ABSTRACT

KOENIG, J. M. A comparison of body density and percent body fat using functional residual capacity and residual volume and development of improved functional residual capacity and residual volume prediction formulas. M.S. in Adult Fitness/Cardiac Rehabilitation, 1990. 76 pp. (W. Floyd)

This study developed prediction formulas (PF) for residual volume (PRV) and functional residual capacity (PFRC) using the variables age (A), height (Ht), weight (Wt), chest depth (CD), and smoking history (SH) in 100 male subjects between the ages of 18 - 69 years. A and Ht were the only variables which contributed significantly to PRV. A, Ht, and Wt were the only variables to contribute significantly to PFRC. A test-retest correlation between two trials of RV (r = .99) and FRC (r = .98) determinations indicated that reliable measures were taken by the closed circuit oxygen dilution technique. Through the use of multiple step-wise regression the following PRV and PFRC formulas were developed:

PRV (liters) = .0260376(A) + .0256005(Ht) - 3.89794

PFRC (liters) = .0493365(Ht) + .0116958(A) - .00919313(Wt) - 6.20966

The standard error of estimation (S.E.E.) of the PRV and PFRC formulas (241 and 403 mls, respectively) were all lower than those reported by Boren et al. (1966) (B), Crapo et al. (1982) (C), Goldman and Becklake (1959) (GB), and Grimby and Soderholm (1963) (GS). The variation (R^2) attributed to the independent variables was .72 and .41 for PRV and PFRC, respectively. These R^2 values were higher than those reported by B, C, and GS. Using the data obtained in this study, an ANOVA with repeated measures followed by a Scheffe' post hoc test determined significant differences ($p<.05$) between PRV and the PF of C and GB. Significant differences ($p<.05$) were also determined between PFRC and the PF of B, C, GB, and GS. A further purpose of this study was to compare body density (BD) and percent body fat (%BF) determined at the RV and FRC lung volume maneuvers in the hydrostatic weighing procedure. There was no significant difference ($p>.05$) between BD at RV and FRC. There was, however, a significant difference ($p<.05$) in %BF at RV and FRC.

A Comparison of Body Density and Percent Body Fat Using Functional Residual Capacity and Residual Volume and Development of Immersed Functional Residual Capacity and Residual Volume Prediction Formulas

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A Thesis Presented

to

The Graduate Faculty

University of Wisconsin - La Crosse

In Partial Fulfillment

of the Requirements for the

Master of Science Degree

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by

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DEDICATION

For Lisa, who always supported me
and acted as my source of inspiration throughout
this entire ordeal.
I will always be forever grateful.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Hydrostatic weighing is commonly accepted as the "gold standard" for determining percent body fat. However, accuracy of the hydrostatic weighing technique is dependent upon an accurate lung volume measurement (Weltman & Katch, 1981).

Residual volume (RV), the amount of air remaining in the lungs following a maximal expiration, has long been the most widely used lung volume in the hydrostatic weighing technique. According to Welch and Crisp (1958), since RV is the smallest lung volume it is least affected by hydrostatic pressure, and therefore, the volume of choice. Although RV may be the most consistent lung volume in and out of the water, a number of researchers have suggested that this method may be adversely affected by pulmonary air-trapping (Bondi, Young, Bennett, & Bradley, 1976; Dahlback & Lundgren, 1972; Girandola, Wiswell, Mohler, Romero, & Barnes, 1977; Robertson, Englo, & Bradely, 1978; Thomas & Etheridge, 1980; Weltman & Katch, 1981). Additionally, the expulsion of all air underwater is very discomforting for some individuals and could result in inaccurate body density determinations (Brozek, Henschel, & Keys, 1949; Thomas & Etheridge, 1980; Timson & Coffman, 1984; Welch & Crisp, 1958; Weltman, Janney, Huber, Rians, & Katch, 1987; Weltman & Katch, 1981).

Weltman and Katch (1981), have described the RV maneuver as a "novel" and impossible technique to "master" sometimes requiring a

substantial number of trials (9-12) for consistent underwater weighing values. Furthermore, full exhalation may be inhibited as a result of the anxiety encountered by some individuals following complete submersion (Brozek, Henschel, & Keys, 1949).

In an attempt to eliminate the pulmonary air-trapping problem, as well as the difficulty and discomfort of the RV maneuver, a number of researchers have attempted to determine body density at larger lung volumes (Latin & Ruhling, 1986; Lundvall & Thorland, 1987; Smith & Bishop, 1987; Thomas & Etheridge, 1980; Timson & Coffman, 1984; Weltman et al., 1987; Weltman & Katch, 1981). In 1958 Welch and Crisp performed the hydrostatic weighing technique at 50% vital capacity (VC). Although this solved the discomfort problem, the body density and percent body fat values were significantly different than body density and resulting percent body fat at RV.

Total lung capacity (TLC), the volume of gas in the lungs following a maximal inspiration, has also been used in the hydrostatic weighing procedure, but with limited success. Weltman and Katch (1981), found body density determined at TLC to be significantly greater than body density at RV. Similar findings were also observed in a study of 28 pre-pubertal males (Weltman et al., 1987). It was hypothesized that the hydrostatic forces would not be as great on the relatively smaller TLC of pre-pubertal males, and therefore, provide similar results to body density at RV. The significantly higher body density determined at TLC led Weltman and associates to conclude that "the use of hydrostatic weighing at total lung capacity for body density determination is not acceptable in a research or clinical setting when applied to pre-

pubertal boys" (p.51).

When TLC was determined with the subject immersed no significant difference was found from the body density determined at RV (Timson & Coffman, 1984). Furthermore, TLC was rated as less difficult to perform by the subjects.

The volume of air remaining in the lungs following a normal resting expiration, functional residual capacity (FRC), has also been utilized in the hydrostatic weighing procedure. Thomas and Etheridge (1980), compared body density and percent body fat at FRC and RV while immersed and found no significant differences between the two methods. In addition, FRC was rated more comfortable by the subjects, caused less scale fluctuation, and reduced the number of underwater weighing trials. Similar findings were also observed in a study by Witherspoon (1984), in which FRC not only compared favorably with body density at RV (on-land and immersed), but was judged as the most comfortable lung volume to achieve and maintain during the hydrostatic weighing procedure.

Need for the Study

Of the eight commonly observed lung volumes, three cannot be measured by simple spirometry: residual volume (RV), functional residual capacity (FRC), and total lung capacity (TLC). Although RV is truly the only lung volume unable to be determined by spirometry it constitutes a significant component of both the FRC and TLC lung volumes (i.e., FRC = RV + ERV, and TLC = RV + VC). As a result, some form of indirect analysis is required.

Indirect methods of measuring RV, as described by Wilmore (1969a), mainly consist of three types: (1) the pneumatometric approach, (2) the closed circuit approach, and (3) the open circuit approach. However, the determination of RV by any of these methods requires elaborate and expensive equipment, a skilled technician, and a considerable amount of time (Wilmore, 1969b). As an alternative, a number of prediction equations to estimate the residual lung volume have been published (Boren, Kory, & Syner, 1966; Crapo, Morris, Clayton, & Nixon, 1982; Goldman & Becklake, 1959; Grimby & Soderholm, 1963). Easily measured physical characteristics such as age, height, and weight are the factors often used in the formation of these prediction equations.

Since RV is the so called "volume of choice" for the hydrostatic weighing technique, the majority of the prediction equations have been developed for this lung volume. However, the discomfort and difficulty along with the effect of pulmonary air-trapping during the RV maneuver suggests that a larger lung volume should be used during the hydrostatic weighing procedure (Welch & Crisp, 1958). Studies by Thomas and Etheridge (1980) and Witherspoon (1984) have determined FRC not only to compare favorably with RV in the determination of body density and percent body fat, but also to be more comfortable for the subject.

Although there are a number of prediction equations for FRC and RV (Boren et al., 1966; Crapo et al., 1982; Goldman & Becklake, 1959; Grimby & Soderholm, 1963), no equation for the prediction of FRC and RV in males while immersed was found in the literature reviewed. The importance of determinin. .RC while immersed is reflected by the large

decreases observed in FRC as a result of hydrostatic forces. FRC has been shown to decrease 21 to 46% during immersion (Agostoni, Gurtner, Torri, & Rahn, 1966; Begin, Epstein, Sackner, Lavinson, Dougherty, & Duncan, 1976; Bondi et al., 1976; Girandola et al., 1977; Ostrove & Vaccaro, 1982; Prefaut, Lupi, & Anthonisen, 1976; Robertson et al., 1978). Although the effects of immersion on RV are not in agreement, the majority of studies have found RV to be significantly reduced following immersion (Agostoni et al., 1966; Bondi et al., 1976; Cox, 1989; Jarrett, 1965; Ostrove & Vaccaro, 1982; Robertson et al., 1978). Therefore, it is important that FRC and RV be measured during immersion if used in the hydrostatic weighing procedure.

The desire to develop a quick and inexpensive method to estimate a lung volume that allows accurate body density calculation, at an easily attained and comfortable lung volume (i.e., FRC), supports the need of this study. In addition, there is need for an equation to predict the most often used lung volume in the hydrostatic weighing technique (i.e., RV) in males while immersed.

Statement of the Problem

The purposes of this study were:

1. Develop formulas for the prediction of FRC and RV while immersed using age, height, weight, chest depth, and smoking history as predictors in 100 males between the ages of 18 - 69.

2. Test the adequacy of these prediction formulas.

3. Determine the test-retest reliability between trials for the closed circuit oxygen dilution technique of FRC and RV determinations.

4. Compare the multiple correlation coefficient (R^2) and standard error of the estimate (S.E.E.) of predicted immersed FRC and RV developed in this study against those of others.

5. Compare body density and percent body fat values obtained at immersed FRC and immersed RV.

Null Hypotheses

The null hypotheses of this study were:

1. Age, height, weight, chest depth, and smoking history, singularly or in combination, are not predictors of FRC and RV in 100 males between the ages 18 - 69.

2. There is no significant correlation between trials for the closed circuit oxygen dilution technique of FRC and RV determinations.

3. There is no significant difference between the predicted FRC and RV of the 100 male subjects using the formulas developed in this study and the prediction of FRC and RV from previously published formulas.

4. There is no significant difference in body density and percent body fat determined at immersed FRC and immersed RV.

Assumptions

The following assumptions were made for this study:

1. All subjects refrained from eating 6 hours prior to hydrostatic weighing.

2. The subjects performed the breathing maneuvers to the best of their ability.

3. The subjects did not engage in any strenuous activity prior to testing.

4. All instruments functioned properly and provided accurate values.

5. All subjects were free of respiratory disease.

6. All subjects answered the questionnaire honestly and accurately.

Limitations

The following limitations were observed in regard to this study:

1. All subjects were volunteers, and therefore, true randomization was not achieved.

2. It was difficult to determine how well the subjects performed the breathing maneuvers.

Delimitations

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

1. All subjects were males between the ages 18 - 69 and lived in the La Crosse area.

2. Only male subjects with heights between 160 - 198 centimeters were tested.

3. Only subjects without known respiratory diseases were allowed to participate in the study.

4. Only age, height, weight, chest depth, and smoking history were used as factors in the prediction of FRC and RV.

Definitions of Terms

The following is a list of the terms used in this study:

1. BTPS - The conversion of gas measurements dealing in lung volumes into body temperature (37°C), ambient pressure, and 100% water saturation (Fox, Bowers, & Foss, 1988).

2. Chest Depth - The distance from the tip of the xiphoid process to the transverse process of the twelfth rib (Tcheng & Tipton, 1973).

3. Closed Circuit Oxygen Dilution - Rebreathing a gas of a specific composition in a closed system to determine a lung volume (Wilmore, 1969a).

4. Expiratory Reserve Volume (ERV) - Maximal volume of gas that can be expired from resting end-expiration (Boren et al., 1966).

5. Functional Residual Capacity (FRC) - The volume of gas remaining in the lungs following a normal resting expiration: FRC = RV + ERV (Boren et al., 1966).

6. Hydrostatic Pressure - The pressure exerted on the thorax and abdomen during immersion which opposes the inspiratory muscles (Prefaut, Lupi, & Anthonisen, 1976).

7. Hydrostatic Weighing - The "gold standard" technique used to determine percent body fat through the complete submersion of the subject and application of Archimedes' Principle.

8. Open Circuit Method - A gas dilution technique in which nitrogen is washed out of the lungs by inhalation of pure oxygen through a series of one-way valves over a specified period of time, and collected in a large spirometer.

9. Pack Years - The number of cigarette packs smoked per day multiplied by the number of years smoked.

10. Pneumatometric Method - A method of indirectly determining lung volumes through the use of whole body plethysmography (Wilmore, 1969a).

11. Pulmonary Air-Trapping - The shifting of blood from the extremities into the thorax causing engorgement of the pulmonary vessels and subsequent air-trapping as a result of whole body immersion (Dahlback & Lundgren, 1972).

12. Residual Volume (RV) - The volume of gas remaining in the lungs following a maximal exhalation (Boren et al., 1966).

13. Smoking History - The total number of cigarettes smoked by the subject measured in pack years.

14. Spirometer - An air-tight device consisting of two metal containers, one inverted over the other, capable of direct measures of lung volumes by the recording of inspirations and expirations on a rotating drum attached to a spirometer (Fox, Bowers, & Foss, 1988).

15. Tidal Volume (TV) - The volume of gas inspired or expired per breath (Boren et al., 1966).

16. Total Lung Capacity (TLC) - The volume of gas in the lungs following a maximal inspiration: TLC = RV + VC (Boren et al., 1966).

17. Vital Capacity (VC) - Maximal volume of gas forcefully expired after a maximal inspiration: VC = TLC - RV (Fox, Bowers, & Foss, 1988).

CHAPTER II

REVIEW OF RELATED LITERATURE

The purpose of this study was to examine the relationship between functional residual capacity (FRC) and residual volume (RV) and the factors of age, height, weight, chest depth, and smoking history. The study was also designed to develop equations using the before-mentioned variables to accurately predict FRC and RV, and to compare the multiple correlation coefficient (R^2) and standard error of the estimate (S.E.E.) of these equations to those of others (Boren et al., 1966; Crapo et al., 1982; Goldman & Becklake, 1959; Grimby & Soderholm, 1963). Hydrostatic weighing at an alternative lung volume (FRC) was tested and evaluated in terms of its effect on body density and percent body fat obtained at RV.

Lung Volume Measurements

Residual volume, the volume of air remaining in the lungs following a maximal expiration, is the only lung volume which cannot be measured by direct spirometry. Since FRC and TLC also possess the RV component (FRC = ERV + RV and TLC = VC + RV) they require some form of indirect assessment.

There are numerous techniques used for the indirect assessment of lung volumes with some dating back to the 1800's when Sir Humphrey Davy measured his own lung volume with a hydrogen dilution method (Boren et al., 1966). In 1882, Pfluger described a method which utilized whole

body plethysmography (i.e., pneumotometric method) in the determination of lung volumes (Boren et al., 1966; Christie, 1932). By the time of the early 1900's researchers (Bohr, 1907; Tobiesen, 1911; and Lundsgaard & Van Slyke, 1918; as cited in Boren et al., 1966) focused their attention on the various lung volume compartments. However, the forced breathing methods required for these measures were poorly reproducible and difficult to perform (Boren et al., 1966).

In 1923, Van Slyke and Binger developed a hydrogen dilution technique in which the subject rebreathes a known hydrogen gas concentration for five to seven minutes (Boren et al., 1966). This was the forerunner of many of today's closed circuit gas dilution techniques. The hydrogen dilution technique was modified by McMichael in 1939 and subsequently replaced the commonly used quiet breathing oxygen dilution technique developed by Christie (1932). In 1941, helium replaced hydrogen as the dilution gas with a modification made by Meneely and Kaltreider, and later simplified in 1953 (Boren et al., 1966). Darling, Cournand, and Richards (1940) developed the open circuit nitrogen washout technique which differed greatly from previous methods by the incorporation of the complete removal of a gas from the lungs and body instead of achieving an equilibrium state (Boren et al., 1966; Christie, 1932).

There have been numerous methods employed to indirectly determine the residual lung volume in man. According to Wilmore (1969a), the majority of these methods are modifications of three major approaches: (1) the pneumatometric method, (2) the closed circuit method, and (3) the open circuit method.

The pneumatometric method, originally developed by Pfluger in 1882, is based on Boyle's Law, which states that the volume of gas varies in inverse proportion to the pressure to which it is subjected. This method requires the subject to be placed in an air-tight chamber connected to a spirometer. The subject is able to breathe room air through a mouthpiece connected to an opening in the chamber. Inspiratory and expiratory processes cause air displacement inside the chamber which is detected and recorded on a spirometer. Expiration is then completely obstructed and the subject is told to make a maximal inspiratory or expiratory effort against this total resistance. The amount of air in the lungs is determined by measuring the change in pressure at the mouthpiece and volume which the thorax expanded.

According to Robertson et al. (1978), this method is able to detect the slightest amount of trapped air which, by gas dilution techniques, is often undetected. There are, however, a number of drawbacks of this method including the requirement for a specialized chamber which has been described in the past to be very cumbersome and difficult to maintain (Christie, 1932). In addition, considerable time is needed to perform the maneuver, which has been described as demanding more cooperation than even the healthiest individual can deliver (Christie, 1932).

The closed circuit method is based on a subject rebreathing a known concentration of gas (e.g., 100% pure oxygen) in a closed system. The subject is instructed to exhale maximally into room air and is then connected to either a spirometer or rebreathing bag containing a known volume of gas. The subject breathes deeply (approximately 5 to 8

breaths) until there is a state of equilibrium between the fraction of nitrogen in the spirometer or rebreathing bag and the fraction of nitrogen in the lungs. The closed circuit method was originally described by Lundsgaard and Van Slyke (1918) and has since been modified by Wilmore (1969a) to provide accurate results in five to eight breaths. This technique appears to provide reliable results, and the short time for duplicate measures (2-3 minutes) minimizes the problem of nitrogen excretion from the blood, as discussed by Wilmore (1969a).

In regard to the claim that measurements of RV in water by gas dilution techniques are "invalid" (Robertson et al., 1978), a more thorough review of Robertson's article was conducted. Robertson et al. (1978), compared gas dilution and plethysmographic techniques and observed that the dilution method underestimated RV by 16% when the subject was immersed. However, in nine of the subjects tested, seven also displayed a lower RV by gas dilution determined on land. Therefore, the disagreement between the two techniques may not have been due to air trapping as a result of immersion, but rather an inherent procedural difference between the two techniques.

The open circuit method, unlike the closed circuit method, is based upon gas washout. In this method the subject is not required to breathe forcefully, but rather passively for five to seven minutes. During this time of quiet breathing nitrogen is washed out of the respiratory system by inhalation of pure oxygen through a series of one-way valves (Baren et al., 1966; Christie, 1932). This technique is generally considered to be the reference method or "gold standard" to which other methods have been compared (Darling, Cournand, & Richards, 1940). There is, as

proposed by Wilmore (1969a), a problem with this method. The seven minute time period needed for the procedure allows considerable time for the release of nitrogen from the tissues and blood into the ventilatory system. Although this amount may seem negligible, 10 - 12 ml of nitrogen per 20 seconds of hyperventilation, it is possible for a total of 200 - 300 ml to be released by the end of the procedure, which could have a significant effect on the results (Wilmore, 1969a).

Of the three methods discussed for the determination of RV, the closed circuit and open circuit methods are the most widely used (Robertson et al., 1978; Wilmore, 1969b). This is probably due to the less expensive equipment and the decreased time needed to perform these methods as compared to the pneumatometric procedure.

In addition to measuring RV, the three before-mentioned methods may also be used to determine larger lung volumes such as FRC (Christie, 1932). The importance of this is the possibility of modifying one of these methods to measure a larger lung volume with the subject immersed, and thereby create a more comfortable hydrostatic weighing method (Witherspoon, 1984).

Lung Volumes Used in Hydrostatic Weighing

The greatest disagreement in determining an individual's body density and percent body fat is in the area of establishing the most appropriate lung volume to be used. According to Brozek et al. (1949), the major source of error in the determination of body density is the uncertainty of the air remaining in the lungs during the weighing procedure. Such factors as hydrostatic pressure, air-trapping, and

subject comfort have been studied in an attempt to establish the "best" lung volume for use during hydrostatic weighing.

Residual Volume

Residual volume, the volume of air remaining in the lungs following a maximal exhalation, has been demonstrated to be the least affected by hydrostatic pressure and the most reproducible in and out of water.

Welch and Crisp (1958) explored the affect of body density measurements following a maximal exhalation, and at approximately one-half maximum expiration on 26 male subjects. Both lung volumes were measured with the subject immersed (umbilicus 30 inches below the surface of the water) with the oxygen flush-out technique developed by Cournand, Baldwin, Darling, and Richards in 1941 (as cited in Welch & Crisp, 1958). They reported average density following maximum expiration to be significantly lower ($p<.01$) than that determined at one-half maximum expiration.

According to theory, any increase in lung volume should produce a corresponding decrease in body density (Welch & Crisp, 1958). Since this was not apparent in their study it was concluded that larger lung volumes are more susceptible to hydrostatic forces, and as a result, should not be used during hydrostatic weighing.

Brozek et al. (1949) utilized the open circuit nitrogen washout method to determine the affect of complete body immersion on RV. Residual volume was determined on nine subjects in duplicate fashion on land (RV dry) and in water (RV wet) while seated. The average RV in air was 1.578 liters and was reduced to 1.449 liters following immersion.

However, in five of the 18 measurements RV dry was slightly smaller than RV wet. It was concluded that although immersion does tend to decrease RV by mechanical compression, some individuals may experience an increase due to a moderate degree of anxiety which may inhibit full exhalation.

Agostoni et al. (1966) measured ERV, FRC, and RV on eight subjects in air and again immersed to the boundary between the thorax and neck. RV was only determined on four of the eight subjects and showed a mean decrease of 16% following immersion. This decrease was approximately two times the 8.2% decrease observed by Brozek et al. (1949). They attributed the decrease to hydrostatic forces causing a shifting of blood into the thorax and thus, counteracting the force of the inspiratory muscles.

Bondi et al. (1976) measured the effects of immersion on RV and airway closure with a study conducted on ten healthy males. RV was measured with a dual inert gas dilution technique (Nunneley, Flynn, & Camporesi, 1974) and airway closure, as determined by closing volume, was measured by the single breath nitrogen technique. Immersion resulted in a 9.4% decrease in RV and a 41.3% increase in closing volume, as compared to RV dry. They suggested these findings were due to the increase in intrathoracic blood volume and subsequent air-trapping. To support the pulmonary vascular engorgement theory, tourniquets were applied to the limbs during immersion and on land to decrease the shift of blood into the thorax. When tourniquets were applied during immersion closing volume only increased 37.1% over the dry controls and upon removal, closing volume increased to 64.3% above

the dry controls. Thus, it was concluded that immersion causes a shifting of blood into the thorax which causes engorgement of the pulmonary vessels resulting in impaired gas exchange.

Ostrove and Vaccaro (1982) also found a decrease in RV with a study on 27 normal females. RV was measured by the helium dilution technique on land (RV dry) and immersed to the chin (RV wet) with the subject in the seated position. RV dry decreased 17.4%, from a mean value of 1.121 liters to .926 liters upon immersion. They suggested the decrease in immersed RV was the result of hydrostatic pressure which "assists the muscles responsible for exhalation allowing for a more complete emptying of the lungs" (p. 222).

Prefaut et al. (1976) and Robertson et al. (1978) concluded that RV was not affected by immersion. According to these researchers, hydrostatic pressure which tends to decrease RV is counterbalanced by the engorgement of the pulmonary blood vessels which tend to increase RV during immersion.

Craig and Ware (1967) predicted RV to be reduced during immersion as a result of hydrostatic forces promoting the exhalation process. However, the reported mean RV dry (1.44 liters) was not statistically different than the mean RV wet (1.38 liters).

In contrast to the findings of others, Girandola et al.(1977) reported a significantly increased RV following immersion. The 6.7% increase over RV dry was attributed to an increased pulmonary blood volume and subsequent stiffening of the lung tissues. The increase in immersed RV resulted in a significantly lower ($p<.01$) percent body fat estimation. This led Girandola and associates to conclude "that when

obtaining body density values, RV should be measured concurrently while the subject is in the water" (p. 276). Table 1 summarizes the effects of immersion on RV as reported in prior studies.

Table 1

Effects of Immersion on Residual Volume as Reported in Prior Studies

Reference	N	Level of Immersion	Mean RV (liters) Air	Water	Difference
Agostoni et al. (1966)	4	xiphoid	1.67	1.39*	-.28
Bondi et al. (1976)	10	thorax	1.55	1.40*	-.15
Hrozek et al. (1949)	9	total	1.58	1.45	-.13
Cox (1989)	100	neck	0.95	0.92*	-.03
Craig & Ware (1967)	21	neck	1.44	1.38	-.06
Etheridge & Thomas (1978)	9	no data	0.93	0.93	.00
Girandola et al. (1977)	20	neck	1.42	1.52*	+.10
Jarrett (1965)	3	sternum	1.25	1.15*	-.10
Ostrove & Vaccaro (1982)	27	chin	1.12	0.93*	-.19
Robertson et al. (1978)	9	larynx	1.45	1.28*	-.17
Witherspoon (1984)	30	total	1.29	1.25*	-.04

Note. * Significantly different than RV determined in air ($p<.05$).

Total Lung Capacity

In an attempt to eliminate the effects of pulmonary air-trapping and discomfort of the RV maneuver, a number of researchers have attempted the hydrostatic weighing (HW) procedure with the volume of air remaining in the lungs following a maximal inspiration (i.e., total lung capacity). A substantial number of studies have been conducted utilizing TLC in the estimation of body density with the method of TLC determination, dry versus immersed, being the source of difference between the studies.

Weltman and Katch (1981) examined body density and percent body fat, as determined by HW, on 72 male and 51 female subjects at RV dry and TLC dry. Although statistically significant differences were observed in body density determinations, the authors stated that the slight differences in percent body fat (.05% for men and .9% for women) were within the measurement error associated with the HW technique. Furthermore, HW at TLC was rated more comfortable by the subject, caused less scale fluctuation, required fewer underwater weighing trials, and reduced the subject's anxiety level.

Other studies comparing body density and percent body fat at TLC dry and RV dry also found body density to be significantly overestimated and percent fat underestimated with the TLC maneuver (Latin & Ruhling, 1986; Smith & Bishop, 1987; Timson & Coffman, 1984; Weltman et al., 1987).

Timson and Coffman (1984) determined body density and percent body fat on 50 male and 50 female subjects via HW at RV (on-land) and TLC (on-land and in water). Measurement of body density and percent fat by

HW at TLC (on-land) was significantly different than measurement at RV (on-land) for both sexes ($p<0.001$). However, no difference was found between these measures when body density and percent fat were estimated from RV (on-land) and TLC (in water). The authors concluded the 1% to 13% reduction in TLC during immersion dictates the need to measure this lung volume with the subject in the water.

In additional studies comparing HW at TLC wet and RV, statistically significant differences in body density and percent fat were observed (Lundvall & Thorland, 1987; Witherspoon, 1984). However, the significantly higher body density values at TLC wet were attributed to methodological errors in one study (Witherspoon, 1984) and too low a level of immersion in the other (Lundvall & Thorland, 1987). Table 2 summarizes the results of the various studies in which TLC (dry and immersed) was used in the determination of body density from HW.

Table 2

Effect of Total Lung Capacity on Body Density as Reported in Prior Studies

Reference	N	Immersion Level	Body Density (g/ml) TLC Dry	TLC Wet	RV Dry	RV Wet
Latin & Ruhling (1986)	25	land	1.049		1.047	
Lundvall & Thorland (1987)	53	chest		1.071*	1.062	
Smith & Bishop (1987)	64	land	1.070*		1.057	
Timson & Coffman (1984)	50	neck	1.063*	1.059	1.059	
	**50	neck	1.028*	1.024	1.025	
Weltman et al. (1987)	28	land	1.066*		1.057	
Weltman & Katch (1981)	72	land	1.037*		1.035	
	**51	land	1.022*		1.020	
Witherspoon (1984)	30	total		1.067*	1.060	1.058

Note. * Significantly different than body density at RV ($p<.05$).
** Indicates female subjects.

Functional Residual Capacity

As an additional alternative to the use of RV measures, HW at functional residual capacity (FRC) has been investigated. Functional residual capacity, the volume of gas remaining in the lungs following a normal exhalation, has not received much attention in the HW technique. This researcher was only able to find two studies utilizing this lung volume for the indirect determination of body density and percent body

fat (Thomas & Etheridge, 1980; Witherspoon, 1984).

Although FRC has not received much attention in regard to the HW procedure, a considerable number of studies have observed the effects of immersion on FRC (Agostoni et al., 1966; Begin et al., 1976; Bondi et al., 1976; Girandola et al., 1977; Ostrove & Vaccaro, 1982; Robertson et al., 1978). Furthermore, FRC measurements were used extensively in the indirect determination of RV from the equation RV = FRC - ERV (Boren et al., 1966; Goldman & Becklake, 1959; Grimby & Soderholm, 1963; Timson & Coffman, 1984). Table 3 summarizes the findings of others on the effects of immersion on FRC.

Table 3

Effect of Immersion on Functional Residual Capacity as Reported in Prior Studies

Reference	N	Immersion Level	Mean FRC (liters) Dry	Wet	Difference
Agostoni et al. (1966)	4	xiphoid	3.53	1.90*	-1.63
Begin et al. (1976)	5	neck	2.83	1.86*	-0.97
Bondi et al. (1976)	10	neck	3.33	1.96*	-1.37
Girandola et al. (1977)	20	neck	2.75	2.05*	-0.70
Ostrove & Vaccaro (1982)	27	chin	2.54	1.35*	-1.19
Robertson et al. (1978)	9	larynx	3.36	1.85*	-1.51

Note. * Significantly different than FRC dry ($p<.05$).

Unlike RV, FRC has been consistently reduced following immersion, and decreases of 21 to 46% of FRC dry have been reported (Agostoni et al., 1966; Begin et al., 1976; Bondi et al., 1976; Girandola et al., 1977; Ostrove & Vaccaro, 1982; Prefaut et al., 1976; Robertson et al., 1978). Due to the substantial decrease in FRC caused by immersion it is obvious that any method utilizing this lung volume in the HW procedure should measure it while the subject is immersed.

Thomas and Etheridge (1980) investigated the effects of RV and FRC on body density and percent fat in 43 male subjects performing the HW procedure. Both lung volumes were measured simultaneously with underwater weight by the use of specialized equipment. Body density and percent fat values for immersed FRC and RV were not significantly different in this study. A high test-retest reliability of 0.99 for the two body density determinations at FRC was also reported. Of additional benefit, the subject was more comfortable performing the HW procedure at FRC, and caused even less scale oscillation than HW at TLC. As a result, the FRC maneuver would be the method of choice when the lung volume can be assessed during the underwater weighing procedure. According to Lundvall and Thorland (1987), "If simplified equipment is developed, then HW at FRC might be an appropriate method to commonly administer" (p. 399).

In a similar study, Witherspoon (1984) compared body density and percent fat on 30 subjects using four different lung volumes: RV dry, RV wet, TLC wet, and FRC wet. Assessment of the four lung volumes was made at the time of underwater weighing. There was no significant difference between HW determination of body density or percent fat using RV dry, RV

wet, and FRC wet. This was not the case, however, when body density and percent fat were assessed at TLC wet. A brief questionnaire was also filled out by each subject regarding the comfort and preference of each of the four methods immediately following the HW procedure. FRC was deemed most comfortable followed by RV dry, TLC wet, and RV wet, respectively. Of additional interest, it was subjectively noted by the researcher that the majority of the subjects performed the FRC maneuver with less difficulty and less scale oscillation than the three other breathing maneuvers.

Witherspoon (1984) has theorized that the paucity of studies using FRC in body density determination is due to the assumption that FRC is not easily reproduced in water. Contrary to these claims Begin et al. (1976) performed eight measures of FRC, dry and immersed to the neck, on five subjects over a four hour time period. Results of the study indicated that immersed FRC only ranged from 1.80 and 1.90 liters over the four hour time period with a mean value of 1.86 $\pm$ .19 liters. During the seated dry measures, FRC ranged between 2.71 and 2.97 liters with a mean value of 2.88 $\pm$ .21 liters being reported.

Support for the reproducibility of the FRC immersed has also demonstrated by Thomas and Etheridge (1980). When immersed FRC and RV lung volumes were used in the determination of body density and percent fat, the standard deviations for the subject population (n = 43) at the two FRC measures were substantially lower than those at RV wet, 2.260 $\pm$ .516 liters and 1.706 $\pm$ .710 liters, respectively.

The Relationship of FRC and RV to Various Physical Characteristics

Prediction formulas for FRC and RV have been developed based on physical characteristics of individuals. Although there have been a number of prediction formulas for FRC and RV dry, there is a void in the literature for the prediction of FRC and RV in males while immersed. Tables 4 and 5 summarize the correlations reported by prior researchers between FRC and RV and various physical characteristics.

Table 4

Correlation Between Physical Characteristics and Functional Residual Capacity

Reference	Age	Height	Weight	Chest Depth	Smoking History
Boren et al. (1966)	**	.36	**	**	+
Crapo et al. (1982)	+	+	**	**	**
Goldman & Becklake (1959)	-.09	.50	.02	**	**
Grimby & Soderholm (1963)	+	+	+	**	**

Note. + Positive correlation indicated but no data were provided.
** No correlation reported.
$p<.05$.

Relationship of FRC and RV with Age

According to Brozek (1960), an increase in FRC is due to "diminished elastic recoil of the lung" brought about by the "normal process of aging" (p. 158). Grimby and Soderholm (1963) and Crapo et al. (1982) reported a significant positive correlation of age with FRC,

but no data were provided. In contrast, Goldman and Becklake (1959) also reported a correlation of age and FRC, but in the inverse direction ($r = -.09$).

Many researchers have observed the effects of age on RV and all have stated that RV increases with age (Boren et al., 1966; Cox, 1989; Crapo et al., 1982; Goldman & Becklake, 1959; Grimby & Soderholm, 1963; Morrow, VanLandel, & Bradley, 1989; Russel, 1987; Weidman, 1986). Bronek (1960) attributed the gradual increase of RV with age due to the reduced elastic recoil of the lungs and thorax.

Relationship of FRC and RV with Height

Numerous researchers have investigated the effect of height on FRC (Boren et al., 1966; Crapo et al., 1982; Goldman & Becklake, 1959; Grimby & Soderholm, 1963) all concluding that FRC increases with height. Positive correlations as high as $r = .36$ and $r = .50$ have been reported (Boren et al., 1966; Goldman & Becklake, 1959). Boren et al. (1966) extrapolated these findings to conclude that "increasing height increases all compartments of the lungs" (p.110). Aitken, Schoene, Franklin, and Pierson (1985) demonstrated that predicted FRC values can be extended to include those at the extremes of stature.

All the before-mentioned researchers reporting a positive correlation between RV and age have also reported a significant correlation between RV and height. Boren et al. (1966) and Goldman and Becklake (1959) found RV to be significantly correlated ($p<.01$) with height by demonstrating an r of .23 and .29, respectively.

Table 5

Correlation Between Physical Characteristics and Residual Volume

Reference	Age	Height	Weight	Chest Depth	Smoking History
Boren et al. (1966)	.20	.23	.17	**	+
Cox (1989) *	.59	.40	.33	.43	.14
Crapo et al. (1982)	+	+	**	**	**
Goldman & Becklake (1959)	.48	.29	.08	**	**
Grimby & Soderholm (1963)	+	+	+	**	**
Morrow et al. (1989)	+	+	+	**	**
Russel (1987) *	.66	.31	.21	**	.28
Waldman (1986)	+	+	**	**	+
York & Jones (1981)	**	**	**	**	+

Note. + Positive correlation indicated but no data provided.
* Data on female subjects only.
** No correlation reported.
$p<.05$.

Relationship Between FRC and RV with Weight

Weight was reported as having a positive correlation ($r = .024$) with FRC in males by a study conducted by Goldman and Becklake (1959). A substantially higher correlation was demonstrated among the female subjects ($r = .264$). Grimby and Soderholm (1963) also reported a positive correlation between weight and FRC with a study on 152 males, ages 20 - 65 years.

Boren et al. (1966) stated that weight correlated positively ($r = .17$, $p<.01$) with RV. Substantially higher correlations ($r = .33$ and $r = .21$, respectively) were reported by both Cox (1989) and Russel (1987) with studies conducted on only female subjects.

Relationship Between FRC and RV with Chest Depth

The only studies pertaining to the effects of chest measurement on lung volumes are those of Boren et al. (1966) and Cox (1989). According to Boren et al. (1966), "chest measurements and chest expansion proved of no additional value in predicting lung compartments" (p. 103). Cox (1989), however, found a significant positive correlation ($r = .43$, $p<.05$) between chest depth and RV in a study conducted on 100 females. Although no relationship was determined between FRC and chest depth in Cox's study, Goldman and Becklake (1959) have stated "the trends in residual volume values follow functional residual capacity values closely" (p. 462). Therefore, one would expect chest depth to be a significant ($p<.05$) predictor of FRC.

Relationship Between FRC and RV with Smoking

York and Jones (1981) stated there was no significant ($p<.05$) difference in overall lung function between young smokers and nonsmokers (mean age = 23.8 years). However, RV in the lower lung regions of the smokers was found to be significantly higher ($p<.05$). They concluded that smoking decreases the elasticity of the lungs and causes alterations in airway function, a pattern often observed among individuals suffering from chronic obstructive lung disease.

Although the relationship between smoking and FRC was not reported by York and Jones (1981), Boren et al. (1966) compared FRC of 143 heavy cigarette smokers to 60 nonsmokers and found the heavy smokers to have a 12.2% larger FRC. Webster, Lorimer, Man, Woolf, and Zammel (1979) reported a large but non-significant difference ($p>.05$) in RV with a study using identical twins, where one smoked and the other did not.

Functional Residual Capacity and Residual Volume Prediction Formulas

There have been various multiple regression formulas developed to predict FRC and RV. However, studies for the prediction of FRC and RV in male subjects while immersed were not found in the literature reviewed. As a result, only those equations for the prediction of FRC and RV dry will be discussed.

Boren et al. (1966) developed a prediction formula using only the physical characteristic of height as a predictor of FRC and included age for the prediction of RV. The actual FRC and RV values were determined by both the closed circuit helium dilution and open circuit nitrogen washout techniques.

Crapo et al. (1982) developed an equation from 123 healthy non-smoking males using height and age as predictors. Direct assessments of FRC and RV were made by the single-breach helium dilution technique as described by Kanner and Morris (1975).

Goldman and Becklake (1959) also developed a regression equation to predict FRC and RV. Height and body surface area (meters^2) were used in the prediction of FRC whereas height and age were the variables utilized for RV. Both FRC and RV values were determined by the closed circuit

hydrogen dilution technique developed by McMichael (1939).

Grimby and Soderholm (1963) used closed circuit helium dilution to determine FRC and RV on 152 male subjects (mean age = 40.4 years). The predictors for these regression formulas were age, height, and weight. Table 6 summarizes the several important aspects of formulas used to predict FRC in males as reported by other researchers, and Table 7 those of RV.

Table 6

Assessment of Previous Functional Residual Capacity Prediction Formulas

Researcher	Variables Used	Standard Error of Estimation	Correlation Coefficient
Boren et al. (1966)	Height (cm)	630 mls	.36
Crapo et al. (1982)	Height (cm) Age (years)	718 mls	.38
Goldman & Becklake (1959)	Height (cm) Surface area (m^2)	605 mls	.57
Grimby & Soderholm (1963)	Age (years) Height (m) Weight (kg)	*560 mls	no data

Note. * Value was reported as residual standard deviation, $p<.05$.

Table 7

Assessment of Previous Residual Volume Prediction Formulas

Researcher	Variables Used	Standard Error of Estimation	Correlation Coefficient
Boren et al. * (1966)	Height (cm) Age (years)	530 mls	.33
Crapo et al. (1982)	Height (cm) Age (years)	374 mls	.71
Goldman & Becklake (1959) *	Height (cm) Age (years)	372 mls	.64
Grimby & Soderholm (1963) *	Age (years) Height (m) Weight (kg)	**380 mls	no data

Note. * RV obtained from FRC (indirect analysis) - ERV (spirometry).
** Value reported as the residual standard deviation.
$p<.05$.

Summary

Functional residual capacity and RV cannot be determined by simple spirometry, and as a result, some form of indirect analysis is required. Indirect methods are usually modifications of three main approaches: plethysmography, tracer gas dilution (closed circuit), or nitrogen washout (open circuit) (Boren et al., 1966; Christie, 1932). Closed circuit oxygen dilution seems to be the most widely used due to a high degree of accuracy in a minimal amount of time (Wilmore, Vodak, Parr, Girandola, & Billing, 1980).

In an attempt to eliminate the effects of air-trapping and discomfort of the RV maneuver, HW at larger lung volumes has been attempted. Body density determinations at TLC wet have yielded conflicting results with some researchers reporting no significant differences from body density at RV (Timson & Coffman, 1984) while others finding the opposite (Lundvall & Thorland, 1987; Witherspoon, 1984).

The results of limited research attempting HW at FRC have been reassuring. Both Thomas and Etheridge (1980) and Witherspoon (1984) have found body density values at FRC to be not significantly different than at RV. Furthermore, HW at FRC caused less scale oscillation than HW at TLC (Thomas & Etheridge, 1980) and provided subjects with the most comfortable lung volume (Witherspoon, 1984).

There are correlations between physical characteristics and the FRC and RV lung volumes. Among these characteristics are age, (Crapo et al., 1982; Goldman & Becklake, 1959; Grimby & Soderholm, 1963) height, (Aitken et al., 1985; Boren et al., 1966; Crapo et al., 1982; Goldman & Becklake, 1959; Grimby & Soderholm, 1963) and, weight (Grimby & Soderholm, 1963; Goldman & Becklake, 1959). Smoking history has also been found to correlate with FRC (Boren et al., 1966) and RV (York & Jones, 1981). Although not directly correlated with FRC, chest depth has been reported to significantly correlate with RV (Cox, 1989).

This literature review has suggested a need to establish equations for the prediction of FRC and RV in males while immersed. These formulas would hopefully provide a higher multiple correlation coefficient (R square) and a lower standard error of estimation (S.E.E.)

than previously published formulas. In addition, there is a need to determine the accuracy of a larger, more comfortable lung volume (i.e., FRC) to be used in the underwater weighing technique.

CHAPTER III

METHODS

Discussed within this chapter are descriptions of the subject selection and the methods used to determine the various physical characteristics of each subject. Also included are sections concerning instrumentation and development of procedures used to collect the measurements.

Subjects

One hundred males from the La Crosse, Wisconsin area volunteered as subjects in this study. To achieve a large and diverse population, sign-up sheets were posted at various establishments around the city. After collecting the sign-up sheets all potential subjects were randomly assigned a number. The numbers were then placed into a bowl and the first 100 drawn were selected as subjects for the study. If a selected subject could not be contacted or decided to withdraw from the experiment, a replacement was selected by drawing another name from the bowl.

The ages of the subjects ranged from 18 to 69 years old. Subjects having any known respiratory dysfunction, acute or chronic, were not allowed to partake in this study. The subjects were asked to refrain from strenuous physical activity for 12 hours prior to the testing. In addition, the subjects were also required to fast for 6 hours prior to the hydrostatic weighing procedure, as recommended by Goldman and

Buskirk (1961).

Each subject was informed of the possible dangers involved in participation and signed an informed consent form (Appendix A). The consent form contained an explanation of the procedures involved, a description of possible discomforts, the experiment's purpose, and the option for the subject to withdraw at any time. In addition, the investigator welcomed any questions, comments, or concerns of the subject prior to and during the testing procedure.

Instruments

The following is a list of the instruments used to collect data for this study:

Anthropometer - A GPM Model 101 Anthropometer was used to measure the height of each subject in centimeters while standing on bare feet.

Chest Depth Caliper - A Sharp and Smith model chest depth caliper was used to determine chest depth in centimeters.

Hydrostatic Weighing Apparatus - A 4'x 4'x 4' S.S. Hydrotesting Tank Model #09771 (Wolfe, nd) was used in the determination of RV and FRC immersed while the subject was seated. Underwater weight was assessed with the use of an immersed, stainless steel chair weighted with lead shot. The chair was suspended from three electronic Omega load-cells (model LCJ-200) which were interfaced to a computer system using a software program developed by the head laboratory technician at the University of Wisconsin-La Crosse Human Performance Laboratory.

Questionnaire - All subjects were required to fill out a questionnaire to provide the researcher with a knowledge of each subject's age, smoking history, and acute or chronic respiratory disease history.

Lung Volume Determination - The closed circuit oxygen dilution technique as outlined by Wilmore (1969a) was used to measure both RV and FRC lung volumes. The percent nitrogen in the system was determined using an electronic nitrogen analyzer, Med-Science Model 505 Nitralyzer (Med-Science Electronics, 1985). An Omega chart recorder was connected to the nitrogen analyzer to provide a graphic recording of all nitrogen values achieved during each test. A 6-liter spirometer (Collins, nd) was used to measure a volume of oxygen which was transferred to a 6-liter rebreathing bag that was previously evacuated via a hand pump. All oxygen volumes were measured to the nearest .01 liter before being delivered into the bag.

Single-beam Balance Scale - A Health-O-Meter scale (Continental model #200 DLK) was used to weigh each subject to the nearest pound. Subjects wore only a swimming suit during the weighing.

Spirometer - A 9-liter water filled spirometer, the Collins Vitalometer (Collins, nd) was used in measuring vital capacity.

Procedures

Order of Procedure

Upon entering the testing site, each subject read and signed the Informed Consent Form (Appendix A). An explanation of the procedures used during the testing was provided to familiarize the subject with the equipment. After signing the consent form each subject was given a

questionnaire (Appendix B) and instructed to answer all questions as honestly and accurately as possible. A screening of the questionnaire was then conducted to ensure that no acute or chronic respiratory disease existed. Smoking history was evaluated and recorded from the questionnaire.

Determinations of height and weight were made with the subject barefoot and wearing only swimming trunks. Chest depth was measured with a chest depth caliper. One end of the caliper was placed on the tip of the xiphoid process while the other end was placed over the vertebrae of the twelfth rib (Tcheng & Tipton, 1973). The subject was then instructed to take a normal breath and exhale, and at this point a measurement was taken. Three determinations were made and an average value was calculated. The subject was then requested to inhale and exhale maximally into a 9-liter Vitalometer spirometer to determine vital capacity (VC). Although VC was not a variable used in the study, it was measured to determine the amount of oxygen to be put into the rebreathing bag during lung volume determinations.

Upon completion of the VC measure, the subject was asked to shower and then proceed into the underwater weighing tank. After entering the tank the subject made an effort to remove all trapped air bubbles from his swimming attire. The water level was adjusted to the level of the sternoclavicular notch while the subject was seated in a stainless steel chair. The order in which the lung volumes (RV or FRC) were to be measured was determined with a flip of a coin. If heads, RV was the first lung volume measured. If tails, FRC was the first lung volume measured.

Residual Volume Procedure

To determine RV, each subject was seated in the immersion tank at the established water level. A 6-liter spirometer was filled with approximately five liters of pure oxygen by an electronic dispensing valve. The spirometer and rebreathing bag were filled and emptied two to three times to flush out all remaining gases from previous tests. The spirometer was then filled with a final oxygen volume (approximately equal to VC + 1 liter for RV, and VC - 1 liter for FRC). This volume was then transferred into the 6-liter rebreathing bag. With a nose clip and disposable mouthpiece in place the subject was instructed to take a full inhalation and then to exhale maximally. When the subject felt that he had expired to his fullest possible capability he raised his index finger to signal the researcher that only RV remained in his lungs. At this point the researcher connected the subject to the oxygen-filled rebreathing bag and coached the subject to breathe in and out rapidly and deeply until a nitrogen equilibrium was reached between the rebreathing bag and the subject's lungs. Although absolute equilibrium is never attained, it was assumed to be reached when the nitrogen readings between inspiratory and expiratory phases reached a minimum on the graphical printout. The values obtained were then placed in the formula developed by Wilmore (1969a).

$$LV = 1.1 \times \left[\frac{BV\ (EN - IN)}{AN - FN} - DS\right]$$

where: LV = lung volume

BV = volume of oxygen in rebreathing bag

AN = % of alveolar nitrogen

IN = % of impurity nitrogen in rebreathing bag

EN = % of nitrogen in rebreathing bag at equilibrium

FN = % of nitrogen in expired air at equilibrium

DS = dead space of tubes and analyzer head (80 mls)

1.1 = BTPS correction factor

Repeated measures of RV were taken until two trials were within 10% agreement of their mean value. A time period of approximately two to three minutes was incorporated between trials to allow for the elimination of any excess oxygen remaining in the lungs following rebreathing.

Functional Residual Capacity Procedure

Determinations of FRC were performed in the same manner as RV and differed in only one respect. Instead of having the subject maximally expire, as in the RV maneuver, he was asked to take several room air breaths and at the end of a normal, resting breath atop all breathing processes and hold. At this time he signaled the researcher that only FRC remained in his lungs and was then connected to the rebreathing bag with a switch of a valve. To ascertain that a "true" resting end expiration was established the subject was asked to relax to the best of his ability and close his eyes if desired. A minimum 15 second time

period of quiet, easy breathing through the four-way valve was also incorporated to clearly establish a resting end expiration. A minimum of two trials were performed and accepted at the same criteria as RV.

Hydrostatic Weighing

Body density and percent body fat were assessed by hydrostatic weighing (HW). Each subject previously weighed in air was then weighed immersed in a 4'x 4'x 4' S.S. Hydrotesting Tank (model #09771) while sitting on a stainless steel chair. The chair was suspended from three Omega load-cells (model LCJ-200) interfaced with a computer system (accurate to .01 kg) capable of sampling 50 underwater weights within a one second time period and computing a mean underwater weight from 100 recordings. The rapid response time of this system eliminated the difficulty of interpreting an oscillating autopsy scale. Water temperature was maintained between 33 - 35°C.

Subjects were weighed by two different methods of HW. One method used RV and the other used FRC for the determination of body density and percent body fat. All subjects were first hydrostatically weighed at FRC. Although this violated true random assignment, it was judged by the researcher that the intense physical strain put on the respiratory system following six to eight maximal expiratory efforts for HW at RV could possibly alter the normal resting breathing pattern needed for HW determination at FRC.

A minimum of two trials was required for HW at FRC. The fewer trials needed at this lung volume was attributed to the work of Weltman and Katch (1981) who have stated using FRC "eliminates the necessity for

multiple underwater weighing trials since there is no learning effect as is the case with HW at RV" (p. 210). If underwater weights were not within .05 kg agreement between two of the trials, further trials were conducted until the .05 kg agreement criteria was achieved. A mean value was then determined.

The HW procedure at RV was repeated a minimum of 5 to 6 times to account for the "learning" affect described by Katch (1969). According to Katch (1969), subjects learn to expel more air from their lungs with each additional underwater trial, and thus, will continue to increase their underwater weight. The subject's "true" underwater weight was established when no more than a .05 kg difference existed between two of the subject's highest obtained weights. A mean value was then determined.

To determine body density the previously measured lung volumes (FRC and RV) and underwater weights were inserted into the following equation developed by Goldman and Buskirk (1961):

$$BD = \frac{M_A}{\frac{M_A - M_W}{D_W} - LV}$$

where: BD = body density

M_A = mass of body in air

M_W = mass of body in water

D_W = density of water

LV = lung volume

Body density is generally converted to percent body fat for practical application. There are two formulas often used in the conversion of body density to percent body fat: Brozek, Grande, Anderson, and Keys (1963) and Siri (1961). The formula developed by Brozek and associates was used in this study and is presented below:

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

Statistical Analysis

All tests to develop a prediction equation for the FRC and RV lung volumes were processed by a Zenith data systems computer and analyzed using ABSTATS step-wise multiple regression (Anderson-Bell, 1987). Each variable was compared to the dependent variables, FRC and RV. The results were evaluated for correlation and significance. A formula was devised to predict both the FRC and RV lung volumes from the previously mentioned physical characteristics.

Predicted FRC and RV values obtained with the formulas developed in this study were compared to FRC and RV values obtained by previously published formulas. A one-way analysis of variance with repeated measures was used to test for significant differences and a *Scheffe'* post hoc test was used to see where the differences lay.

Body density and percent body fat values at RV and FRC were tested for significant differences using paired t-tests.

CHAPTER IV

RESULTS AND DISCUSSION

The data collected for the prediction of residual volume (RV) and functional residual capacity (FRC) are presented in this chapter. The data were processed through the use of multiple step-wise regression formulas. Prediction formulas were developed for both RV and FRC lung volumes and their adequacy was evaluated. A comparison was made between the prediction of RV and FRC from the formulas developed in this study against previously published formulas (Boren et al., 1966; Crapo et al., 1982; Goldman & Becklake, 1959; Grimby & Soderholm, 1963).

A test of significance was conducted between body density and percent body fat obtained at the FRC and RV breathing maneuvers. This was done to evaluate the effectiveness of an alternative (i.e., more comfortable) underwater weighing technique.

Subject Characteristics

A total of 198 subjects volunteered, of which 100 were randomly selected and tested as described in Chapter III. All subjects were males between the ages 18 and 69 years and were from the La Crosse, Wisconsin area. The subject characteristics of age, height, weight, chest depth, smoking history, RV, FRC, and percent body fat are summarized in Table 8.

Table 8

Characteristics of Test Population

Variable	Mean	S.D.	S.E.M.
Age (yr)	32.71	13.74	1.37
Height (cm)	177.76	7.30	.73
Weight (kg)	78.70	9.71	.97
Chest Depth (cm)	20.28	2.24	.22
Smoking History (pkyr)	3.40	11.08	1.11
RV (L)	1.50	.46	.05
FRC (L)	2.22	.52	.05
Body Fat (%)	15.47	6.05	.60

Note. N = 100. pkyr = pack years.

Test-Retest Reliability of RV and FRC Measures

The test-retest correlations between the two RV and two FRC lung volume measurements showed significant correlations of $r = .99$ and $r = .98$ ($p<.001$), respectively. This suggests that reliable measurements were taken with the closed circuit oxygen dilution technique described by Wilmore (1969a).

Development of RV Prediction Formula

The development of the RV prediction formula was accomplished by singularly and collectively regressing the physical characteristics on the actual measured RV. Table 9 depicts the correlation of the

independent variables age, height, weight, chest depth, and smoking history with the dependent variable, RV.

Table 9

Residual Volume Correlation Matrix of Variables

	RV	Age	Height	Weight	Chest Depth	Smoking History
RV						
Age	.75					
Height	.35	-.07				
Weight	.41	.29	.46			
Chest Depth	.48	.60	.05	.67		
Smoking History	.29	.36	-.09	.14	.30	

When each independent variable was analyzed singularly age showed the highest correlation to RV. Chest depth and weight showed the next highest correlation to RV, followed by height and smoking history. Table 10 illustrates the development of the prediction formula by analyzing the contributions of the independent variables separately and collectively to the variation of the dependent variable. Weight, chest depth, and smoking history were not included in the final formula due to no significant increase ($p<.05$) in the variance of the dependent variable. The results of the step-wise regression are summarized in Table 11.

Table 10

Step-Wise Regression of Variables for the Prediction of Residual Volume

Variable	B	S.E. B	BETA	T	PROB
Step 1					
Age	0250310	.0022	.750790	11.25	.0000
Constant	.6858370				
Step 2					
Age	.0260376	.0018	.780983	14.74	.0000
Height	.0256005	.0033	.407950	7.70	.0000
Constant	-3.8979400				

Note. N = 100.

Table 11

Summary of the Development of the Residual Volume Prediction Formula

Step	R	Adjusted R Square*	R Square	S.E.E.
1. Age	.75	.56	.56	.304
2. Age + Height	.85	.72	.73	.241

Note. * R square modified to recognize number of independent variables.

Age was found to contribute the most as a predictor of RV, explaining 56% of the variance (R square). With the addition of the variable height, 72% of the variance of RV was accounted for and a standard error of estimation (S.E.E.) of 241 mls resulted. The inclusion of weight, chest depth, and/or smoking history did not result in a significant increase ($p<.05$) in the predictor value of the formula.

Comparison of RV Prediction Formulas

The formula developed from this study was compared to the formulas developed by Boren et al. (1966), Crapo et al. (1982), Goldman and Becklake (1959), and Grimby and Soderholm (1963). These formulas with the reported multiple correlation coefficient (R square) and standard errors of estimation (S.E.E.) are listed in Table 12. The formula developed in this study resulted in a lower S.E.E. (241 mls) and a higher R square (.72) than the previously published formulas.

The physical characteristics obtained in this study were inserted into the four previously derived RV prediction formulas. The means, standard deviations, and standard error of the means are presented in Table 13.

Analysis of Variance

Table 14 presents analysis of variance data which was performed on the predicted RV determined with the formula developed in this study and the predicted residual volumes determined by previously published formulas. This was used to determine if statistically significant differences existed among the five formulas for the prediction of RV.

Statistical significance was noted [$F(5,495) = 135.37$, $p<.001$], and a Scheffe' post hoc test was performed to determine where the differences lay.

Table 12

Comparison of Prediction Formulas for Residual Volume

Formula	R^2	S.E.E.
Boren et al. (1966)		
.019(Ht) + .0115(Age) - 2.24	.33	.530
Crapo et al. (1982)		
.0216(Ht) + .0207(Age) - 2.84	.71	.374
Goldman & Becklake (1959)		
.027(Ht) + .017(Age) - 3.447	.64	.372
Grimby & Soderholm (1963)		
.0198(Ht) + .022(Age) - .015(Wt) - 1.54	no data	.380*
Present Study		
.0260376(Age) + .0256005(Ht) - 3.89794	.72	.241

Note. * Value reported as the "residual standard deviation".
Ht = height(cm). Age = years. Wt = weight(kg).

Table 13

Means, Standard Deviations, and Standard Error of Means of the Residual Volume Prediction Formulas

Formula	Mean	S.D.	S.E.M.
Boran et al. (1966)	1.51	.202	.020
Crapo et al. (1982)	1.68*	.315	.031
Goldman & Becklake (1959)	1.91*	.294	.029
Grimby & Soderholm (1963)	1.52	.286	.029
Present Study	1.50	.391	.039
Actual RV	1.50	.458	.046

Note. * Significantly different than RV predicted from present study ($p<.001$).

Table 14

Statistical Analysis of Variance Data for Residual Volume Predictions

Source of Variation	S.S.	D.F.	M.S.	F
Between	56.68570	99	.57258	
Trials	13.33110	5	2.66623	135.373*
Residual	9.74923	495	.01970	
Total	79.76610	599		

Note. * $p<.001$.

It was determined that the predicted residual volumes from the formulas of Boren et al. (1966) and Grimby and Soderholm (1963) were not significantly different ($p>.05$) than the predicted residual volumes from the formula of this study. However, there was a significant difference ($p<.001$) between the formula developed in this study and those developed by Crapo et al. (1982) and Goldman and Becklake (1959).

Development of FRC Prediction Formula

The development of the FRC prediction formula was also developed by singularly and collectively regressing the physical characteristics on the actual measured FRC. Table 15 depicts the correlation of the independent variables age, height, weight, chest depth, and smoking history with the dependent variable, FRC.

Table 15

Functional Residual Capacity Correlation Matrix of Variables

	FRC	Age	Height	Weight	Chest Depth	Smoking History
FRC						
Age	.21					
Height	.59	-.07				
Weight	.23	.29	.46			
Chest Depth	.11	.60	.05	.67		
Smoking History	.06	.36	-.09	.14	.30	

When each independent variable was analyzed singularly height showed the highest correlation to FRC. Weight and age revealed the next highest correlation to FRC, followed by chest depth and smoking history. Table 16 illustrates the development of the prediction formula.

Table 16

Step-Wise Regression of Variables for the Prediction of Functional Residual Capacity

Variable	B	S.E. B	BETA	T	PROB
Step 1					
Height	.0420940	.0059	.585988	7.16	.0000
Constant	-5.2631000				
Step 2					
Height	.04342630	.0056	.604535	7.70	.0000
Age	.00956365	.0030	.250597	3.19	.0019
Constant	-5.81276000				
Step 3					
Height	.0493365	.0065	.686811	7.65	.0000
Age	.0116958	.0032	.306466	3.67	.0004
Weight	-.0091931	.0051	-.170275	-1.82	.0721
Constant	-6.2096200				

Note. N = 100.

Chest depth and smoking history were not included in the final formula due to no significant increase ($p<.05$) in the variance of the dependent variable. The results of the step-wise regression are summarized in Table 17.

Table 17

Summary of the Development of the Functional Residual Capacity Prediction Formula

Step	R	Adjusted R Square*	R Square	S.E.E.
1. Height	.59	.34	.34	.427
2. Height + Age	.64	.39	.41	.408
3. Height + Age + Weight	.65	.41	.43	.403

Note. * R square modified to recognize number of independent variables.

Height was found to contribute the most as a predictor of FRC, explaining 34% of the variance (R square). With the additions of the variables age and weight, 41% of the variance of FRC was accounted for and standard error of estimation (S.E.E.) of 403 mls resulted. The inclusion of chest depth and/or smoking history did not result in a significant increase ($p<.05$) in the predictor value of the formula. Although the addition of weight did not significantly ($p = .07$) increase the predictor value of the formula, the researcher felt that the ease of which this variable is measured, along with favorable contributions to the formula, justified its acceptance.

Comparison of FRC Prediction Formulas

The formula developed from this study was compared to those developed by Boren et al. (1966), Crapo et al. (1982), Goldman and Becklake (1959), and Grimby and Soderholm (1963). These formulas along with the reported multiple correlation coefficient (R square) and standard error of estimation (S.E.E.) are listed in Table 18.

Table 18

Comparison of Prediction Formulas for Functional Residual Capacity

Formula	R^2	S.E.E.
Boren et al. (1966)		
.032(Ht) - 2.94	.36	.630
Crapo et al. (1982)		
.0472(Ht) + .009(Age) - 5.29	.38	.718
Goldman & Becklake (1959)		
.081(Ht) - 1.792(BSA) - 7.11	.57	.605
Grimby & Soderholm (1963)		
5.30(Ht) + .015(Age) - .037(Wt) - 3.89	no data	.560*
Present Study		
.0493365(Ht) + .0116958(Age) - .00919313(Wt) - 6.20966	.41	.403

Note. * Value reported as the "residual standard deviation". Ht = height(cm), Age = years, Wt = weight(kg), BSA = body surface area (m^2).

The formula developed in this study resulted in a lower S.E.E. (403 mls) than all the previously published formulas. However, the formula developed by Goldman and Becklake (1959) resulted in a higher R square than the formula developed in this study.

The physical characteristics obtained in this study were inserted into the four previously derived FRC prediction formulas. The means, standard deviations, and standard error of the means are presented in Table 19.

Table 19

Means, Standard Deviations, and Standard Error of Means of the Functional Residual Capacity Prediction Formulas

Formula	Mean	S.D.	S.E.M.
Boren et al. (1966)	2.75*	.234	.023
Crapo et al. (1982)	3.39*	.357	.036
Goldman & Becklake (1959)	3.78*	.432	.043
Grimby & Soderholm (1963)	3.11*	.372	.037
Present Study	2.22	.342	.034
Actual FRC	2.22	.524	.052

Note. * Significantly different than FRC predicted from present study ($p<.001$).

Analysis of Variance

Table 20 presents analysis of variance data which was performed on the predicted FRC determined with the formula developed in this study and the predicted functional residual capacities determined by previously published formulas. This was used to determine if statistically significant differences existed among the five formulas for the prediction of FRC. Statistical significance was noted [$F(5,495) = 798.43$, $p<.001$], and a Scheffe' post hoc test was performed to determine where the differences lay.

Table 20

Statistical Analysis of Variance Data for Functional Residual Capacity Predictions

Source of Variation	S.S.	D.F.	M.S.	F
Between	64.1420	99	.647899	
Trials	200.3600	5	40.071900	798.425*
Residuals	24.8434	495	.050189	
Total	289.3450	599		

Note. * $p<.001$.

Results of the Scheffe' post hoc test indicated that the predicted functional residual capacities from all the previously published formulas were significantly different ($p<.001$) than the predicted FRC obtained from the formula developed in this study.

A possible explanation for the noted differences among the obtained predicted functional residual capacities may have been due to the effect immersion has on FRC. As mentioned earlier, immersion has been demonstrated to reduce on-land determinations of FRC by as much as 46%. Therefore, the consistent overestimation of FRC by the four previously published formulas may have been attributed to the very fact that these formulas were developed on FRC measures made on-land as opposed to immersed determinations.

Comparison of Body Density and Percent Body Fat at FRC and RV

Body density and percent body fat were determined at two different lung volumes (FRC and RV) to evaluate the effectiveness of an alternative (i.e., more comfortable) underwater weighing technique. A paired t-test was used to test for significant differences between body density and percent body fat obtained at the two lung volumes. The means, standard deviations, standard errors of the means, and t-test values are presented in Table 21.

Table 21

T-Test Values of Body Density and Percent Body Fat Obtained at the FRC and RV Lung Volumes

Procedure	Mean	S.D.	S.E.M.	T
Body Density (g/ml)				
FRC	1.0625	.01613	.00161	-1.222
RV	1.0698	.06202	.00620	
Percent Body Fat				
FRC	16.01	6.580	.658	3.187*
RV	15.47	6.048	.605	

Note. N = 100.
* Significantly different than percent body fat at RV ($p<.01$).

Results of the paired t-test indicated a significant difference ($p<.01$) between percent body fat determined at FRC and RV. However, no significant difference ($p>.05$) was found between body density determined at FRC and RV.

The significant difference found in percent body fat determined by the two methods are not in agreement with the findings of Thomas and Etheridge (1980) and Witherspoon (1984). However, the failure to find a significant difference in body density determined at the FRC and RV lung volumes do support the findings of Thomas and Etheridge (1980) and Witherspoon (1984).

The results of this study indicate the difference between body density determinations by hydrostatic weighing (HW) at FRC and RV is negligible. Although this may be the case for body density, the same cannot be said for percent body fat determinations by HW at FRC and RV. However, the .54% mean difference between percent body fat determined at FRC and RV may not be of physiological importance, since this is well within the measurement error (± 3.8%) associated with the HW technique (Siri, 1961).

Summary

Formulas for the prediction of FRC and RV were developed through the use of multiple step-wise regression based on the following independent variables: age, height, weight, chest depth, and smoking history. The variables of weight, chest depth, and smoking history were not found to contribute significantly to the prediction of RV, and thus, were not included in the final formula. Chest depth and smoking history were also not included in the formula developed to predict FRC since their inclusion did not significantly increase the predictor value of the formula.

The failure of smoking history to be a significant predictor of either lung volume may have been due to the subject population. Only 22 of the 100 subjects tested were smokers with an average smoking history of 15.45 pack years.

The failure of chest depth as a significant predictor of either lung volume may have been attributed to the fact that only male subjects were tested. In a study conducted on only women subjects chest depth

was reported as a significant predictor of RV (Cox, 1989). In contrast to the findings of Cox (1989), Boren et al. (1966) has stated chest measurements are "of no additional value in predicting lung compartments" (p. 103). However, since Boren et al. (1966) only used male subjects it may be concluded that chest measurements are only applicable to lung volume predictions if used for female subjects.

This study also compared body density and percent body fat arrived at by the FRC and RV lung volume maneuvers in the HW procedure. There was no significant difference ($p>.05$) between HW determinations of body density using the two lung volumes. There was, however, a significant difference ($p<.05$) between the two lung volumes in the determination of percent body fat. Although the percent body fat difference between the two methods was slight (.54%), it suggests that if FRC is to be used as an alternative to HW at RV in research or clinical settings it should be measured simultaneously with underwater weight, as recommended by Thomas and Etheridge (1980).

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to develop formulas for the prediction of residual volume (RV) and functional residual capacity (FRC) while immersed. It was also the purpose of this study to compare body density and percent body fat determined in the hydrostatic weighing (HW) procedure at the FRC and RV lung volume maneuvers.

A high test-retest correlation between trials of RV (r = .99) and FRC (r = .98) determinations via the closed circuit oxygen dilution technique suggested that reliable measures were taken.

The adequacy of the developed RV and FRC prediction formulas were proven by multiple correlation coefficients (R square) of .72 and .41, respectively. These values were higher than those reported by prediction formulas developed by Boren et al. (1966), Crapo et al. (1982), and Grimby and Soderholm (1963). The formulas developed in this study resulted in a lower standard error of the estimation (S.E.E. of 241 and 403 mls for RV and FRC, respectively) than all the previously published formulas.

This study also applied the data obtained from the subjects to four previously published prediction formulas, as well as to the formulas developed in this study. Significant differences ($p<.05$) were found between the RV prediction formulas of Crapo et al. (1982) and Goldman and Becklake (1959) when compared to the RV prediction formula

developed in this study. Significant differences ($p<.05$) were also determined between all of the previously published FRC prediction formulas when compared to the FRC prediction formula developed in this study. This suggests the need to measure this lung volume while immersed if it is to be used in the HW procedure.

The formulas developed in the present study for the prediction of immersed RV and FRC are as follows:

RV (liters) = .0260376(Age) + .0256005(Ht) - 3.89794

FRC (liters) = .0493365(Ht) + .0116958(Age) - .00919313(Wt) - 6.20966

Note. Age = years. Ht = Height(cm). Wt = Weight(kg).

All subjects were HW at the FRC and RV lung volumes. Body densities and percent body fats were calculated for each lung volume and tested for significant differences. Significant differences ($p<.05$) between percent body fat at the FRC and RV lung volume maneuvers were determined. However, the .54% difference was judged to be within the measurement error associated with the HW procedure. There was no significant difference ($p>.05$) between HW determinations of body density using the FRC and RV lung volume maneuvers. It was concluded that although the use of HW at FRC (as measured immersed) for percent body fat determination may be acceptable in the practical setting, it may be inadequate for research purposes. It is suggested that if a more comfortable lung volume is desired without sacrificing extreme accuracy in the HW procedure then FRC should be measured simultaneously with

underwater weight, as described by Thomas and Etheridge (1980).

Conclusions

The results of this study support the following conclusions:

1. Age and height were significant predictors of RV. The null hypothesis was rejected. Weight, chest depth, and smoking history were not significant predictors of RV. The null hypothesis could not be rejected for these characteristics.

2. Age, height, and weight were the best predictors of FRC. The null hypothesis was rejected. Chest depth and smoking history were not significant predictors of FRC. The null hypothesis could not be rejected.

3. There was a significant correlation between trials for the closed circuit oxygen dilution technique of RV and FRC determinations. The null hypothesis was rejected.

4. Utilizing the data from this study, there were significant differences between the RV prediction formulas of Crapo et al. (1982) and Goldman and Becklake (1959) and RV values based on the formula developed in this study. The null hypothesis was rejected.

5. There were no significant differences between RV values predicted by the formulas of Boren et al. (1966) and Grimby and Soderholm (1963) and RV predicted by the formula developed in this study. The null hypothesis could not be rejected.

6. Utilizing the data from this study, there were significant differences between the FRC prediction formulas of Boren et al. (1966), Crapo et al. (1982), Goldman and Becklake (1959), and Grimby and

Soderholm (1963). The null hypothesis was rejected.

7. There was no significant difference in body density in the subjects tested using the FRC and RV lung volume maneuvers in the HW procedure. The null hypothesis could not be rejected.

8. There was a significant difference in percent body fat in the subjects tested using the FRC and RV lung volume maneuvers in the HW procedure. The null hypothesis was rejected.

Recommendations

Based on the findings of this study the following recommendations were made:

1. Use another group of male subjects to evaluate the accuracy of the developed formulas against an outside population.

2. Compare calculated body density and percent body fat differences using the residual volume formula developed in this study against the actual measured residual volume.

3. Compare calculated body density and percent body fat differences using the functional residual capacity formula developed in this study against the actual measured functional residual capacity.

4. Further research is needed to determine the influence of hydrostatic forces on total lung capacity if it is to be used in the hydrostatic weighing procedure.

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APPENDICES

APPENDIX A

INFORMED CONSENT FORM

Informed Consent Form

I,_____ have agreed to volunteer to be a subject in this research study. My participation in this study involves breathing into a specially designed apparatus to determine the amount of air remaining in my lungs after a normal and maximal exhalation. My height, weight, and chest depth will be measured and I will also complete a questionnaire regarding cardiac and respiratory disorders, age, and smoking history. The purpose of this thesis is to develop a prediction equation for functional residual capacity and residual volume from the characteristics of age, height, weight, chest depth, and smoking history. It is also the purpose of this thesis to establish a more comfortable lung volume used in body fat determination from underwater weighing.

The possible risks that may occur in this study are dizziness, nausea, possible electrocardiographic (EKG) changes due to forced expiration or slight discomfort due to total immersion while at the end of a maximal exhalation. Instruments will be sterilized and cleaned prior to testing, but the possibility of infection always exists. In addition, there exists the possibility of injury as a result of slipping or falling upon entrance into the underwater weighing tank.

I have read the above information, and I have been fully advised of the nature of the procedure and what is expected of a participant in this study. I am aware of the possible risks involved and that I may withdraw from this study at any time.

In signing this consent form, I hereby release the University of Wisconsin - La Crosse, the La Crosse Exercise and Health Program, the Human Performance Laboratory employees and students engaged in my evaluation process from any and all legal liability associated with the above described procedures.

To my knowledge, I am not limited by any condition(s) that would affect my ability to participate in this study.

Signed _____ Date _____

Witness _____ Date _____

I, _____ (parent or guardian) of the above-named subject have read the experimental consent form and do hereby consent to said procedure.

Signed _____ Witness _____

APPENDIX B

SUBJECT QUESTIONNAIRE

Subject Questionnaire

Name _____ (please print) Date _____

Parent and/or Guardian (if under 18 years) _____

Address _____

Telephone # (home) _____ (work) _____

Age _____ (at last birthday) Height _____ (inches)

1. Date of Birth _____ (month/day/year)
2. Do you have any respiratory disorders such as asthma, bronchitis, or tuberculosis? YES _____ NO _____
3. Have you ever had heart surgery of any kind or had a heart attack?

   YES _____ NO _____
4. Do you or have you ever smoked? YES _____ NO _____

   If yes, how many packs per day do/did you smoke? _____

   If yes, how many years have/had you smoked? _____
5. Are you apprehensive about holding your breath while completely submerged in water? YES _____ NO _____
6. Do you have any other condition(s) that the investigator should be aware of? If so, please explain: _____

   _____

APPENDIX C

DATA RECORD SHEET

Data Record Sheet

A. Anthropometry

Dry Weight _____ lb _____ kg Height _____ cm

Chest Depth ∅1 _____ cm ∅2 _____ cm ∅3 _____ cm Avg. _____

B. Vital Lung Capacity ∅1 _____ L ∅2 _____ L

C. Smoking History: smoker ____ non-smoker ____ ex-smoker ____

packs/day ____ years smoked ____ pack x years = _____ pack years

D. Residual Volume	Trial 1	Trial 2	Trial 3
Bag Volume of Oxygen (BV)			
Alveolar Nitrogen (AN)			
Impurity Nitrogen (IN)			
Equilibrium Nitrogen (EN)			
Final Nitrogen (FN)			
RV (L)			

E. Functional Residual Capacity	Trial 1	Trial 2	Trial 3
Bag Volume of Oxygen (BV)			
Alveolar Nitrogen (AN)			
Impurity Nitrogen (IN)			
Equilibrium Nitrogen (EN)			
Final Nitrogen (FN)			
FRC (L)			

F. Immersed Weight (water temp _____ C)

FRC 1_____ 2_____ 3_____ 4_____ 5_____ 6_____ 7_____

Avg. _____ kg

RV 1_____ 2_____ 3_____ 4_____ 5_____ 6_____ 7_____

Avg. _____ kg