. Total lung capacity was calculated as vital capacity plus residual volume corrected to body temperature and pressure, saturated.

Hydrostatic weighing with head submersion and without head submersion were administered in random order to minimize effects of learning or fatigue. All subjects were weighed to the nearest 0.1kg on a calibrated scale. Water temperature was maintained between 34-38 degrees Celsius. The subjects sat in a chair suspended from a 15 x 25g autopsy scale attached to a mechanical winch. A horizontal reference line from the angle of the mandible to an area on the neck below the inferior ear was drawn in order to maintain consistent placement of the head above water. The head was rotated so the water just touched the inferior surface of the chin and the horizontal reference.

Ten trials of hydrostatic weighing at residual volume were conducted, with the average of the last three trials used for calculation. Five trials at total lung capacity with the head above water were conducted with the average of the three middle values used for calculation. Body densities were calculated using the Goldman and Buskirk equations (Goldman & Buskirk, 1961), and percentage of body fat was determined by the Brozek equation (Brozek, Grande, Anderson & Keys, 1963). The Borg scale of perceived exertion (Borg, 1982), was used to indicate the difficulty of the procedure immediately after the final trial of each method at site one. Nine males and 10 females were retested for hydrostatic weighing at total lung capacity with their heads above water within one hour of the original trial. The same investigator and procedures were used for the retest. Subjects with body fat less than 4% or greater than 35% were eliminated from the study.

No significant differences for males and females were found between body density from hydrostatic weighing at residual volume and the prediction equation used to estimate hydrostatic weighing at total lung capacity without head submersion. The mean difference between body density from hydrostatic weighing at residual volume and the predicted body density of hydrostatic weighing at total lung capacity without head submersion was 0.0001 $g*ml^{-1}$ for males and 0.0014 $g*ml^{-1}$ for females. The mean difference for males did not correspond to any mean difference in body fat percentage to the nearest tenth of a percentage point; however, the mean difference in females corresponded to a difference of 0.7% body fat. The correlation coefficient was r = 0.82 for females and r = 0.95 for males between body density from hydrostatic weighing at residual volume and the predicted body density of hydrostatic weighing at total lung capacity without head submersion.

A previous unpublished study completed by Donnelly and Sintek observed a non-submersive method of hydrostatic weighing at residual volume; however, the results were not successful. The subjects tended to sink and could not hold their breath long enough to maintain proper positioning of their head placement above water (Donnelly et al., 1988). Evans, Israel, Flickinger, O'Brien, and Donnelly (1989) conducted a study testing the validity of hydrostatic weighing without head submersion of morbidly obese females. Eighty females performed four trials of traditional hydrostatic weighing at residual volume and four trials of hydrostatic weighing without head submersion. The residual volume was determined by oxygen dilution. Twenty of the subjects were randomly selected and excluded from the experimental group to use for cross-validation. The mean difference between the two methods was 0.66% of body fat. Hydrostatic weighing without head submersion at residual volume proved to be a valid technique for assessing body composition in morbidly obese females.

Summary

This review provides a historical view of the methods used in hydrostatic weighing that have been considered the "gold standards" in the assessment of body composition for more than 50 years. The initial work by Behnke et al. (1942) measured weight in water with the head totally immersed with full expiration (only residual volume) and with full inhalation (total lung capacity). The results of their study was underwater weighing with full expiration can be used to predict body fat in adults with a simple regression equation.

In the 1990s, some modifications were made to this standard method by suggesting that a “head above water” weighing at full lung capacity could be an alternative for those with fear of water and those who could not bend forward to fully exhale the air from their lungs. Donnelly et al. (1988) produced a regression equation that has been reported in textbooks for use with healthy adults. This linear regression equation provided an adjustment (y-intercept), which allowed for expected differences in water weight when the head was positioned above the water.

The need to determine total lung capacity in the water during the actual weighing creates some potential problems for subjects who have restrictive lung disorders (cannot inhale maximally), or with large lung volumes and high body fat that create a “negative” value for water weight. The method proposed for this study, head above water with full expiration of air in the lungs, provides another alternative for those wishing to be measured for body composition using densitometry.

CHAPTER III

METHODOLOGY

Participants

Subjects were recruited by posting informational flyers around various recreational centers, promoting the research study in classes offered at the University of Northern Iowa, and by recruiting some participants from the general public who contacted the university wanting to conduct a body composition measurement. A total of 68 subjects participated in the research experiment. Subjects who were physically unable to enter/exit the hydrodensitometry tank, had restrictive lung disorders, hearing impairment, or were pregnant were to be excluded from participation due to safety precautions. However, for this study, no subjects were excluded for these reasons. A total of 10 subjects were excluded due to their age (over 50 years old) or extremely high levels of body fat (morbidly obese) in order to perform analyses on a more homogenous group. Twenty-nine males and 29 females were selected for the analyses.

Procedures

The data for the investigation were collected in the University of Northern Iowa's Exercise Physiology Laboratory by a team of three laboratory technicians. All technicians were trained on the testing procedures prior to initiation of the data collection. The Institutional Review Board at the University of Northern Iowa approved all procedures of recruitment and testing. All participants read and signed an informed consent form prior to data collection. Subjects were asked to refrain from vigorous exercise and to limit consumption of solid foods two hours prior to their scheduled time for testing. Each subject was scheduled for 30 minutes in order to conduct all testing.

Age and gender were recorded for each subject. Standing height was measured to the nearest centimeter using a wall-mounted stadiometer (Digi-Kit) calibrated using a standard. Dry land body mass was measured to the nearest tenth kilogram using a digital scale (Sega) prior to the underwater weighing with subjects in form-fitting shorts (i.e., compression shorts). All of these measures were recorded on a data sheet.

Vital capacity was measured with a wet spirometer (Warren E. Collins) to the nearest tenth of a liter. The subjects sat down while testing vital capacity and used a nose plug to direct all air from the mouth. At least two trials for vital capacity were performed for each subject. Additional trials were done if there were inconsistencies greater than 0.10L amongst the results. Residual volume was determined using the oxygen rebreathing technique described by Wilmore et al. (1980). Subjects were seated in an upright position similar to what was expected during the head above water weighing. A nitrogen analyzer (Exertech) connected to a laptop computer with software (N2 Logger) was used to determine concentration of air in a rebreathing bag after each subject fully ventilated (4-6 times) in order to dilute the 100% oxygen content in the bag. The software uses the concentration differences before and after a known volume of air in the rebreathing bag to determine residual volume. This procedure was repeated to determine reliability within 0.10L, and then averaged to determine residual volume. Before each test, the instrument was calibrated using a one-liter syringe to an error of less than 0.10L.

Underwater weighing was performed with the subject sitting on a customized flat weighing platform. The water was maintained at a temperature of 31-34 degrees Celsius. The apparatus was calibrated every day of testing before the first subject was weighed. Four different methods of underwater weighing were performed: total immersion with maximal expiration, total immersion with maximal inhalation, partial immersion with maximal expiration, and partial immersion with maximal inhalation. Subjects remained sitting on the platform during the data collection. They were instructed to hold on to the sides of the platform throughout the tests and to keep their feet off of the bottom of the tank by placing them on a cross bar.

The first method was total immersion with maximal expiration (UWW_{RV}). Subjects were instructed to lean forward while remaining seated until their bodies and heads were completely underwater and to maximally exhale their air. Once air bubbles stopped emerging from underwater, the weight was recorded for three seconds. After collection of the weight, the instructor yelled “UP!” to inform the subject to emerge from underwater.

The second method consisted of total immersion with maximal inhalation (UWW_{TLC}). The subjects were instructed maximally inhale while their heads were out of the water, then to slowly lean forward while remaining seated until their bodies were completely underwater. Once the water was steady, the weight was collected for three seconds, followed by an “UP!” to inform the subject to rise up from underwater.

The third method consisted of partial immersion with full expiration (HAW_{RV}). The subjects sat upright with their heads tilted back until the water level was aligned with the tip of the chin and the bottom of the ear lobes. Any subjects with long hair were instructed to either wear a swim cap or tie their hair in a way that it would not touch the water. Subjects were instructed to exhale maximally and to physically close their eyes to indicate when all of their air has been expired. Once their eyes are closed, the instructor collected data weight for three seconds and then told the subject to relax.

The fourth method consisted of partial immersion with full inhalation (HAW_{TLC}). The subjects remained in the same position as the previous method (HAW_{RV}); however, they maximally inhaled. Once their mouths visibly closed, data collection was recorded for three seconds and then the subjects were instructed to relax.

Each method was executed a minimum of three times to obtain a value within ±0.10kg over three trials. The average of the three trials with the greatest weight and least between-trial variability were used for data analysis. All subjects performed the testing procedure in the method order listed above. After the completion of all four methods, subjects were asked to select their preferred method. These responses were recorded on the data sheet.

Data Analysis

All data were transcribed to an EXCEL spreadsheet. The spreadsheet was then copied into the Statistical Package for Social Science (SPSS) Version 22 spreadsheet. The raw data for each individual test were used to calculate body volume (in liters) for the UWW_{RV} method. The mean gender group differences of water weights between UWW_{RV} and HAW_{RV} were applied to the calculation of body volume for the HAW_{RV} method. These body volume measures were then used to calculate body density (in kilograms per liter), and using the Siri equation to estimate body fat percentage. Descriptive statistics were used to identify means, standard deviations (SD), and ranges for each method used in this study.

These derived data were transformed using SPSS compute variable functions to determine the difference for each subject between two methods for estimates of body fat percentage. Mean differences and standard deviations were calculated for each comparison and the 95 percent confidence intervals were calculated using 1.96 * standard deviation added to (upper) or subtracting from (lower) the mean. Bland-Altman Plots were then created to illustrate agreement between two methods reporting the mean difference. Y-axis reference lines were added to identify the mean difference and 95th level of confidence around the mean. Linear regression analyses were used on each dependent variable to test for significance across the range of subject data to detect proportional bias. Finally, the frequency of each preferred method was tallied to determine the percentage chosen for the total group and each gender group. These results are reported by percentage of the totals.

CHAPTER IV

RESULTS

Tables 1 and 2 list the subject characteristics. The range of ages for the subjects places them in a young adult category. Body mass index indicates a range of normal to overweight categories for this subject pool. Table 3 lists the mean and standard deviations of lung volumes for each group and the total. Table 4 lists the mean and standard deviation for each water weight tested in the analyses. The mean (SD) difference between water weights for HAW_{RV} and UWW_{RV} was 3.34 (±0.681) kg for males and 3.40 (±0.451) kg for females. The mean (SD) difference between HAW_{TLC} and HAW_{RV} was 4.10 (±0.918) kg for males and 3.26 (±0.522) kg for females. The means, standard deviations, and ranges for body fat percentages are reported in Table 5.

Bland-Altman Plots are shown in Figures 2-5. For males comparing the UWW_{RV} to HAW_{RV}, there was no significant difference between methods, however, applying the lower and upper confidence levels the estimates of body fat differed by 7.4 – 8.0 % which exceeds the +/- 5% range expected. For females, a similar application resulted in no significant mean difference, but the 6.8 – 7.0% 95th confidence levels difference between methods also exceeded the expected error. However, the results of the regression indicated no proportional bias in the range of data between each of the comparison weights for both groups.

For males comparing HAW_{RV} to HAW_{TLC}, there was a significant mean difference ($t = 4.616$, $df = 28$, $p<0.001$) between methods and the range of confidence intervals varied by more than 10%. For females comparing HAW_{RV} to HAW_{TLC}, there was a significant mean difference ($t = 14.661$, $df = 28$, $p <0.001$) and the range of confidence intervals were greater than 10%.

For the total group of study participants (both males and females), subjects ranked UWW_{TLC} the most preferred method with 39.3% of the votes. Underwater weighing at residual volume ranked second with 28.5% and HAW_{RV} third with 17.9%. The least preferred method was HAW_{TLC} at 14.3%. Within gender, females preferred UWW_{RV} and UWW_{TLC} at the same rate of 34.6%, while 19.3% preferred HAW_{RV} and 11.5% preferred HAW_{TLC}. Males preferred UWW_{TLC} 43.3% and 23.3% for UWW_{RV}. Only 16.7% preferred for both HAW_{RV} and HAW_{TLC}.

Table 1. Male Subjects (n=29)

	Mean	SD	Range (min.)	Range (max.)
Age (yrs)	24.5	6.0	19.0	41.0
Body Mass (kg)	81.54	10.19	65.75	102.25
Stature (cm)	177.55	7.22	163.90	191.90
BMI ($kg*m^{-2}$)	25.83	2.41	20.71	30.08

Table 2. Female Subjects (n=29)

	Mean	SD	Range (min.)	Range (max.)
Age (yrs)	22.07	4.68	18.0	39.0
Body Mass (kg)	67.74	7.57	52.50	83.90
Stature (cm)	171.13	8.13	154.70	185.42
BMI ($kg{*}m^{-2}$)	23.17	2.58	18.75	30.13

Table 3. Mean (SD) Lung Volumes (L)

	RV (L)	VC (L)	TLC (L)
Males	1.50, ±0.36	4.89, ±0.71	6.88, ±0.84
Females	1.27, ±0.33	3.78, ±0.48	5.42, ±0.73
Total	1.38, ±0.37	4.34, ±0.82	6.16, ±1.07

Table 4. Mean (SD) Water Weights (kg)

	UWW (RV)	UWW (TLC)	HAW (RV)	HAW (TLC)
Males	3.50, ±1.13	-0.84, ±1.17	6.83, ±1.38	2.74, ±1.38
Females	1.86, ±0.69	-1.46, ±0.61	5.25, ±0.60	1.99, ±0.60
Total	2.69, ±1.25	-1.14, ±1.28	6.06, ±1.13	2.37, ±1.13

Table 5. Body Fat Percentage: Mean, SD, and Range

Method	Mean (%)	SD (%)	Range (%)
UWW_{RV} (Males)	17.24	7.02	4.41 – 32.18
HAW_{RV} (Males)	17.59	7.47	2.55 – 34.36
UWW_{RV} (Females)	24.47	5.66	13.58 – 34.98
HAW_{RV} (Females)	24.59	5.51	14.84 – 34.94
HAW_{TLC} (Males)	14.60	7.59	1.28 – 31.12
HAW_{TLC} (Females)	17.15	5.76	6.69 – 32.77

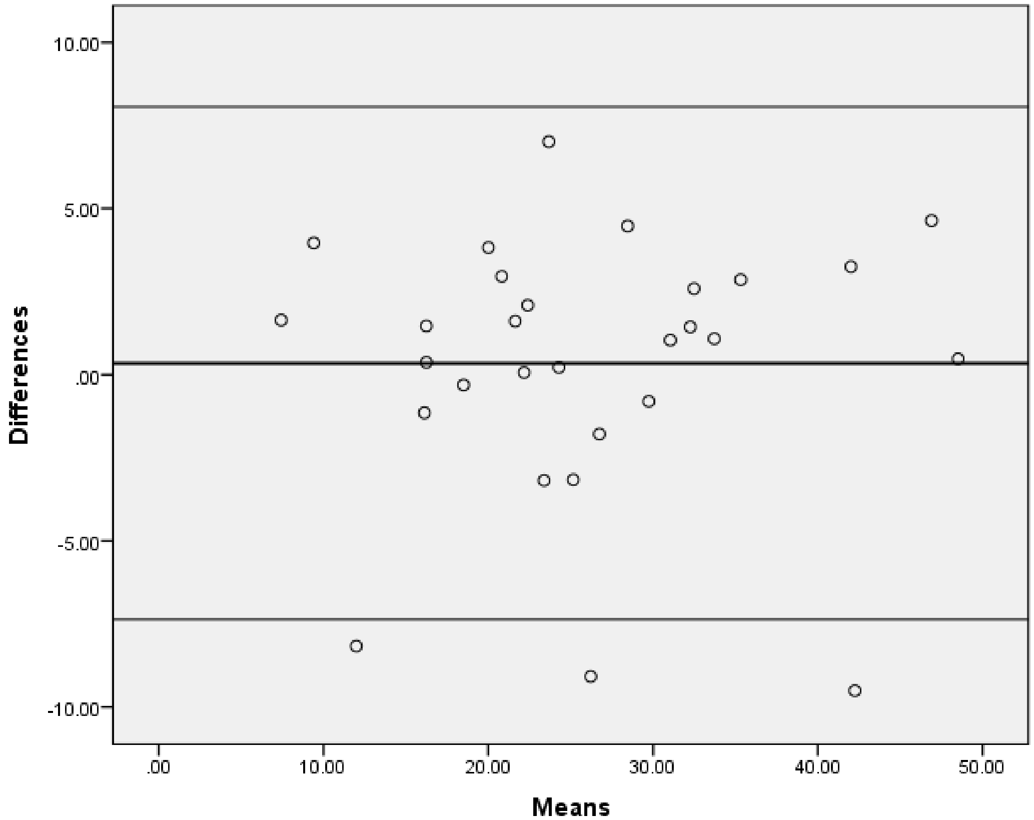

Figure 2. Bland-Altman Plot: Males UWW_{RV} vs. HAW_{RV}

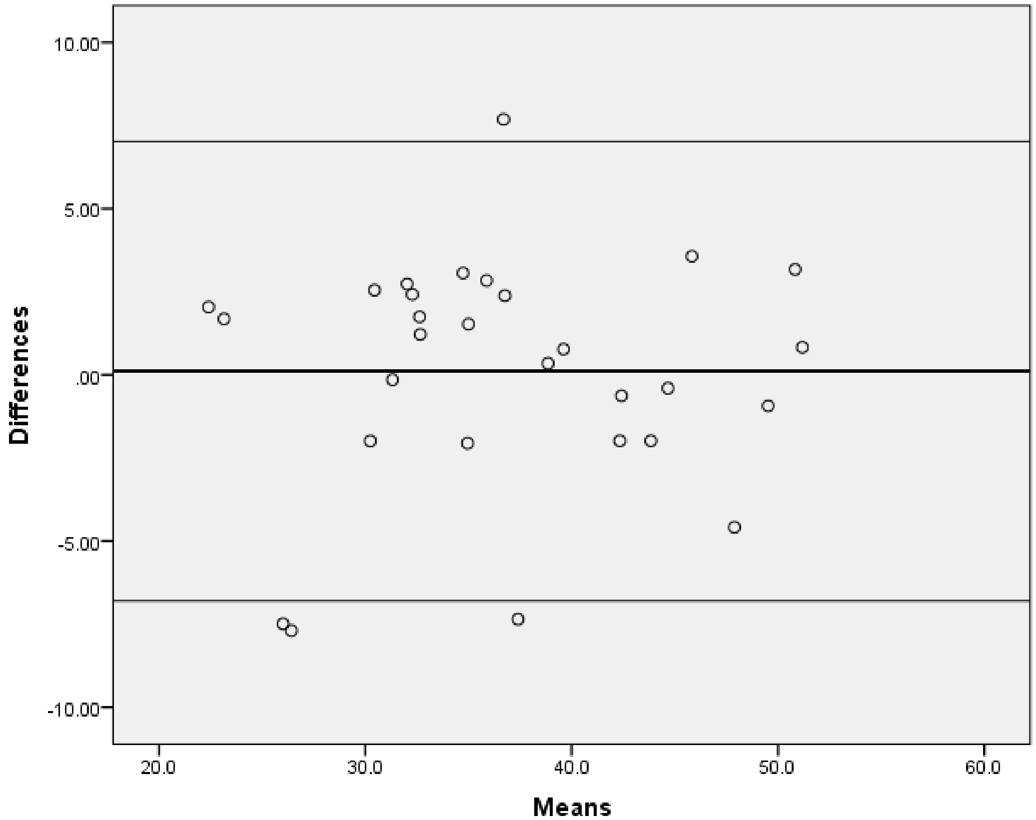

Figure 3. Bland-Altman Plot: Females UWW_{RV} vs. HAW_{RV}

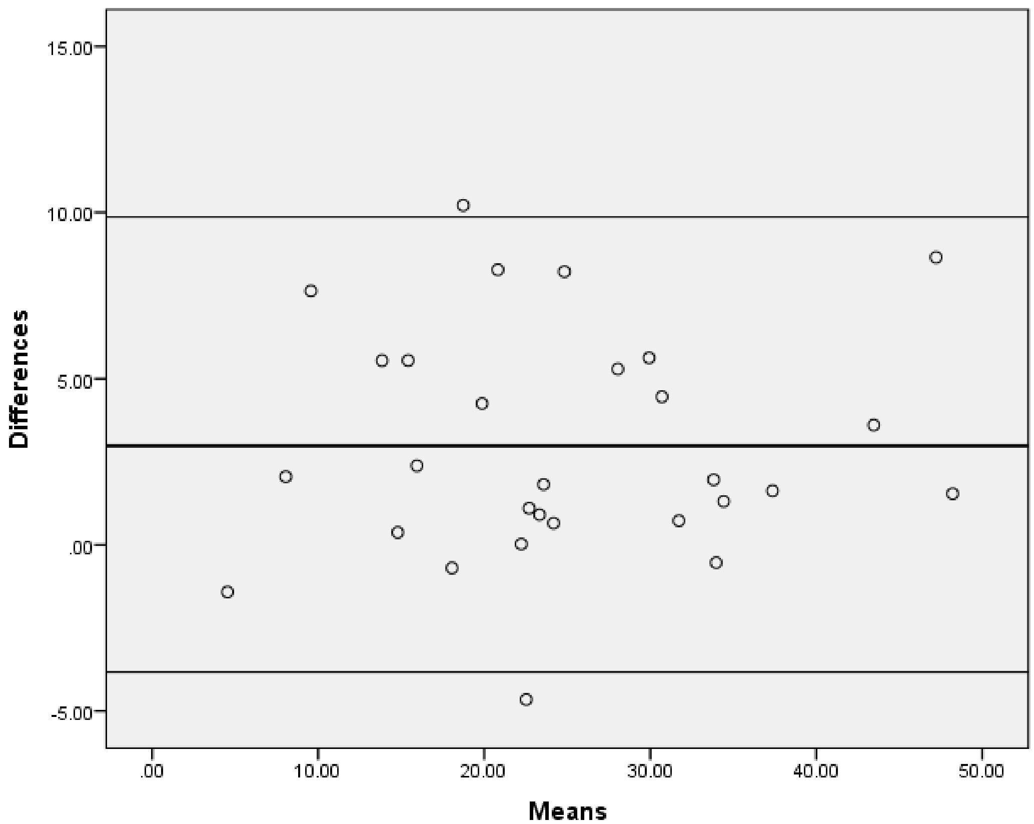

Figure 4. Bland-Altman Plot: Males HAW_{TLC} vs. HAW_{RV}

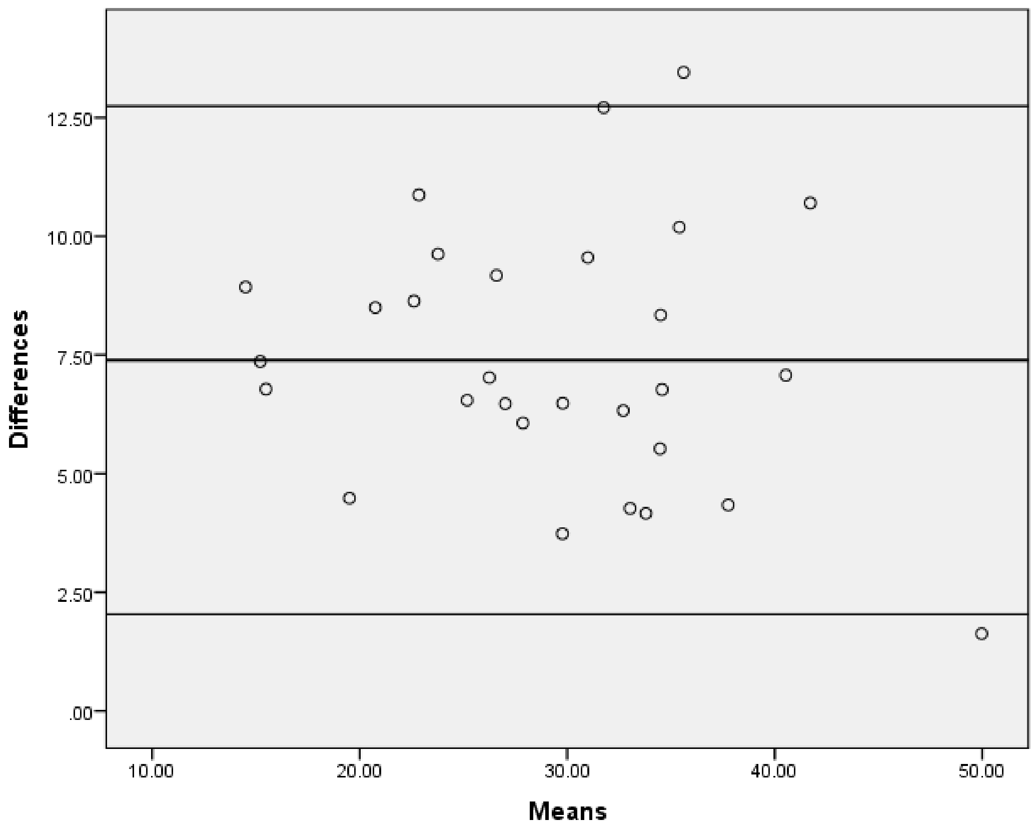

Figure 5. Bland-Altman Plot: Females HAW_{TLC} vs. HAW_{RV}

CHAPTER V

DISCUSSION AND CONCLUSION

This study tested the differences in body mass in water using a full submersion method (head under water) and partial submersion method (head above water) measured at two lung volumes (residual volume and total lung capacity). The mean difference between head above water and underwater weighing resulted in a mean water weight difference of 3.40kg for residual volume and 3.45kg for total lung capacity in females. For males, there was an average difference of 3.34kg when comparing head above water and underwater weighing at residual volume. The average difference between head above water and underwater weighing at total lung capacity was 3.57kg in males. For instance, a 72.95kg male with an underwater weight of 2.0kg at a residual volume of 1.5L would have a body volume equal to 69.80L. His body density would result in 1.045kg/L. Applying the Siri equation, his body fat would be estimated at 23.68%. Using this male's head above water weight of 6.67kg and subtracting the mean difference of 3.34kg, his body volume would equal 68.46L at the same residual volume. He would have a body density of 1.065kg/L and an estimated body fat of 14.79%. This 8.89% body fat difference between the two methods is too large for application in testing body composition. Upon visual observation of the Bland-Altman plots identify four males and four females that exceeded the 5% accepted error between UWW and HAW. Reviewing the body sizes, age, percentage body fat, and residual volumes, no individual factors seemed to explain their large errors.

Subjects' preferred weighing methods were somewhat surprising. More individuals preferred complete submersion compared to keeping their heads above water. Between the two underwater methods, however, it was not surprising that total lung capacity was favored compared to residual volume due to the comfort of subjects being underwater with air in their lungs. There may have been some bias with the UWW_{RV} method in the female group due to a selection of subjects having been exposed multiple times to this standard method of UWW. Some subjects reported they were already comfortable with this method; however, they mentioned the HAW method would be more convenient. Comparing the estimates of body fat percentage between UWW_{RV} and UWW_{TLC} might be prudent. However, since there were significant mean differences between HAW_{RV} and HAW_{TLC}, it does not seem practical to test these differences. For many of the subjects, holding a maximal amount of air in the lungs and submerging the body completely underwater resulted in negative (less than zero) readings. That challenges the ability to do this measurement if technicians are not using a heavy chair (the upward forces would flow the body and chair to the surface).

Some limitations of this study included subjects who were unfamiliar with the process of hydrostatic weighing and were hesitant to exhale all of their air in order to accurately measure at residual volume. The order of the testing methods were the same for all subjects. Non-randomization of the order of methods may have affected the subjects' preference of method due to learning or fatigue throughout the testing process. For head above water measurements, taller subjects sometimes had to compress their torso in order to maintain proper positioning. Some subjects found the head above water measurements difficult due to not being able to adjust the seat in the tank. Residual volume and vital capacity were measured on land due to the location of the instrumentation. If these measurements were performed in the water, the results may be slightly different due to water pressure exerted against the chest cavity.

The age range of the study population was limited due to a number of outliers with subjects over 50 years old. The data was minimized to those of young adults in order to have a more homogenous population. This allowed the data to be analyzed without extreme outliers due to an age category that is more susceptible to obesity. Having a larger sample size would increase the confidence level and therefore would improve the ability of a prediction equation (low SEE).

Underwater weight measurements taken at the end of maximal expiration still require correction for the air in the lungs. The uncertainty of residual volume in the lungs at the time of weighing is the greatest source of error in density measurements (Brozek, Henschel, & Keys, 1949). Using an estimate of residual volume might increase the error in the use of these methods. Assuming residual volume may lead to errors as large as ±500ml in body volume (Goldman & Buskirk, 1961). Test technicians could measure vital capacity; however, it's not certain this is better than the age, sex, and height prediction equations for residual volume.

In conclusion, the following points are made:

1. The mean difference between complete submersion water weight and head above water weight at residual volume is not significant and across a range of mean values, there was no bias. However applying the 95th confidence

interval results in a large error (>5%) in the estimate of body fat percentage and therefore the first hypothesis is rejected.

2. The mean difference between head above water using either the total lung capacity or exhaling to residual volume resulted in a significant difference between the methods. Therefore we accept the second hypothesis and expect differences in lung volumes to have an effect on using total lung capacity as a suitable method for measure.
3. Among the study population the preferred method was complete submersion at total lung capacity. This method provided lower water weights as compared to the standard underwater weighing (at residual volume) method. This method, although not tested, would expect a significant mean difference in estimates of body fat percentage as compared to the standard water weighing at residual volume.
4. The limitations of this study indicate a need to continue evaluation of the head above water methods on a larger sample size including those of middle-aged and older adults.

REFERENCES

Behnke, A. R., Feen, B. G., & Welham, W. C. (1942). The specific gravity of healthy men: body weight÷ volume as an index of obesity. *Journal of the American Medical Association*, *118*(7), 495-498.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine & Science in Sports & Exercise*, *14*(5), 377-381

Brozek, J., Grande, F., Anderson, J. T., & Keys, A. (1963). Densitometric analysis of body composition: revision of some quantitative assumptions. *Annals of the New York Academy of Sciences*, *110*(1), 113-140.

Brozek, J., Henschel, A., & Keys, A. (1949). Effect of submersion in water on the volume of residual air in man. *Journal of Applied Physiology*, *2*(5), 240-246.

Donnelly, J. E., Brown, T. E., Israel, R. G., Smith-Sintek, O'brien, K. F., & Caslavka, B. (1988). Hydrostatic weighing without head submersion: description of a method. *Medicine and science in sports and exercise*, *20*(1), 66-69.

Evans, P. E., Israel, R. G., Flickinger, E. G., O'Brien, K. F., & Donnelly, J. E. (1989). Hydrostatic weighing without head submersion in morbidly obese females. *The American Journal of Clinical Nutrition*, *50*(2), 400-403.

Goldman, R. F., & Buskirk, E. R. (1961). Body volume measurement by underwater weighing: description of a method. *Techniques for Measuring Body Composition*, *3*, 78-89.

Heymsfield, S. B., Lohman, T. G., Wang, Z., & Going, S. B. (2005). *Human Body Composition*. Champaign, IL: Human Kinetics.

Jackson, A. S., Pollock, M., Graves, J., & Mahar, M. T. (1988). Reliability and validity of bioelectrical impedance in determining body composition. *The American Physiological Society*, 529–534.

Katch, F., Michael, E., & Horvath, S. (1967). Estimation of body volume by underwater weighing: description of a simple method. *Journal of Applied Physiology*, *23*(5), 811–813.

Lukaski, H. C. (1987). Methods for the assessment of human body composition: traditional and new. *American Society for Clinical Nutrition*, *46*, 537–556.

Spencer, F. (1997). History of Physical Anthropology. In *History of Physical Anthropology* (1st ed., pp. 190–193). New York, NY: Garland Publishing, Inc.

Wilmore, J. H., Vokak, P.A., Parr, R. B., Girandola, R.N., & Billing, J.E. (1980). Further simplification of a method for determination of residual volume. *Medicine & Science in Sports & Exercise*, *12*,216-218.