A Comparison of Body Density and Percent Body Fat as Computed Using Four Different Lung Volumes in the Hydrostatic Weighing Technique

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ABSTRACT

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This study compared body density (BD) and percent body fat (%BF) arrived at by using four different lung volumes in the hydrostatic weighing (HW) procedure. The four lung volumes were residual volume as measured in air (RV-dry), residual volume as measured immersed in water (RV-wet), functional residual capacity as measured immersed (FRC), and total lung capacity as measured immersed (TLC). The closed circuit oxygen dilution technique was used to measure all lung volumes. A questionnaire completed by the Ss was used to assess the comfort of each method. Ss included 14 male and 16 female students of the University of Wisconsin-La Crosse, ages 19-34. Two BD and %BF were calculated for Ss by applying lung volume measurements at RV-dry, RV-wet, FRC, and TLC. A mean of the two trials was computed for lung volume, BD, and %BF, and were used in statistical comparison of the four techniques. An ANOVA with repeated measures followed by a Scheffé Post Hoc Test was used to analyze BD and %BF data. T-test was used to compare RV-dry and RV-wet lung volumes. There was no sig (p .05) dif between HW determination of BD and %BF using RV-dry, RV-wet, and FRC. There was a sig (p .05) increase in HW determination of BD and %BF using TLC compared to RV-dry, RV-wet, and FRC. FRC was deemed most comfortable by Ss. It was concluded that with the apparatus and methods described in this study, RV-dry, RV-wet, and FRC could be used interchangeably in BD and %BF determinations by HW. The TLC method can not be used interchangeably with the other three methods in BD and %BF determinations by HW.

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Dedication

For Lani and Jami, who made all the sacrifices,

and deserve all the credit.

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CHAPTER I

INTRODUCTION

One of the criteria by which the success of an exercise program is evaluated for an individual is the change in body composition toward a more lean state. Body composition is described as the relationship of lean body weight to percent body fat (Cureton, Hensley & Tiburzi, 1979). Many methods of evaluating the ideal relationship between lean body weight and percent body fat have been proposed over the years.

The first attempts to establish ideal body composition norms were the standard height-weight tables developed by life insurance companies with data collected on 200,000 policy holders between 1885 and 1900. The tables were designed to show which height-weight combinations correlated with a lower mortality rate compared to the general population (keys & Brozek, 1953). Many revisions of these early height-weight tables continued into the 1950's. Although each revision attempted to correct the shortcomings of earlier height-weight tables, all had the obvious flaw of not compensating for increases in weight que to an addition of lean body weight brought on by greater levels of physical activity (Keys & Brozek, 1953).

The use of anthropometric measurement to assess body composition has gained wide acceptance in recent years. The low cost and ease of performing skinfold measures have made this technique appealing to the clinician (Wilmore, 1983). The reliability of skinfolds has been and continues to be an area of controversy in the literature, primarily because there is a wide variation between researchers in percent body fat values obtained on the same subjects measuring the same skinfold sites (Katch & Katch, 1980; Keys & Brozek, 1953; Martin, Drinkwater, Clarys & Ross, 1981; Sinning, 1980; Wilmore, 1983). Circumferences and girth measurements of various body segments alone, or in combination with skinfold measurements, have also been used in predicting body composition. The apparent flaw is again the low reproducibility as experienced in skinfold measurements (Katch & Katch, 1980).

The current "gold standard" for the evaluation of body composition, and the method against which all other techniques are validated is an estimated value derived from hydrostatic weighing at residual lung volume. This technique appears to have the least variance between researchers and is generally thought to be the most accurate for all segments of the population (Katch & Katch, 1980; Katch, Michael & Horvath, 1967; Wilmore, 1983).

Need for the Study

To obtain an accurate estimation of body composition by hydrostatic weighing the subject must expire maximally in air and under water, and maintain this immersed breathless position for several seconds while a weighing determination is made (Welch & Crisp, 1958). This maneuver appears to be quite discomforting for some individuals regardless of unimpaired pulmonary function (Thomas & Etheridge, 1980). Additionally, this procedure is contraindicated in those individuals with a history of cardiovascular pathology (Girandola, Wiswell, Mohler, Romero & Barnes, 1977). The ability of subjects to adapt comfortably to the water environment has been a problem in hydrostatic weighing since the technique was first used (Brozek, Grande, Anderson & Keys, 1963).

Welch and Crisp (1958) suggested that the most appropriate lung volume to use in hydrostatic weighing was residual volume (RV) because it was the lung volume least affected by the pressure exerted on the thorax and abdomen by the surrounding water. Other investigators have suggested that this method may yield inaccurate results due to pulmonary vascular engorgement and resultant air trapping (Agostoni, Gartner, Torri & Rahn, 1966; Bondi, Young, Bennett & Bradley, 1976; Dahlback & Lundgren, 1972; Robertson, Engle & Bradley, 1978). In addition, forcing out all air while immersed seems very difficult for some individuals and could result in inaccurate estimation of body density and percent body fat.

In an effort to eliminate the vascular engorgement and resultant air trapping problem and make hydrostatic weighing more comfortable, many researchers have attempted to develop an accurage assessment of body composition by hydrostatic weighing using larger lung volumes with varying degrees of success. The desire to develop a hydrostatic weighing technique at a comfortable lung volume that allows accurate body density assessment indicated the need for this study.

Four different lung volumes were selected for comparison in hydrostatic weighing to determine body density and percent body fat of each subject in the study. Residual volume as measured on land

(RV-dry) was chosen as the standard against which the remaining lung volumes were compared since it is the technique employed in the majority of the research on body density and percent body fat. Residual volume as measured immersed (RV-wet) was chosen to see what effect the water environment had on residual lung volume. Total lung capacity and functional residual capacity immersed were chosen because of the anticipated ease with which the subjects could perform these breathing maneuvers.

Statement of the Problem

The problems addressed in this study were threefold:

1. Since the current accepted lung volume used in hydrostatic weighing is RV as measured on land, the researcher compared body density and percent body fat of subjects using RV on land (RV-dry) versus RV immersed (RV-wet), and had subjects rate each method in terms of comfort and preference.
2. The researcher compared RV-dry to functional residual capacity immersed (FRC) in hydrostatic determination of body density and percent body fat, and had subjects rate each method in terms of comfort and preference.
3. The researcher compared RV-dry to total lung capacity (TLC) immersed in hydrostatic determination of body density and percent body fat, and had subjects rate each method in terms of comfort and preference.

Hypotheses

The following hypotheses were formulated:

1. There is no significant difference in body density and percent body fat using RV-dry versus RV-wet.
2. There is no significant difference in body density and percent body fat using RV-dry versus FRC.
3. There is no significant difference in body density and percent body fat using RV-dry versus TLC.
4. There is no significant difference between subject ratings of comfort and preference for the four lung volumes used in the study.

Limitations

The following limitations were observed in regard to this study:

1. The subjects were volunteers, therefore, the sample did not meet the criteria to be classified as randomly selected.
2. A small number of subjects (n = 4) volunteered for the pilot study to determine the test-retest reliability of the proposed hydrostatic methods.
3. It was difficult to determine how well breathing maneuvers were performed when the subjects were submerged.

Delimitations

In reference to this study, the following delimitations were made:

1. The population studied was delimited to male and female college students, ages 19-34, from the University of Wisconsin-La Crosse

because of the availability of the subjects.

2. Participants were to be free of cardiorespiratory illness.
3. The hydrostatic weighing technique was delimited to the use of four lung volumes: (1) RV-dry, (2) RV-wet, (3) FRC, (4) TLC.

Assumptions

The following assumptions were made in regard to the scope of this study:

1. All subjects performed the respiratory maneuvers to the best of their ability.
2. All subjects refrained from eating for 12 hours prior to participation in the study.
3. All subjects responded honestly to the questionnaire regarding comfort and preference of the testing procedures.
4. All subjects were free of cardiorespiratory pathology.

Definition of Terms

Archimedes Principle - a law of fluid mechanics: a body submerged in a fluid is bouyed up by a force equal to the weight of the fluid displaced (Behnke, 1961).

Body Plethysmograph - an airtight box enclosing the entire body measuring gas and volume pressure changes in the system produced by breathing (Wilmore, 1969).

Density - the mass per unit volume of a body expressed as gm/cc ($D = m/v$).

Functional Residual Capacity (FRC) - the volume of gas remaining in the lungs following a normal resting expiration.

Hydrostatic Weighing - a technique used to calculate percent body fat through total submersion of the subject to determine body density based on Archimedes Principle.

Percent Body Fat - the percent of the total body weight which is composed of adipose tissue.

Residual Volume (RV) - the volume of gas remaining in the lungs following a maximal expiration.

Spirometer - a device that measures exhaled or inhaled air volume per unit time, by recording breathing patterns on a motor driven drum adjacent to a spirometric cylinder which raises on expiration and lowers on inspiration.

Total Lung Capacity (TLC) - the volume of gas contained in the lungs following a maximal inspiration.

Vital Capacity (VC) - the maximum volume of gas that can be exhaled following a maximal inspiration.

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

The purpose of this study was to compare body density and percent body fat computed using four different lung volumes in the hydrostatic weighing procedure. The four lung volumes were: residual volume on land (RV-dry), residual volume immersed in water (RV-wet), functional residual capacity immersed in water (FRC), and total lung capacity immersed in water (TLC). In this study, immersed was defined as the body totally submerged in water in a forward leaning sitting position. This chapter examines: (1) the principles and practice of hydrostatic weighing, (2) the lung volumes used in hydrostatic weighing, (3) methods of assessing the lung volumes used in hydrostatic weighing, and (4) the conversion of body density to percent body fat.

Hydrostatic Weighing

Many methods of determining the amount of fat on a human body have been proposed over the years. The current "gold standard" is the hydrostatic weighing technique first described by Behnke, Feen and Welham (1942). This technique makes use of the Archimedian Principle which states that a body submerged in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the submerged body. The buoyancy force exerted on an individual submerged in water is related to the amount of body fat. The greater the percent body fat, the less the fluid displaced, and the greater the tendency to float. Thus, by measuring the weight of an individual submerged in water, the body density can be calculated and the conversion made to percent body fat. In addition to the buoyancy of fat, the volume of air in the lungs and gastrointestinal tract contribute to the upward force on the body. Controversy surrounds the issue of the influence these volumes of air have on the final determination of body density and percent body fat (Weltman & Katch, 1981).

Goldman and Buskirk (1961) state that the most accurate and widely used method of assessing body density is by hydrostatic weighing. The hydrostatic weighing technique utilizes Archimedes Principle which states that a body immersed in a fluid is acted upon by a buoyancy force, which is noted as an apparent loss of weight equal to the weight of the displaced fluid. When hydrostatically weighed, the individual's body density is related to his apparent loss of weight corrected for for density of water. Thus, Goldman and Buskirk arrived at the following formula for body density:

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

where: D_B = Body Density

M_A = Mass of Body in Air

M_W = Mass of Body in Water

D_W = Density of Water

A correction must be provided for the air remaining in the lungs, and the gas remaining in the gastrointestinal system.

Volume of Gastrointestinal Gas

Controversy clouds the issue on the amount of gas contained in the gastrointestinal system. Keys and Brozek (1953) made reference to a series of unpublished studies on 21 healthy male subjects measuring the maximum volume of gas contained in the stomach and intestines. Radiologic studies following a barium meal showed the maximum gas volume of the stomach and intestines to be 49 ml. One subject who swallowed a great deal of air was found to have a volume of 133 ml. Thus, Keys and Brozek concluded that in the healthy individual the upper limit of gastrointestinal air was probably 50-100 ml.

Goldman and Buskirk (1961) conducted research on the volume of gas remaining in the gastrointestinal system following a meal at various time intervals, and concluded that a 12 hour fast is needed to ensure that the volume of gas in the system remained below 100 ml. Durnin and Satwanti (1981) experimentally created different gastrointestinal gas volumes for the purpose of body density measurement utilizing hydrostatic weighing by having 15 subjects ages 17 to 51 years ingest a light meal (500 kcal), heavy meal (1200-2200 kcal), and carbonated drink. The effects of the light meal demonstrated a mean increase of 0.8 percent body fat as compared to percent body fat determinations made in the fasting state, suggesting an increase in gastrointestinal gas. Similarly, the heavy meal and carbonated drink produced a mean increase of 1.1 and 1.6 percent body fat, respectively, indicative of even larger enteric gas volumes. Their conclusions were that large volumes of gas in the intestine resulted in a difference of about 1.5 percent body fat, which was statistically significant, but for non-precise laboratory work was an acceptable margin of error. Thus, most current studies use the upper limit of allowable volume of gastrointestinal gas (Katch & Katch, 1980; Wilmore, 1983), 100 ml, when computing body density and percent body fat by hydrostatic weighing.

Lung Volumes Used in Hydrostatic Weighing

Residual Volume

Residual volume, defined as the volume of gas remaining in the lungs following a maximal expiration, is the preferred lung volume during most hydrostatic weighing procedures. It is the volume that has been shown to have the least amount of fluctuation from air to water.

Welch and Crisp (1958) tested 26 males at maximal expiration, and one-half maximal expiration in air versus immersed in water. The maximum expiration level was established by several trials under water in which weight and vital capacity were measured simultaneously. One-half maximal expiration was determined in the same manner, except the subject was signaled to cease exhaling at a point equivalent to one-half his vital capacity. The average depth of submersion for all subjects in the seated position was to have the umbilicus 30 inches below the surface of the water. They found a significant difference in body density determination using maximal expiration versus one-half maximal expiration. Their conclusions were that for extremely critical laboratory work, the smallest attainable lung volume should be used in body density determinations.

Brozek et al. (1949) measured the residual volume of nine subjects in air and again in water. Subjects were in the seated position in each case, and an overall average decrease of 129 ml was noted in residual volume measured submerged versus measured in air. They concluded the mechanical compression of the water on the submerged subjects caused a decrease in residual volume. However, the psychological effect of submersion with no air may create a degree of anxiety that would inhibit exhalation in some individuals. This was their explanation for an increased immersed RV in five of the 18 subjects tested.

Craig and Ware (1967) found similar results in 21 healthy male adults. The subjects in this study had their RV determined in the seated position in air and again immersed to the neck in water in the vertical position. The average RV in air was 1.44 liters, while immersed RV was 1.38 liters. Fifteen subjects experienced a decrease in immersed RV, five an increase in immersed RV, and one subject experienced no change in immersed RV.

Bondi, Young, Bennet and Bradley (1976) supported these findings with research conducted on 10 subjects immersed to the larynx versus in air in the seated position. A mean decrease in immersed RV of 9.35 percent was noted compared to RV in air. They suggested the decrease in immersed RV may have been due to mechanical assistance offered by the breathing apparatus. They also noted a slightly greater decrease in immersed RV of the younger non-smoking subjects versus the older smoking subjects. The small number of subjects (n = 10) has made this finding of little significance.

Prefaut, Lupi and Anthonisen (1976) found virtually no change in immersed RV measurements versus those in air in five healthy male subjects ages 30-40. No actual numbers were provided to support the lack of change, and no explanation. Again, the small population studied decreases the significance of the findings.

Girandola et al. (1977) found a significant increase in immersed RV versus RV measured in air in 20 male subjects. Subjects in this study were in the vertical position standing on a ladder in the hydrostatic weighing tank with the water at the crotch level for the in air procedure. Subjects then stepped down the ladder and the RV measurement was repeated in the vertical position immersed to the neck. The significant RV increase of 6.7 percent produced a 0.6 percent decrease in calculation of percent body fat. They attributed the increase to possible stiffness in the lung tissue caused by vascular engorgement and resultant air trapping induced by water immersion. Five subjects in the study experienced a slight decrease in RV immersed versus RV in air, supporting previous discussions. Girandola et al. suggested that the discrepancy in the literature regarding increase or decrease in immersed versus dry RV measurements is due to the fact that water immersion affects individuals to varying degrees, and RV measurements for the purpose of body density calculations should be recorded simultaneously with hydrostatic weight. This would make a false immersed RV measurement due to air-trapping insignificant since the added bouyance of the trapped air would be noted as a decreased hydrostatic weight.

Functional Residual Capacity (RFC)

Functional residual capacity, defined as the volume of gas remaining in the lungs following a normal exhalation, has been recently studied with regard to volume changes upon water immersion. Thomas and Etheridge (1980) hydrostatically weighed 43 male subjects at FRC and RV immersed in the prone position. The percent body fat values for immersed FRC and RV were 9.3 $\pm$ 5.2 percent and 9.2 $\pm$ 5.1 percent, respectively, and were not statistically different. They concluded that hydrostatic weighing in the prone position at FRC and RV produced similar body fat results. Since measurement at FRC was more comfortable for the subjects in this study and caused the least scale fluctuation, this would be the method of choice when the lung volume could be assessed during hydrostatic weighing. Prefaut et al. (1976) found a 27 percent decrease in the FRC of five male subjects immersed to the neck versus FRC in the air. This large decrease from air to immersed indicated the need for the determination of lung volumes larger than RV while immersed and at hydrostatic weight.

Based on the relatively few studies using FRC in body density determination it is apparent that this lung volume is not easily reproduced in water. Therefore, FRC should be measured simultaneously with hydrostatic weight for the purpose of body density calculation.

Vital Capacity (VC)

Vital capacity, defined as the volume of gas that is forcefully and completely expired after a maximal inspiration, has also been used in assessing body density by hydrostatic weighing. Craig and Ware (1967) found a statistically significant difference in VC as measured in a seated position in air versus an upright position in water in 21 adult males. The mean decrease of 230 ml (9.5 percent) from air to immersion was attributed to the hydrostatic pressure exerted on the chest wall by the water environment. This decrease was approximately four times greater than the decrease in RV immersed compared to RV in air measured in the same subjects. The authors concluded that the hydrostatic pressure would produce a greater decrease of VC than in RV because of the differences in compliance in two extremes of the relaxation pressure curve. Specifically, the lungs are more compliant and thus affected more by hydrostatic forces at VC than at RV.

Bondi et al. (1976) found a 9.94 percent decrease in VC immersed versus VC in air in 10 healthy male subjects. They attributed this decrease to a shift of blood to the thoracic region resulting in a decrease in airway diameter. This decrease in immersed VC agrees with the 9.5 percent decrease noted by Craig and Ware (1967).

McGarty (1982) similarly found a statistically significant 9.4 percent (282 ml) decrease in immersed VC versus VC in air in 99 competitive and non-competitive swimmers. The researcher attributed the decrease to the hydrostatic influence of immersion. It was also noted that the males in the study experienced a greater decrease than the females. This finding agrees with Craig and Ware (1967) in which it was noted that subjects with larger lung volumes were influenced to a greater degree by hydrostatic pressure exerted on the thorax and abdomen.

Based on the review of literature concerning the use of VC in hydrostatic weighing it is apparent that immersed VC is significantly less than VC measured in air. Therefore, VC measurement should be performed simultaneously with hydrostatic weight measurement in body density calculation.

Total Lung Capacity (TLC)

Total lung capacity, defined as the volume of gas contained in the lungs following maximal inspiration, was also found to decrease significantly from air to water in McGarty's (1982) study. The TLC in this study was derived from addition of forced vital capacity immersed and in air to residual volume measured in air. Weltman and Katch (1981) measured TLC and RV in air and compared the two lung volumes in the hydrostatic weighing determination of body density and percent body fat. Similar to McGarty (1984), and Craig and Ware (1967), it was noted that the larger lung volume (TLC) decreased significantly due to the influence of hydrostatic pressure.

Lung Volume Measurements

Residual volume, the preferred lung volume in hydrostatic weighing, is the only fractional lung volume that cannot be directly measured by the use of a spirometer. Therefore, some form of indirect analysis is needed. Larger lung volumes may be measured indirectly by spirometry or by the same indirect methods as RV. Wilmore (1969) stated that the indirect measurement methods can be classified into three categories: (1) the pneumatometric method, (2) the closed circuit method, and (3) the open circuit method.

The pneumatometric method uses whole body plethysmography in measuring lung volumes. This requires that the subject be sealed in an airtight chamber connected to a spirometer. The subject breathes to the outside of the chamber through a mouthpiece. Total lung capacity and RV are calculated by measuring the change in pressure at the mouthpiece and the volume of expansion of the thorax. This technique has advantages over others because it can be used accurately on subjects with some form of airway obstruction (Wilmore, 1969). Robertson et al. (1978) claim that this technique also detects small amounts of trapped air which could exist in RV measurement. The primary disadvantages are the special body chamber required for the procedure, and the amount of time required to perform the maneuver.

The closed circuit method involves the subject rebreathing a gas of specific composition, e.g. 100 percent oxygen in a closed system. The subject exhales maximally in room air, and is connected to 100 percent oxygen in a closed system, such as an oxygen-filled spirometer. The subject breathes deeply until the oxygen and remaining lung volume have thoroughly mixed and an equilibrium is reached between the oxygen originally in the closed system and the fraction of gas being analyzed in the lungs at the moment of lung volume measurement. This technique was first proposed by Lundsgaard and Van Slyke (1918) and has since been modified by Wilmore (1969) to yield accurate results in six to eight breaths.

The open circuit method involves the washing out of nitrogen from the pulmonary system over a period of approximately seven minutes. The subject sits quietly and inhales pure oxygen until virtually all the nitrogen is removed from the ventilated air. Wilmore (1969) indicates that the problem with this method is that there is a small amount of nitrogen, approximately 200 ml, dissolved in the body tissues, and an additional 20 ml dissolved in the blood, that is continually being released to the ventilation in minute quantities. This could have an effect on the results over the seven minute period required for the procedure. In order for a second trial to be performed, the subject would have to wait several minutes for the nitrogen content of the pulmonary air to return to normal.

Of the three methods discussed in measurement of residual volume, the closed circuit and open circuit methods are most common (Robertson et al., 1978). This is probably because of the need for less equipment and the decreased time in performing these maneuvers as compared to the pneumatometric approach.

All three of the above techniques, in addition to measuring RV, may also be used to measure larger lung volumes. This is important because if one of these three techniques could be modified to allow for measurement of larger lung volumes while immersed, a more comfortable hydrostatic determination of body density and percent body fat would be possible. Keys and Brozek (1953) cited the unpublished observation of Carlson and Chen:

> When the residual air at the moment of underwater weight is directly estimated, it is immaterial what phase of respiration is used, and we have found close agreement between the corrected (air free) body density at full expiration and at moderate inspiration in repeated trials on the same men (p. 272).

Conversion of Body Density to Percent Body Fat

With the immersed lung volume determined by spirometry or one of the three indirect methods discussed, and the estimated volume of gastrointestinal gas, 100 ml, the body density is calculated by hydrostatically weighing as previously discussed and placing the values in the body density formula (Buskirk, 1961).

$$D_B = \frac{M_A}{\frac{M_A - M_W}{D_W} - LV - 100 \text{ mls}}$$

Body density is generally converted to percent body fat for practical application. Two formulas are most commonly used in recent research and clinical application (Sinning, 1980), and will be discussed.

Brozek, Grande, Anderson and Keys (1963) analyzed data collected on three male cadavers by three different researchers. From their study a "reference body" was derived from the mean values of body constituents of the three male cadavers. The reference body's fat density was determined to be 0.915 gm/cc. This information was used in the derivation of the following formula to convert body density to percent body fat:

$$\text{Percent Body Fat} = \frac{4.570}{D_B} - 4.50 \quad X\ 100$$

Work by Siri (1961) led to the development of a conversion formula based on lean body mass. He estimated that the density of fat was 0.900 gm/cc, and used this in the derivation of the following formula:

$$\text{Percent Body Fat} = \frac{4.95}{D_B} - 4.50 \quad X\ 100$$

According to Siri (1961), the standard error in percent body fat estimation is $\pm$ 3.8 percent when using hydrostatic weighing determination. This error was believed to consist of four major sources: (1) the variability in the water content of the body independent of body fatness, (2) variance in protein to bone mineral ratio, (3) variance in the density of adipose tissue, and (4) variance in fat content. The experience and proficiency of the researcher performing the lung volume and hydrostatic weighing procedure also contributes to the possibility of error which amounts to approximately $\pm$ 0.002 gm/cc (Katch & Katch, 1980). Although slight variations exist between the formulas of Brozek et al. (1963) and Siri (1961), Wilmore and Behnke (1969) found a high correlation (r = .99) between the formulas when predicting percent body fat. This suggests that both formulas are acceptable for conversion of body density to percent body fat.

Martin, Drinkwater, Clarys, and Ross (1981) used the standard equations of Siri (1961) and Brozek et al. (1963) in comparison to direct chemical analysis of 12 male cadavers and found statistically significant differences in body density and percent body fat. It appears that although the density of fat is relatively consistent, 0.900 to 0.915 gm/cc, the density of the lean component of body composition can vary considerably (Wilmore, 1983). With both young and older population, variations in bone mineral and total body water content may lead to overestimations of body fat (Wilmore & McNamara, 1974; Wilmore, Miller & Pollock, 1974).

Conclusions

Body density and percent body fat determinations are generally considered to be most accurate when assessed by hydrostatic weighing. The most widely accepted lung volume used in hydrostatic weighing is residual volume as measured in air. When reproducing RV immersed, many individuals experienced anxiety and discomfort, thus increasing the possibility of measurement error.

Based on the review of literature it is apparent that there is a need to establish a hydrostatic weighing technique at a comfortable immersed lung volume. The technique should correlate highly with the present accepted practice of hydrostatic weighing at RV.

CHAPTER III

METHODS

Introduction

The purpose of this study was to compare body density and percent body fat computed using four different lung volumes in the hydrostatic weighing procedure. The four lung volumes were: residual volume on land (RV-dry), residual volume immersed in water (RV-wet), functional residual capacity immersed in water (RFC), and total lung capacity immersed in water (TLC).

Immersed was defined as the body totally submerged in water in the forward leaning seated position. The subjects employed in this study were men and women from the student body at the University of Wisconsin-La Crosse. This chapter describes the methods used in obtaining body density and percent body fat values of the subjects.

Subject Selection

Sixteen females and 14 males, ages 19 to 34 years, volunteered for the hydrostatic weighing procedure. The subjects were required to refrain from strenuous physical activity for four hours prior to the testing procedure. The subjects were also required to fast for 12 hours prior to the hydrostatic weighing procedure as recommended by Goldman and Buskirk (1961). Subjects were presumed to be free of cardiorespiratory illness.

Instrumentation and Procedures

Pilot Study

A pilot study was conducted to determine the test-retest reliability of the four lung volume measurements used in hydrostatic determination of body density and percent body fat. Four volunteers similar in age and physical characteristics to the subjects in the study were employed. Each subject performed one of the four different lung volume techniques in the hydrostatic weighing procedure. Subjects performed the technique six times on two different occasions within a 24 hour period. A discussion of the results of the pilot study has been included in Chapter IV.

Hydrostatic Weighing

Each subject was weighed in air on a Continental Health-O-Meter scale (model #200 DLK) and immersed in a 4' X 4' X 4' S.S. Hydrostatic tank (model # 09771) while sitting on a plastic tubing chair suspended from a Chatillon autopsy scale (model # 8-2096). Water temperature was maintained between 31-38°C.

With the exception of RV-dry, hydrostatic weight was noted at the same time lung volume measurements were made in the sitting, forward leaning position. This position is pictured in Figure 1. Each subject was given a practice trial without being connected to pure oxygen or measurements made. Two successive trials of each lung volume were then performed in the order of random selection by the subject while hydrostatic weight were recorded in formulas for RV (Wilmore, 1969) and body density (Buskirk, 1961). Body density was converted to percent body fat (Brozek et al., 1963) and the mean body density and percent body fat of the two trials for each lung volume were calculated.

Figure 1. Hydrostatic Weighing Position

Spirometry

A 13.5 Collins Respirometer (model # 2136) was used in collecting and measuring the volume of oxygen used for rebreathing to determine all four lung volumes of the subjects in this study. The spirometer was modified for the purposes of this study by the head laboratory technician at the University of Wisconsin-La Crosse Human Performance Laboratory to effectively reduce the spirometer and connecting apparatus dead space to 1.46 liters. To maintain this known dead space, the spirometer water level was maintained at the same line for each subject. Oxygen dilution and direct volume measurements were used in calculation of the dead space of the spirometer, snorkel tube, analyzer head, and mouthpiece.

Lung Volume Determination

The closed circuit oxygen dilution method as outlined by Wilmore (1969) was used to determine the lung volumes of all subjects, with both dry and immersed determinations performed with the same apparatus. The percent nitrogen of each lung volume was determined using a Collins Nitrogen Analyzer (model #21232). A Fisher Recordall Series 5000 chart recorder (model # B5217-51) was connected to the nitrogen analyzer and graphically recorded nitrogen fraction values for later analysis. The lung volume apparatus is pictured in Figure 2.

Order of Procedures

Each subject had their RV determined on land prior to entering the hydrostatic weighing tank. The subject then randomly selected the four techniques to be used in the hydrostatic weighing procedure by drawing four pennies from a container. Each technique corresponded to a different penny identified by the year the penny was made. The four procedures were RV-dry, RV-wet, FRC, and TLC. Although the lung volume used in the RV-dry technique was determined prior to the subject

Figure 2. Lung Volume Apparatus

entering the hydrostatic tank, the hydrostatic weight measurement for RV-dry was performed in random order with the three other techniques.

The researcher flushed the spirometer with oxygen until an impurity of 0.00 percent nitrogen was displayed by the nitrogen analyzer. At this point the valve connecting the spirometer to the outside air was closed, and the spirometer was filled to the desired amount of oxygen. The amount of oxygen collected in the spirometer and used in rebreathing was subjectively determined by the researcher based on subject size and ventilatory technique for each trial. When the desired amount of oxygen was collected, the supply of oxygen was turned off, and the subject was then instructed on the proper breathing technique.

Residual Volume Dry Procedure (RV-dry)

The RV of each subject was measured on land as mentioned earlier. The subject was instructed with noseclip and mouthpiece in place, to lean forward and maximally exhale. This position is pictured in Figure 3. When the subject felt all the air he could remove was gone, he was to tap the hydrostatic tank to his left as a signal that only RV remained in the lungs. At this point, the researcher connected the subject to the oxygen-filled spirometer and coached the individual to breathe deeply until an equilibrium was reached between the spirometer air and the subject's air nitrogen fraction. The values obtained were then placed in the formula presented by Wilmore (1969).

$$LV = \frac{VO_2\ (EN_2 - IN_2)}{AN_2 - FN_2} - .35 \times 1.1$$

Figure 3. RV-dry Lung Volume Position

where: LV = volume of air remaining in the lungs following ventilatory technique described by researcher

VO_2 = volume of oxygen collected in the spirometer for rebreathing

AN_2 = percent nitrogen in the alveolar air after connection to pure oxygen

EN_2 = percent nitrogen at equilibrium while rebreathing

IN_2 = percent nitrogen impurity found in the oxygen of the spirometer before rebreathing

FN_2 = percent nitrogen found in expired air after equilibrium was reached

0.35 = volume of air in snorkel tube and analyzer head

1.1 = correction for BTPS

The RV obtained was the assumed lung volume used in the RV-dry hydrostatic weighing procedure.

The RV-dry hydrostatic technique was performed with the subject completely submerged in the forward leaning seated position. The subject was instructed to maximally exhale above the surface, and slowly submerge and exhale any remaining air. Once air bubbles ceased to rise to the surface, the researcher noted hydrostatic weight of the subject and gave an audible signal to the subject to return to the surface. Two trials were performed, and the RV measured on land along with hydrostatic weight were placed in the body density formula presented by Buskirk (1961):

$$D_B = \frac{M_A}{\frac{M_A - M_W}{D_W} - RV - 0.1\ L}$$

where: D_B = body density

M_A = mass of subject in air

M_W = mass of subject in water

D_W = density of water

0.1L = Estimation of volume of enteric gas

Having computed body density, the percent body fat was calculated using the formula developed by Brozek et al. (1963):

$$\text{Percent Body Fat} = \frac{4.570}{D_B} - 4.142 \times 100$$

The mean percent body fat and body density were computed for the two trials. This formula is the current conversion formula used in the Human Performance Laboratory, and was used in this investigation to utilize the computer program performing this function.

<u>Residual Volume Wet Procedure</u> (RV-wet)

The RV for the RV-wet hydrostatic weighing procedure was determined in a similar manner as the RV in the RV-dry hydrostatic weighing procedure, except measurements were made with the subject completely immersed in the forward leaning seated position. This position is pictured in Figure 4.

With noseclip, mouthpiece, and weighted snorkel in place, the subject was instructed to bend forward at the waist to a level at which there was no tendency for the mouthpiece to pull up or down, thus effectively eliminating any influence on the hydrostatic weight.

Figure 4. Residual Volume Wet Subject Position

After several breaths through the snorkel in the submerged position, the subject was instructed to maximally exhale. Once maximal exhalation was achieved, the individual was instructed to hold his breath and point with the index finger of the right hand. At this time the researcher noted hydrostatic weight, connected the subject to the oxygen-filled spirometer, and gave an audible signal to the subject to begin deep respiration as performed during the RV measurement on land. The subject slowly returned to the surface and continued deep breathing until equilibrium was reached.

The nitrogen fraction values and hydrostatic weight were recorded in the formulas for RV (Wilmore, 1969) and body density (Buskirk, 1961) as noted previously for RV-dry. Again, two trials were performed, and the mean body density and percent body fat were calculated.

Functional Residual Capacity Procedure (FRC)

Functional residual capacity was also measured using the closed circuit oxygen dilution method. With the breathing apparatus in place, the subject submerged as before, and after several room air breaths exhaled normally and held, while he indicated with a pointed index finger that FRC was achieved. At this point the researcher noted hydrostatic weight, connected the subject to the oxygen-filled spirometer, and gave an audible signal to the subject to begin deep breathing as in the RV measurements. The subject slowly returned to the surface and continued deep breathing until equilibrium was reached. Two trials were performed, and mean body density and percent body fat values were calculated.

Total Lung Capacity Procedure (TLC)

Total lung capacity was also measured using the closed circuit oxygen dilution method. The same technique was followed with the exception that the researcher instructed the subject to maximally inhale and hold while a hydrostatic weight was noted. The subject then performed the rebreathing maneuver previously described. Two trials at TLC were performed and the means for body density and percent body fat were calculated as in RV-dry, RV-wet, and FRC.

Subjects Rating of Comfort and Preference

Each subject was requested to fill out a questionnaire on the comfort and preference of each of the hydrostatic techniques. The first section asked the subject to rate the degree of comfort of each of the four hydrostatic techniques on a one to five scale, with one being very comfortable and five being very uncomfortable. The second section asked the subjects to list the four techniques in order of comfort from the most comfortable to the least comfortable.

Statistical Treatment of Data

A t-test was performed to determine if there was a statistically significant difference between RV measured in air, and RV immersed. The means and standard deviations for all lung volumes were computed. An analysis of variance with repeated measures was used to compare the values for body density and percent body fat obtained from all four techniques. A Scheffé Post Hoc further analyzed these data. The means for comfort and preference were calculated.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The purpose of this study was to compare body density and percent body fat computed using four different lung volumes in the hydrostatic weighing procedure: residual volume on land (RV-dry), residual volume immersed in water (RV-wet), functional residual capacity immersed in water (FRC), and total lung capacity immersed in water (TLC). It was also the intention of this study to establish which of the four techniques was perceived to be most comfortable. This chapter presents data collected using the four lung volumes to compute body density and percent body fat, a statistical analysis of the data, and a discussion of the relevant findings.

Two trials of each lung volume were used to compute the means for body density and percent body fat. An analysis of variance with repeated measures was performed to establish statistical significance. A Scheffé Post Hoc test was used to determine where the means for body density and percent body fat were significantly different. Subjects noted hydrostatic weighing preference and degree of comfort of all four techniques. The means for comfort and preference were computed. A discussion of the possible factors that influence variation in body density and percent body fat determined from the use of the four different techniques is included in this chapter.

Subjects

The subjects involved in this investigation were 14 male and 16 female college students, ages 19-34. The subjects were volunteers. Table 1 presents age and weight characteristics of these volunteers.

Table 1. Means and standard deviations for age and weight of subjects

Subjects	Age Range (yrs)	Mean Age	(S.D.)	Mean Weight (kg)	(S.D.)
Male & Female	19-34	23.5	4.19153	69.63	(12.62)

Pilot Study

A pilot study was conducted to determine the researcher's test-retest reliability and reproducibility in carrying out the testing procedures. Four different volunteers performed one of the hydrostatic techniques six times on two different occasions within a 24 hour period. A Pearson Product Mement correlation was used to determine the test-retest reliability coefficients of RV-dry, RV-wet, FRC, and TLC in measurement of body density (Pilot study data presented in Appendix D). The correlations for all measured variables were as follows: r = .9950 for body density using RV-dry, r = .96287 for body density using RV-wet, r = .96251 for body density using FRC, and r = .97095 for body density using TLC. These correlations were adequate to demonstrate test-retest reliability sufficient to proceed with the study.

Lung Volumes

The four lung volumes used in the hydrostatic weighing procedure were determined by the oxygen dilution technique outlined by Wilmore (1969). Residual volume was first measured on land using the same apparatus as was used in determining the immersed lung volumes. The order of the immersed lung volume determinations were randomly performed as indicated in Chapter III.

RV-wet vs RV-dry

A comparison of RV-dry to RV-wet shows a three percent decrease in lung volume. Although not statistically significant by t-test comparison, this difference may suggest that hydrostatic pressure on the thoracic compartment may reduce this particular lung volume, a finding that agrees with the research of Bondi et al. (1976), Brozek, Henschel, Keys, and Carlson (1949), Craig and Ware (1967), and Ostrave and Vacarro (1982). The means, standard deviations and t-test values for the RV-dry and RV-wet lung volumes are shown in Table 2.

Table 2. Means, standard deviations, and t-test values of RV-dry and RV-wet lung values

Lung Volume	Mean	S.D.	t value
RV-dry	1.29046	.286946	
RV-wet	1.25107	.272396	1.9337

df = 29

Girandola et al. (1977), however, found a statistically significant increase (p 0.01) in RV immersed to the neck versus RV in air in 20 healthy male subjects. He attributed the 6.7 percent increase to a possible stiffness of the lung tissue caused by pulmonary vascular engorgement. Interestingly, 10 of the 30 subjects in the present investigation experienced a slight increase in immersed RV versus RV on land. Girandola et al. (1977) suggested that the discrepancy found in the literature regarding increases versus decreases in immersed RV is due in part to the fact that water immersion affects individuals to differing degrees.

Previous research comparing RV immersed to RV on land has had the subject immersed to the neck or chin in an upright position at the time of measurement. Immersed values were compared to values for RV on land in similar body positions (Bondi et al., 1949; Craig & Dvorak, 1975; Craig and Ware, 1967; Girandola et al., 1977; Prefaut et al., 1976; Robertson et al., 1978). The present investigation attempted to match body position while measuring RV on land with the body position used in the other three lung volumes completely immersed.

FRC and TLC

Numerous investigations have found a low correlation in larger lung volumes as measured in air versus measured immersed (Craig & Dvorak, 1975; McGarty, 1982; Prefaut et al., 1976; Thomas & Etheridge, 1980; Welch and Crisp, 1958). Therefore, the present investigator felt it of little merit to repeat these comparisons, and looked only at totally immersed FRC and TLC and the resulting body density and percent body fat computed from each. The means and standard deviations for FRC and TLC lung volumes are shown in Table 3.

Table 3. Means and standard deviations for FRC & TLC

Lung Volume	Mean	S.D.
FRC	1.96112	.4307
TLC	5.87685 5.5831	1.6168

The means and standard deviations presented in Table 2 are consistent with previous investigations of these immersed lung volumes (Craig & Dvorak, 1975; McGarty, 1982; Prefaut et al., 1976; Thomas & Etheridge, 1980; Welch & Crisp, 1958).

Body Density and Percent Body Fat Determinations

The means and standard deviations of the subjects' body density and percent body fat are presented in Table 4. These determinations were made by hydrostatically weighing at RV-dry, RV-wet, FRC, and TLC. Each maneuver was performed twice, and the means for lung volume, body density and percent body fat were calculated.

Correlations

The correlations for body density and percent body fat as determined using RV-dry, RV-wet, and FRC were .99, corresponding to a percent body fat variance of less than one percent between the three methods. Correlations between TLC and the other three methods were .88, corresponding to a percent body fat variance of three percent between the three other methods. Correlation data is presented in Tables 5 and 6.

Analysis of Variance

Tables 7 and 8 present analysis of variance data which was performed on both body density and percent body fat measures to determine if there was a statistically significant difference in the results obtained in the four techniques. Statistical significance was noted, and a Scheffé Post Hoc test was performed to determine where the differences lay (Tables 9 and 10).

It was determined that there were no significant differences between RV-dry and RV-wet, RV-dry and FRC, and FRC and RV-wet at the .05 confidence level. However, there was a significant difference between RV-dry and TLC, RV-wet and TLC, and FRC and TLC at the .05 confidence level.

The results of the analysis of variance and post hoc test suggest that with this experimental tool, and the techniques described herein, RV-dry, RV-wet, and FRC can be used interchangeably, with statistically similar results in body density and percent body fat determinations. The correlation coefficient of .99 for all three of the techniques suggests interchangeability, also. Total lung capacity can not be used interchangeably with the other three methods of body density determination with the expectation of no significant difference.

It should be noted that when comparing means for the four methods there is a 3.8 percent (17.77 — 17.08 ÷ 17.77 = .038) mean increase in

Table 4. Means and standard deviations for body density and percent body fat

Procedure	Body Density	(S.D.)	% Body Fat	(S.D.)
RV-dry	1.05986	(0.060900)	17.0875	(6.657486)
RV-wet	1.05817	(0.015819)	17.7722	(6.646960)
FRC	1.05907	(0.016032)	17.3830	(6.575980)
TLC	1.06659	(0.025324)	14.3019	(10.27970)

Table 5. Body density correlations for RV-dry, RV-wet, FRC, and TLC

Method	RV-dry	RV-wet	FRC	TLC
RV-dry	1.0			
RV-wet	.99342	1.0		
FRC	.99203	.99298	1.0	
TLC	.88530	.89160	.88499	1.0

Table 6. Percent body fat correlations for RV-dry, RV-wet, FRC, and TLC

Method	RV-dry	RV-wet	FRC	TLC
RV-dry	1.0			
RV-wet	.99333	1.0		
FRC	.99182	.99271	1.0	
TLC	.87911	.88720	.87929	1.0

Table 7. Statistical analysis of variance data for body density determinations

Source of Variation	S.S.	D.F.	M.S.	F
Between	0.03489	29	0.0012	
Within	0.01	90		
Treatments	0.0021	3	0.0007	9.57*
Residuals	0.00638	87	0.00007	

* denotes statistical significance at .05 level

Table 8. Statistical analysis of variance data for percent body fat determinations

Source of Variation	S.S.	D.F.	M.S.	F
Between				
Within				
Treatments				
Residuals				

* denotes statistical significance at .05 level

Table 9. Scheffé post hoc analysis of body density determinations

Comparison	Body Density
RV-dry vs RV-wet	F = .611957
RV-dry vs FRC	F = .133776
RV-dry vs TLC	F = 9.70585*
RV-wet vs FRC	F = .173491
RV-wet vs TLC	F = 15.1921*
FRC vs TLC	F = 12.1186*

* denotes statistical significance at .05 level

Table 10. Scheffé post hoc analysis of percent body fat determinations

Comparison	% Body Fat
Rv-dyr vs RV-wet	F = .921653
Rv-dry vs FRC	F = .171663
RV-dry vs TLC	F = 15.2547*
RV-wet vs FRC	F = .297795
RV-wet vs TLC	F = 23.6756*
FRC vs TLC	F = 18.6628*

*denotes statistical significance at .05 level

RV-wet determination of percent body fat versus RV-dry determination of percent body fat. This corresponds to the three percent reduction in RV immersed as compared to RV in air. Thus, for many people, such as the subjects in this study, using RV on land as the assumed hydrostatic lung volume may underestimate their percent body fat by giving them credit for more air than is actually in the lungs at immersed RV. This is of little practical significance to the individual since the hydrostatic weighing procedure is only accurate within ± 3.8 percent (Siri, 1961).

Finally, it should be observed that the mean for FRC (17.383) percent body fat determination falls midway between the mean for RV-dry and RV-wet. Thus, regardless of the technique to which FRC is compared, RV-dry or RV-wet, it will be well within the accepted standard of measurement to produce reliable results.

TLC Variance

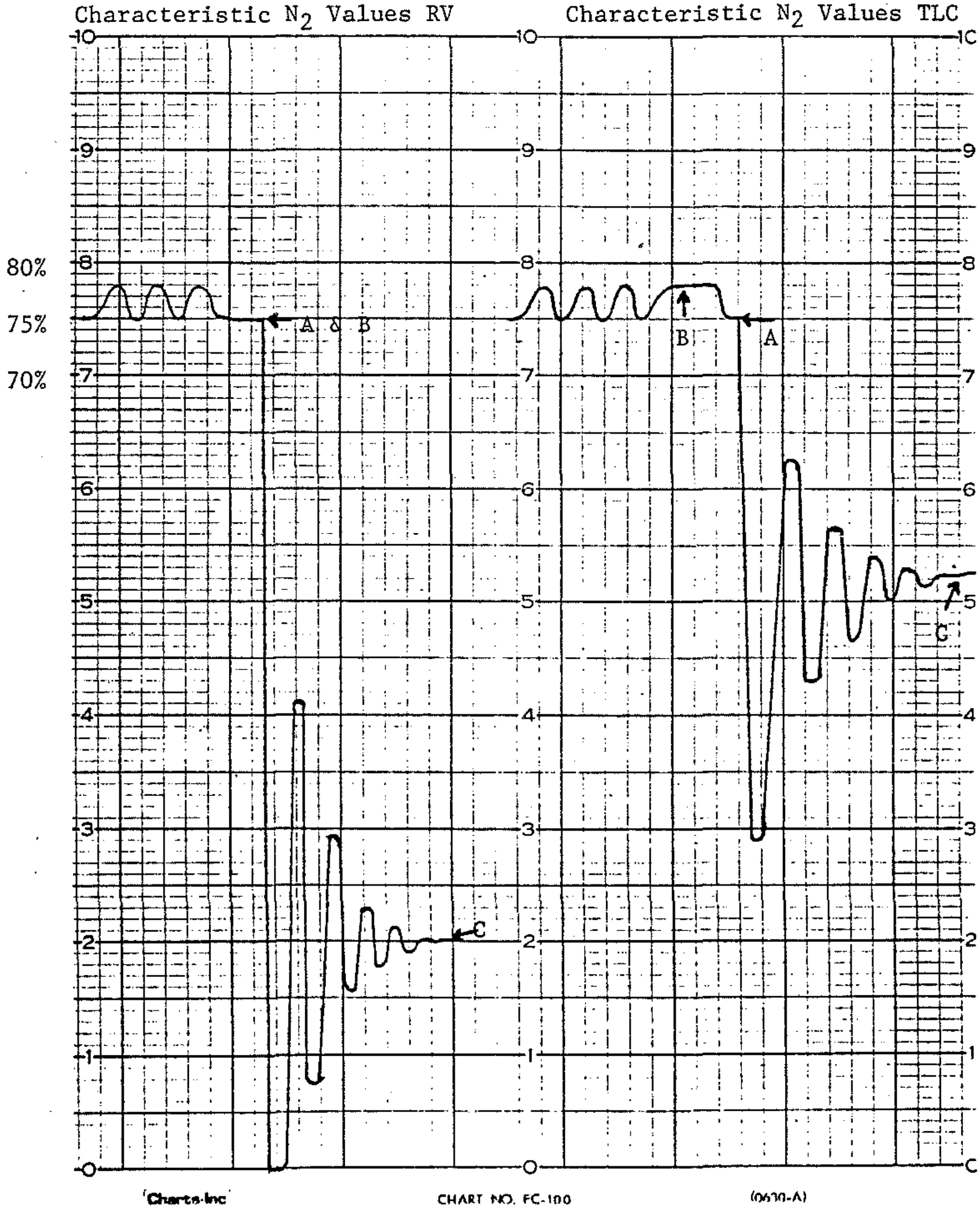
The significant difference TLC showed from all other techniques in body density and percent body fat determinations provided some concern. Previous investigations (Dahlback & Lundgren, 1972; Girandola et al., 1977; McGarty, 1982) have suggested that TLC measurements may be more accurate than RV determinations of percent body fat because of the decreased role vascular engorgement and resultant air trapping induced by water immersion plays in larger lung volumes. If TLC was more accurate in assessing body density and percent body fat, it would also suggest that the individual would appear more dense and less fat than with the FRC technique, since it is a larger lung volume than RV (FRC =

1.9609, RV-dry = 1.2904). In the present investigation, however, the opposite occurs. FRC produced a mean percent body fat of 17.383, while RV-dry produced a mean percent body fat of 17.0875. Additionally, very lean individuals had a greater variation in TLC percent body fat determination from the other three techniques. Two particularly lean individuals had a greater variation in TLC percent body fat determination from the other three techniques. Two particularly lean individuals demonstrated a negative percent body fat as computed using the TLC values. This may indicate that the mangitude of error becomes greater in direct proportion to the leanness of the individual. Finally, it has not been demonstrated that vascular engorgement results in sufficient air trapping to significantly affect body density and percent body fat at any lung volume.

A more reasonable explanation of the discrepancy between the TLC measurement and the other techniques described is an apparatus and procedural error in recording the correct nitrogen fraction to compute TLC. Refer to Diagram 1 for the following text. Following maximal inspiration, the dead space of the apparatus as well as the anatomical dead space is filled with room air. When the valve to close off room air and connect the subject to the oxygen-filled spirometer is engaged, the nitrogen analyzer is initially sampling room air. In all other methods in this study, the analyzer is sampling an exhaled gas at the moment the subject is connected to the oxygen-filled spirometer. This exhaled gas is generally in the vicinity of 75 percent nitrogen, while room air is closer to 78 percent nitrogen. When recording the alveolar

Diagram 1. Nitrogen fraction values for RV and TLC

A = value recorded for AN_2 - end of characteristic scoop
B = point at which subject was connected to pure O_2
C = point at which equilibrium is reached in system



nitrogen fraction (AN_2), the researcher recorded the value indicated at the end of the characteristic scoop, just before the pure oxygen is inhaled by the subject. This same method of recording is performed in a similar manner for the RV and FRC measurements (Diagram 1).

The value at the end of the characteristic scoop in TLC is not, however, a true representation of the correct AN_2 found in the lungs at the time of TLC measurement. The correct value is probably closer to 78 percent, although with the present apparatus there is no way of knowing exactly what it is. When this incorrect value is placed into the body density formula and converted to percent body fat, it demonstrates a significant difference in determination of body density and percent body fat when compared to the other lung volumes used in this research.

It was also noted by the researcher that there was considerable scale fluctuation at TLC, making the hydrostatic weight difficult to determine. Thomas and Etheridge (1980) noted this same difficulty, and suggested that it may be the cause of error in hydrostatic weighing at TLC.

Subject Preference

One of the intentions of this study was to establish a hydrostatic weighing technique that was both comfortable for the subject and statistically reliable. Herein lies the importance of the above findings in regard to this study. A brief questionnaire was filled out by each of the subjects regarding the comfort and preference of the methods immediately following the hydrostatic weighing procedure. The results of the questionnaire are found on Tables 11 and 12.

Each subject was requested to rate each of the techniques as to its degree of comfort on a one to five scale, with one being the most comfortable, and five being the least comfortable. It was noted that a majority of the subjects preferred the FRC technique to the other three techniques, with 16 subjects rating it very comfortable, and none rating it at the uncomfortable end of the scale. When all scores were totaled and the means computed, the results were as follows: mean = 2.6 for RV-dry, mean = 2.5 for RV=wet, mean = 1.6 for FRC, mean = 1.8 for TLC.

Table 11. Subject rating of comfort of techniques

Method	Very Comfortable 1	2	3	Very Uncomfortable 4	5	$\bar{X}$
RV-dry	8	4	11	6	1	2.6
RV-wet	4	13	7	6	0	2.5
FRC	16	10	4	0	0	1.6
TLC	6	8	10	6	0	1.8

Each subject was also requested to list in order of comfort preference the technique they felt was the most comfortable to the least comfortable. Thirteen subjects chose the FRC method as the most comfortable, while 10 subjects chose RV-dry as the most comfortable. Thirteen subjects chose FRC as the second most comfortable, while only three chose RV-dry as the second most comfortable. It should also be noted that 6 of the 10 subjects who chose RV-dry as the most comfortable method had prior experience with this hydrostatic weighing technique. Finally, 10 subjects selected RV-dry as the least comfortable, while only one person selected FRC as the least comfortable.

Table 12. Subject ranking of most comfortable to least comfortable hydrostatic method

Method	Most Comfortable 1	2	3	Least Comfortable 4	$\overline{X}$
RV-dry	10	3	7	10	2.56
RV-wet	2	7	11	10	2.96
FRC	13	13	3	1	1.73
TLC	5	7	9	9	2.73

Very little is reported in the literature as to subject preference or comfort in the hydrostatic weighing procedure. McGarty (1982) noted that subjects in her study felt more comfortable at TLC compared to RV. Although no data was supplied, Brozek et al. (1949) reported on the psychological effect of submersion causing a moderate degree of anxiety, which may, in some individuals, inhibit exhalation. Thomas and Etheridge (1980) suggested that FRC should be the method of choice since the subject was more comfortable than at RV, and there was less scale fluctuation than at TLC.

Summary

Based on the results of the present study, it appears that with the apparatus and methods described, RV-dry, RV-wet, and FRC may be used interchangeably in determination of body density and percent body fat. Total lung capacity, however, demonstrates a statistically significant difference from the other three methods. In considering subject comfort and preference, FRC was the method of choice, followed by RV-dry, TLC, and RV-wet, respectively. Therefore, when performing the hydrostatic weighing procedure, FRC appears to be the most appropriate technique based on subject comfort, high degree of reproducibility as demonstrated in the pilot study and this investigation, and the lack of significant difference compared to the present accepted method of RV-dry determination of body density and percent body fat.

CHAPTER V

CONCLUSIONS

Summary

The purpose of this study was to compare body density and percent body fat computed using four different lung volumes in the hydrostatic weighing procedure. It was also the purpose of this study to establish which of the four lung volumes was considered to be the most comfortable by the subjects in the hydrostatic weighing procedure. All subjects were hydrostatically weighed at RV-dry, RV-wet, FRC, and TLC. Two body densities and percent body fats were calculated for each technique in all subjects. Subjects noted hydrostatic weighing method of preference and degree of comfort for all four techniques. Statistical analyses were then applied to determine if significant differences existed between body density and percent body fat calculations as computed using the four lung volumes in the hydrostatic weighing technique.

Conclusions

The result of this study indicated the following conclusions:

1. There was no significant difference in residual volume as measured in air versus measured immersed, therefore, the null hypothesis was accepted.

2. There was no significant difference in body density and percent body fat in the subjects tested using RV-dry versus RV-wet in the hydrostatic weighing procedure, therefore, the null hypothesis was

accepted.

3. There was no significant difference in body density and percent body fat in the subjects tested using RV-dry versus FRC in the hydrostatic weighing procedure, therefore, the null hypothesis was accepted.

4. There was no significant difference in body density and percent body fat in the subjects tested using RV-wet versus FRC in the hydrostatic weighing procedure, therefore, the null hypothesis was accepted.

5. There was a significant difference in body density and percent body fat in the subjects tested using RV-dry versus TLC in the hydrostatic weighing procedure, therefore, the null hypothesis was rejected.

6. There was a significant difference in body density and percent body fat in the subjects tested using RV-wet versus TLC in the hydrostatic weighing procedure, therefore, the null hypothesis was rejected.

7. There was a significant difference in body density and percent body fat in the subjects tested using FRC versus TLC in the hydrostatic weighing procedure, therefore, the null hypothesis was rejected.

8. Hydrostatic weighing at FRC was the preferred method of the subjects involved in this study. The high correlation of repeated trials and the lack of significant difference compared to the conventional RV-dry hydrostatic technique also make FRC a desirable method for the researcher. The null hypothesis concerning subject rating of comfort was rejected.

9. Though not evident in this study, pulmonary air trapping, as suggested in previous investigations, would be eliminated with the larger FRC lung volume, thus effectively reducing the error involved

in hydrostatic lung volume measurement. The researcher subjectively noted that the majority of the subjects performed the FRC technique with less difficulty and less scale fluctuation than all the other techniques. It is suggested that hydrostatic weighing at FRC be clinically applied and is indicated especially with individuals who do not adapt well to water immersion.

Recommendations

The following recommendations are made in regard to future studies:

1. Since the anticipated danger of hydrostatically weighing cardiac patients at RV has been the risk of creating a large intrathoracic pressure and thus decreasing the venous return (i.e., the valsalva maneuver), it is suggested that hydrostatic weight measurements be performed with cardiac patients at FRC and compared to present anthropometric measures in determination of body density and percent body fat.

2. It is suggested that hydrostatic electrocardiographic studies be performed on selected non-cardiac and cardiac individuals to assess the hydrostatic influence on normal and abnormal cardiac function at various lung volumes.

3. Further research is needed to determine the hydrostatic influence on lung volumes of persons of different body size and musculature, as well as sex and age difference.

4. The problem of statistically significant differences in TLC versus the other techniques in this study suggests that further research

is needed to arrive at unequivocal results for body density and percent body fat using any selected lung volume.

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APPENDIX A

INFORMED CONSENT FORM

INFORMED CONSENT FORM

University of Wisconsin-La Crosse

Project Title: A Comparison of Hydrostatic Weighing Determination of Body Density and Percent Body Fat at Three Different Immersed Lung Volumes.

Principal Investigator: Dr. Linda Hall/Dean Witherspoon

1. Procedures:

   A. The subject will have their weight recorded on land and in the hydrostatic weighing tank.

   B. The subject will perform each of the following breathing maneuvers twice through a snorkel system, rebreathing a known volume of oxygen until an equilibrium is reached between the spirometer and lungs percent of nitrogen.

      1) Residual Volume Dry - The subject will exhale maximally on dry land through the snorkel system. The subject will then be connected to a known volume of oxygen and will rebreathe this volume until an equilibrium is reached.

      2) Residual Volume Wet - The subject will perform the same maneuver as above, but while immersed in the hydrostatic weighing tank.

      3) Functional Residual Capacity wet - The subject will perform a normal exhalation while immersed and then be connected to a known volume of oxygen for rebreathing to equilibrium as above.

      4) Total Lung Capacity Wet - The subject will inhale maximally while immersed, and then be connected to a known volume of oxygen for rebreathing to equilibrium as above.

2. Potential Discomfort and Risks:

   The subject will experience no greater discomfort or risk than the present accepted procedure for hydrostatic weighing as practiced by the Human Performance Laboratory.

3. The Principal Investigator will answer any and all inquiries concerning procedures, risks, and benefits.

INFORMED CONSENT FORM (continued)

1. I, ________________________________, being of sound mind and ____
(name of subject)
years of age do hereby consent to, authorize and request the person named above (and co-workers, agents and employees) to undertake and perform the proposed procedure on me.

2. I have read the above document, and I have been fully advised of the nature of the procedure and the possible risks and complications involved in it, all of which risks and complications I hereby assume voluntarily.

3. I hereby acknowledge that no representations, warranties, guarantees and assurances of any kind pertaining to the procedure have been made to me by the University of Wisconsin-La Crosse, the officers, administration, employees or by anyone acting on behalf of any of them.

4. I understand that I may withdraw from the procedure at any time.

Signed at ______________________________ this _____ day of ________

___________________, 1984, in the presence of the witnesses whose signatures appear below opposite my signature.

WITNESSED BY:

________________________________ ________________________________
(subject)

____

I, ______________________________ (husband, wife, parent, other), of the above named subject, ______________________________, have read the foregoing consent and the document attached hereto and made a part of such consent, and I hereby consent to said procedure.

WITNESSED BY:

________________________________ ________________________________

____

APPENDIX B

COMFORT OF PROCEDURES QUESTIONNAIRE

COMFORT OF PROCEDURES QUESTIONNIARE

1. On a scale of 1 to 5, rate the overall comfort of each of the techniques described (circle appropriate number):

RV-Dry = maximal exhalation on land through the breathing aparatus, and maximal exhalation in water without the breathing apparatus

RV-Wet = maximal exhalation through the breathing apparatus while immersed

FRC Wet = normal exhalation through the breathing apparatus while while immersed

TLC Wet = maximal inhalation through the breathing apparatus while immersed

	Very Comfortable..	..Moderately Comfortable...		...Very Uncomfortable	
RV Dry	1.............	2.............	3.............	4.............	5
RV Wet	1.............	2.............	3.............	4.............	5
FRC Wet	1.............	2.............	3.............	4.............	5
TLC Wet	1.............	2.............	3.............	4.............	5

2. If you had to have your present body fat determined by hydrostatic weighing on an annual basis, the technique you would prefer in order of comfort would be:

(Most Comfortable) (Least Comfortable)

1 ______________ 2 ______________ 3 ______________ 4 ______________

APPENDIX C

SUBJECT DATA SHEET

	WT	MX	MY	TEMP	VOLO2	AN2	IN2	EN2	FN2	LVOL	DB	%FAT	$\overline{LV}$	$\overline{DB}$	$\overline{\%FAT}$
RVDRY															
RVDRY															
RVWET															
RVWET															
FRC															
FRC															
TLC															
TLC															
RVDRY															
RVDRY															
RVWET															
RVWET															
FRC															
FRC															
TLC															
TLC															
RVDRY															
RVDRY															
RVWET															
RVWET															
FRC															
FRC															
TLC															
TLC															
RVDRY															
RVDRY															
RVWET															
RVWET															
FRC															
FRC															
TLC															
TLC															
RVDRY															
RVDRY															
RVWET															
RVWET															
FRC															
FRC															
TLC															
TLC															

APPENDIX D

PILOT STUDY DATA

PILOT STUDY

Test-Retest Reliability of Hydrostatic Weighing Techniques

RV-dry Trial 1

Body Density	Percent Body Fat
1.0477163	17.86292
1.058316	17.61809
1.059871	16.98454
1.0604423	16.82679
1.0104423	16.75225
1.061188	16.44942

RV-dry Trial 2

1.0580671	17.71967
1.0584552	17.5613
1.0593064	17.21436
1.0593546	17.19473
1.0595583	17.1118
1.0600576	16.90864

RV-dry Trial 1 vs. RV-dry Trial 2 r = .99550

RV-wet Trial 1

Body Density	Percent Body Fat
1.0739983	11.31277
1.0740539	11.29075
1.0752316	10.82471
1.075443	10.74116
1.0759326	10.54779
1.760357	10.50709

RV-wet Trial 2

1.0713352	12.3705
1.0718834	13.15234
1.0723245	11.97696
1.0726427	11.85053
1.0728779	11.75713
1.0731037	11.66584

RV-wet Trial 1 vs RV-wet Trial 2 r = .96287

FRC Trial 1

Body Density	Percent Body Fat
1.0702837	12.78959
1.0703469	12.76437
1.0704273	12.73231
1.0709724	12.51501
1.0709724	12.51501
1.0718155	12.17935

FRC Trial 2

1.0703501	12.7631
1.0705167	12.69665
1.0707229	12.61444
1.0708481	12.56454
1.071104	12.46361
1.0715601	12.28097

FRC Trial 1 vs. FRC Trial 2 r = .96251

TLC Trial 1

Body Density	Percent Body Fat
1.0581257	17.69575
1.0586857	17.4673
1.059597	17.09604
1.0599498	16.95249
1.0609166	16.55959
1.0609166	16.55959

TLC Trial 2

1.0590645	17.3129
1.0597589	17.02015
1.059982	16.94907
1.060313	16.8048
1.0614239	16.35371
1.0616035	16.28087

TLC Trial 1 vs. TLC Trial 2 r = .97295