ABSTRACT

RUSSELL, Donna D. A new formula for the prediction of residual volume in females. M.S. in Adult Fitness/Cardiac Rehabilitation, 1987. 59pp. (P. J. Buckenmeyer)

The purpose of this investigation was to develop a new prediction equation for residual volume (RV) in females, based on measurements using the closed circuit, oxygen dilution method. A sample population of 124 females, from 10 to 82 years of age, was selected so that there were 20 subjects (Ss) in each age decade. The physical characteristics of age, height (Ht), weight (Wt), smoking history (Sm), vital capacity (VC), and forced expiratory volume per second (FEV-1) were measured and subjected to stepwise regression analysis, resulting in the prediction equation:

$$RV\ (liters) = .029\ Age + .025\ Ht - .011\ Wt + .013\ Sm - 2.689.$$

The standard error of estimation (S.E.E.) of this equation (332 mls) compared favorably with previous equations for predicting RV in females reported by Crapo et al. (S.E.E. = 381 mls), Goldman and Becklake (S.E.E. = 360 mls), and Grimby and Soderholm. However, using the physical characteristics of the subjects from the present study, each of the previously published equations gave predictied RVs that were significantly ($p < .05$) different from both the actual predicted RVs and the RVs predicted by the new equation.

A New Formula for the Prediction

of Residual Volume in Females

A Thesis Presented

to

The Graduate Faculty

University of Wisconsin - La Crosse

In Partial Fulfillment

of the Requirements for the

Master of Science Degree

---

by

Donna D. Russell

July 1987

UNIVERSITY OF WISCONSIN - LA CROSSE
College of Health, Physical Education and Recreation
La Crosse, Wisconsin 54601

Candidate: Donna D. Russell

We recommend acceptance of this thesis in partial fulfillment

of this candidate's requirements for the degree:

Master of Science in Adult Fitness/Cardiac Rehabilitation

The candidate has completed her oral report.

Philip J. Buckenmeyer — 7/27/87
Thesis Committee Chairman — Date

Alan Freeman — 7/27/87
Thesis Committee Member — Date

Michael Olson — 7/27/87
Thesis Committee Member — Date

Jeffery C. Tesch — 7.27.87
Thesis Committee Member — Date

This thesis is approved for the College of Health, Physical Education and Recreation.

John C. Mitchem — July 29, 1987
Dean, College of Health, Physical Education and Recreation — Date

Howard E. Rose — July 30, 1987
Dean of Graduate Studies — Date

ACKNOWLEDGEMENTS

I would like to acknowledge the following people:

To Dr. Philip Buckenmeyer for his guidance and encouragement in the deliberation of this thesis.

To Dr. Allan Freeman for his support and friendship during the process of this thesis.

To Dr. Michael Olan for his clear explanations statistics.

To Jeffery Tesch for always being there with clear explanations and for his unending assistance during the preparations of this thesis.

To my family for their eternal love and confidence to help me push forward and realize my ability to accomplish anything.

DEDICATION

For Jody who I love dearly.

For Mom, Dad, and Jeanne
who are always there to help me through anything.

For Tonka, my loyal friend.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Several prediction formulas have been introduced for estimating residual volume. Residual volume is the volume of air remaining in the lungs after a maximum expiration. The importance of estimating residual volume is that it quite often provides a means of determining residual volume where equipment is not available to measure it directly. The direct means of measuring residual volume involves instructing the subject to exhale as much air as possible, at which time residual lung volume is remaining. Then by using a gas dilution method this residual volume air is diluted by a tracer gas and calculated by a simple mixture equation.

Indirect determination of residual volume involves measuring lung volumes other than residual volume for the calculation of residual volume (e.g. by subtracting expiratory reserve volume (ERV) from functional residual capacity (FRC). Estimating residual volume using prediction formulas based on easily measured physical characteristics (e.g. age, height, weight) has provided a convenient alternative to measuring residual volume (Boren,Kory, & Syner, 1966; Crapo et al., 1982; Goldman & Becklake, 1959; and Grimby & Soderholm, 1963). Several prediction formulas have been published for males (Boren et al., 1966; Crapo et al., 1982; Goldman & Becklake, 1959; Grimby & Soderholm, 1963;

and Weidman, 1986) and females (Crapo et al., 1982; Goldman & Becklake, 1959; and Grimby & Soderholm, 1963) to permit the estimation of residual volume.

The significance of residual volume is that it is the air which is present in the alveoli at all times to aerate the blood during the normal breathing cycle. If residual volume was not available the concentrations of carbon dioxide and oxygen in the blood stream would increase and decrease markedly with each breath (Guyton, 1986).

Measuring residual volume has several usages, one of them being the use of it when calculating body density. When calculating body density, corrections for the amount of residual volume remaining in the pulmonary tree after a maximal expiration should be made (Behnke, Feen, & Welham, 1942; and Wilmore, 1969a). Since there is a need to predict accurate body density to determine an individual's percent body fat, an accurate residual volume prediction is imperative.

Need for the Study

Only three equations were found for predicting residual volume in females. To derive the data used in the equations, "actual" residual volume was only directly measured in one equation, and indirectly measured using FRC and ERV in the other two equations. Actual residual volume was not measured by the oxygen dilution method in any of the published pediction equations (Crapo et al., 1982; Goldman & Becklake, 1959; and Grimby & Soderholm, 1963).

It is faster to estimate residual volume using a prediction equation than it is to measure "actual" residual volume. Otherwise, qualified operators to operate the costly equipment are necessary for the accurate measurement of residual volume. Many institutions rely on prediction formulas to predict residual volume (Boren et al., 1966; Crapo et al., 1982; Goldman & Becklake, 1959; and Grimby & Soderholm, 1963). These prediction formulas may have large estimation errors for certain populations due to a lack of a representative sample which was evenly distributed by age (Goldman & Becklake, 1959; and Grimby & Soderholm, 1963). One recent study developed a prediction formula using a representative male population that predicted residual volume in males (Weidman, 1986). A separate equation for the prediction of residual volume is needed for men and women (Boren et al., 1966; Crapo et al., 1982; Goldman & Becklake, 1959; Grimby & Soderholm, 1963). The development of a better prediction formula to estimate residual volume with a low standard error of estimation using a representative sample of female subjects is needed.

Purpose

The purpose of this study was to develop a formula for the prediction of residual volume in females. To develop this formula the physical characteristics of age, height, weight, smoking history, vital capacity, and forced expiratory volume in one second (FEV-1), were used as predictors of residual volume in 120 female subjects from the of age 10 to 69 years. This formula was then compared to the previously published prediction formulas for women.

Null Hypotheses

The null hypotheses of this investigation, provided below, were tested at a significance level of ($p < .05$):

1. There is no significant correlation of age, height, weight, smoking history, vital capacity, and FEV-1 singularly or in combination, to predict residual volume in females age 10 to 69;
2. There is no significant difference between the estimation of residual volume using the equation developed from this study and the estimation of residual volume from prediction formulas published in the past.
3. There is no significant difference between the actual residual volume of the volunteers and the residual volume estimated by the formula developed from this investigation.

Assumptions

Within the limits of this study the following assumptions were made:

1. Subjects completed the questionnaire honestly and thoroughly.
2. The apparatus used to measure the specific variables were accurate and consistent.
3. The participants maximally exhaled with their utmost ability for determination of residual volume.
4. The volunteers, to the best of their ability, exhaled as rapidly as possible for the determination of vital capacity and FEV-1.
5. The subjects did not exercise strenuously or eat a heavy meal prior to the testing.

Delimitations

The following were determined to be delimitations of this study:

1. All subjects were female.

2. Volunteers were free of any known respiratory disease.

2. The representative sample size for each group was to be a minimum of 20 individuals for each of the following age decade groups.

   Group 1 = 10 to 19 years of age
   Group 2 = 20 to 29 years of age
   Group 3 = 30 to 39 years of age
   Group 4 = 40 to 49 years of age
   Group 5 = 50 to 59 years of age
   Group 6 = 60 to 69 years of age

3. The participants were between 10 and 69 years of age.

4. Only age, smoking history, height, weight, vital capacity, and FEV-1 were used as factors which could contribute to residual volume prediction.

Definition of Terms

<u>BTPS</u>: The conditions of a gas in the lungs: Body temperature (37 degrees celsius), ambient pressure, and complete saturation with water vapor (Wilmore, 1969b).

<u>Body weight</u>: The total weight of an individual to the nearest pound, converted to kilograms by dividing the number of pounds by 2.205.

<u>Closed circuit method</u>: The method of rebreathing an indicator gas that is eventually diluted and an equilibrium is reached between the air in the lungs and the indicator gas (Wilmore, 1969b).

<u>Expiratory reserve volume</u> (ERV): The volume of air that can still be exhaled by a forceful exhalation after the end of a normal tidal expiration (Guyton, 1986).

<u>Forced expiratory volume performed in one second</u> (FEV-1): The volume of air measured when a maximum inspiration to total lung capacity, followed by a maximal expiration within one second period is performed (Guyton, 1986).

<u>Functional residual capacity</u> (FRC): The amount of air remaining in the lungs at the end of normal expiration: FRC = RV + ERV (Boren et al., 1966; and Guyton, 1986),

<u>Height</u>: The length of a person's body while standing without shoes, measured in inches from the top of the head to the soles of the feet, converted to centimeters by multiplying by 2.54.

<u>Hydrostatic weighing</u>: An indirect means of determining body density and subsequently amounts of fat and lean body components through underwater submersion of an individual (Wilmore, 1969a).

<u>Inspiratory reserve volume</u> (IRV): The additional volume of air that can be inspired above the normal end-inspiratory tidal volume (Guyton, 1986).

<u>Open circuit method</u>: A gas dilution method in which nitrogen is washed out of the lungs during a specified period by inhaling oxygen through one valve and then exhaling it through another valve (Wilmore, 1969b).

<u>Pack years</u>: The average number of packs of cigarettes smoked per day multiplied by the number of years smoked.

<u>Pneumatometric method</u>: The use of whole body plethysmograph to measure lung volume (Wilmore, 1969b).

<u>Residual volume</u> (RV): The volume of air remaining in the lungs after a maximal expiration (Guyton, 1986).

Smoking history: The number of cigarettes smoked by the volunteers, measured in pack years.

Spirometer: An apparatus consisting of a cylinder bell immersed in water and equipped with outlets so that gases can be "exhaled into" or "inhaled out of" it while measurements of volume are made.

Tidal volume (TV): The amount of air inspired or expired per normal breath (Guyton, 1986).

Total lung capacity (TLC): The maximum amount of air in the lungs after the greatest maximal inspiration: TLC = RV + VC (Boren et al., 1966; Guyton, 1986).

Vital capacity (VC): The maximum amount of air one can exhale after a maximum inhalation: VC = ERV + TV + IRV (Boren et al., 1966; Guyton, 1986).

CHAPTER II

RELATED LITERATURE

Introduction

In this chapter, a historical approach is used to discuss the various techniques for measuring residual volume. The correlations between physical characteristics and residual volume, and existing regression equations used to predict residual volume are also discussed.

Historical Approach to Measuring Residual Volume

Throughout the years a number of methods have been introduced for the indirect analysis of residual volume. Some methods are a modification of an earlier method, and others are new methodological approaches to measuring residual volume. These methods can be divided into three main groups proposed by Christie (1932) and Wilmore (1969b):

1. the pneumatometric approach.
2 the closed circuit approach (gas dilution with "forced breathing")
3. the open circuit approach (gas dilution without "forced breathing")

Dating back to 1800, Sir Humphrey Davy first defined residual volume as a quantity of air remaining after a maximum expiration (Lundsgaard & Van Slyke, 1918). Davy measured his own lung volume using a hydrogen dilution method (Wilmore, 1969b). In 1882, Pfluger described the pneumatometric method to measure lung volume (Boren et al., 1966). It was not until the early twentieth century that there were increased investigations dealing with compartmental lung volumes (Boren et al., 1966). These early twentieth century investigations used forced breathing techniques that were difficult to perform and were poorly reproducible, and had many sources of error (Boren et al., 1966; and Christie, 1932).

Originally described by Pfluger in 1882, the pneumatometric method, using whole body plethysmograph 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. The subject was placed in an airtight chamber and breathes to the outside through a mouthpiece. The air displaced from the chamber by the expansion and contraction of the chest was graphically recorded by means of a spirometer. With respiration completely obstructed, the subject was told to make a maximal respiratory effort against this absolute resistance. The resulting pressure in the respiratory tract was also recorded. From the relationship of the volume change to the pressure change, the volume of air in the lungs can be computed. This method involves cumbersome apparatus frought with technical difficulties, demanding more cooperation of the subject than can be given even by the healthiest individual (Christie, 1932; and Wilmore, 1969b).

In 1923, two authors described a method for determination of lung volumes without forced breathing (Van Slyke & Binger, 1923). These two authors originated a modern type of closed circuit gas dilution technique by devising a hydrogen dilution method. McMichael (1939) corrected considerable systematic error of Christié's (1932) quiet breathing oxygen dilution technique, by developing a modification of the hydrogen dilution technique later adapted for helium by Meneely and

Kaltreider (1949). The closed circuit method is based on the dilution of a known volume of gas (hydrogen or oxygen) by the air in the lungs. After a forced maximum expiration the subject is connected to a rebreathing bag, and then takes five to seven deep and rapid breaths from a rubber bag or spirometer containing a known volume of gas (e.g. hydrogen or oxygen) to attain an equilibrium with respect to the gas in the lungs and the gas in the remainder of the closed system. The closed circuit method was originally described by Davy in 1800 but has been modified numerous times. The method described above is a modification of the closed circuit method proposed by Lundsgaard and Van Slyke (Christie, 1932; Lundsgaard & Van Slyke, 1918; and Wilmore, 1969b).

In 1940, an open circuit nitrogen washout method was described which contrasted with the previous methods in which gases were brought to equilibrium in a closed circuit system (Darling, Gournand, & Richards, 1940). This technique seemed to be generally considered the "reference method" or "gold standard" to which other methods are compared. The open circuit method is based on washing the nitrogen out of the respiratory system with a known volume of gas (usually pure oxygen). This is accomplished by having the subject breathe quietly from a spirometer containing oxygen for five to seven minutes (Christie, 1932; and Wilmore, 1969b). In the late 1950's, DuBois and associates developed a lung volume measurement using body plethysmography by applying new precise pressure measurements to Pflugers pneumatometric technique (Boren et al., 1966).

There are changes in the nitrogen dissolved in the blood that affect the open and closed circuit methods of measuring residual volume. The more easily removable nitrogen (200-300 mls) under normal atmospheric pressure in the human body is constantly available to cross the interface between the blood and the alveoli, but is removed in a few minutes by breathing pure oxygen (Campbell & Hill, 1931; and Wilmore, 1969b). The amount of nitrogen released from the blood into the ventilation system within five to seven minutes of oxygen breathing during the open circuit method (65-200mls) is high enough to significantly alter the results of residual volume calculation. If repeated trials are needed in the open circuit technique then the subject would have to wait several minutes between trials to allow nitrogen levels in the lungs and blood to normalize.

Rahn, Fenn, and Otis (1949) stated that only an average of 4.2 mls of nitrogen would be released from the blood in three breaths over a ten second period. Similarly, Christie (1932) reported this value to be 10 to 12 mls of nitrogen for twenty seconds of hyperventilation. Even if there is a release of 20 mls of nitrogen during 15 to 20 seconds of hyperventilation needed to complete the closed circuit method, the resulting error would only be 20 to 30 mls, in which no correction factor is required (Christie, 1932; Rahn et al., 1949; Wilmore, 1969b).

The closed circuit and the open circuit methods are the primary techniques utilized to determine residual volume of the three methods described. The use of these two methods are less time consuming than the pneumatometric method regarding set-up, testing, and analysis (Wilmore, 1969b).

It has been documented that residual volume should be measured directly and not estimated using ERV and FRC values (Christie, 1932; and Wilmore & Behnke, 1968). Christie (1932), Motley (1957), and Wilmore (1969b) stated that there is a relatively large intraindividual variation in expiratory reserve volume (ERV). Christie (1932) reported that this variation in ERV results in a large fluctuation in functional residual capacity (FRC), thus altering the calculation of residual volume. Direct calculation of residual volume by a closed circuit method described by Wilmore resulted in a standard error of measurement of only 30 mls for females (Wilmore, 1969b). Wilmore (1969b) seems to have instituted a technique that was more accurate and reproducible than previously published methods. The validity of Wilmore's (1969b) closed circuit method was established by comparing it with the nitrogen wash-out (open circuit) method originated by Darling et al. (1940) and modified by Cournand, Baldwin, Darling, & Richards (1941). There was a correlation of $r = .96$, which is significantly ($p < .05$) high.

Physical Characteristics and Residual Volume

Prediction formulas for residual volume, have been developed based on physical characteristics of individuals. A discussion of the individual physical characteristics that have been previously studied follows.

Age and Residual Volume

Brožek (1960), reported a gradual increase of residual volume with aging due to the reduced elastic recoil of the lungs and thorax. He went on to state that residual volume values may be a tool in establishing the physiological age of an individual. Jones, Overton, Hammerlindl, and Sproule (1978) reported that the increase of residual volume with age involves both the upper and lower lung regions. Table 1 includes a summary of the correlations reported by prior researchers between age and residual volume.

Height and Residual Volume

In regards to height, each compartment of lung volume increases as height increases (Boren et al., 1966). Aitken, Schoene, Franklin, and Pierson (1985) extended the predicted calculations of pulmonary testing (including residual volume) to persons at the extremes of stature. Residual volume is generally smaller in females than males (Sloan & Bredell, 1973). Table 1 depicts the positive correlations reported.

Weight and Residual Volume

As Table 1 reveals, weight was reported as not significantly correlating with residual volume. Some authors did not mention any correlation of weight to residual volume in female subjects. The previously published studies did not use weight as a variable in the prediction of residual volume. One study did use weight as a predictor variable in their male equation (Grimby & Soderholm, 1963).

Smoking History and Residual Volume

Webster, Lorimer, Man, Woolf, and Zamel (1979) looked at the pulmonary function of identical twins. When one twin smoked and the other did not, the residual volumes they reported were different but not significantly ($p < .05$).

Table 1

CORRELATION BETWEEN PHYSICAL CHARACTERISTICS AND RESIDUAL VOLUME IN SELECTED STUDIES

Author	Age	Height	Weight	Smoking History	Vital Capacity	Forced Expiratory Volume
Boren et al.* (1966)	.20	.23	.17	+	.16	**
Brozek (1960)	.75′	+	**	**	**	**
Crapo et al. (1982)	+	+	**	**	**	**
Goldman & Becklake (1959)	.27	.42	.06	**	**	**
Grimby & Soderholm (1963)	+	+	**	**	**	**
Petersen, Lapp, & Amandus (1975)	**	**	+	**	**	**
York & Jones (1981)	**	**	**	+	**	**

Note: $p<.05$
*male subjects
+ positive correlation indicated but no data was provided
** no correlation reported
′correlation is between age and "relative residual air" (RV/TLC)x100

York and Jones (1981) stated that there was no significant ($p < .05$) difference in overall lung function between young smokers and nonsmokers, but that residual volume was significantly higher ($p < .05$) in the lower lung regions of the smokers. This study revealed that lung function (including residual volume) was disrupted in smokers. A pattern was observed similar to that of individuals with chronic obstructive lung disease. Table 1 reveals the data reported for the correlation between smoking history and residual volume.

Vital Capacity and Residual Volume

Brozek (1960) stated that in female subjects vital capacity decreased with age, thus since residual volume is known to increase with age, a strong relationship between residual volume and vital capacity would not be expected to exist. Rahn et al. (1949) discovered no constant relationship between the values of residual volume and vital capacity. Wilmore (1969a) has given his opinion that using vital capacity to predict residual volume would result in seriously questionable results. Table 1 summarizes the information on the correlation of vital capacity with residual volume.

Forced Expiratory Volume-1 and Residual Volume

The literature did not discuss any correlation of FEV-1 and residual volume in females. Boren et al. (1966) stated that there was no correlation between FEV-1 and residual volume. FEV-1 can be used as a lung volume measurement to screen individuals for respiratory dysfunction. Table 1 shows no reported correlations of FEV-1 to residual volume.

Summary of Physical Characteristics

All the physical characteristics excluding FEV-1 were shown to correlate to some degree with residual volume (see Table 1). The interrelationship between the variables and residual volume can be delineated in a stepwise multiple regression analysis, producing an equation to predict residual volume.

Residual Volume Prediction Formulas

Prediction formulas have been published in the past. In this section these prediction formulas will be discussed.

Table 2 summarizes the several important aspects of formulas for female subjects developed by different authors. The method used to determine actual residual volume is presented. Also included in Table 2 is the standard error of estimation of each equation and the correlation coefficient reported by the author.

Goldman and Becklake (1959) developed a formula using the physical characteristics of age (years) and height (cm) as predictors of residual volume. The actual residual volume values were achieved by subtracting expiratory reserve volume (ERV) from functional residual capacity (FRC). ERV was directly measured using spirometry and FRC was measured by the closed circuit hydrogen dilution method (McMichael, 1939).

Grimby and Soderholm (1963) developed a prediction formula for women using the characteristics of age (years) and height (cm) to estimate residual volume. Residual volume values were calculated by determining FRC (helium dilution method) and subtracting ERV (spirometry).

Crapo et al. (1982) published a prediction equation for nonsmokers. The equation developed for females involved age (years) and height (cm) as the predictor variables. Direct measurement of residual volume was done using a single breath helium dilution technique.

Table 2

ASSESSMENT OF PREDICTION FORMULAS

Author	Variables Used	Method of Residual Volume Determination	Standard Error of Estimation	Multiple Correlation Coefficient
Goldman & Becklake (1959)	Age (years) Height (cm)	FRC - ERV	360 mls	.55
Grimby & Soderholm (1963)	Age (years) Height (cm)	FRC - ERV	*320 mls	**
Crapo et al. (1982)	Age (years) Height (cm)	helium dilution method	381 mls	.69

Note: $p<.05$
* value was reported as the "residual standard deviation"
** no value was reported

When body fat is estimated from body density by the method of hydrostatic weighing, the error produced by assuming a mean pulmonary residual volume for young women is considerably greater than that due to errors in measurement of pulmonary residual volume (Sloan & Bredell, 1973). When body density, percent body fat, or lean body weight assessment are used for research purposes, and precision is required, then it would be crucial to directly measure residual volume (Wilmore, 1969a).

Summary

Residual volume cannot be measured simply by spirometry and the method of measurement influences the accuracy of the calculation. The methods available to measure residual volume are plethysmography, tracer gas dilution (closed circuit), or nitrogen washout (open circuit) (Christie, 1932; and Wilmore, 1969b). The reviewed literature suggested that the closed circuit oxygen dilution method seemed to be the fastest, and does not allow time for enough nitrogen from the blood to cross over into the alveoli to significantly alter the results.

Accurate residual volume measures by the closed circuit method are unattainable when determining residual volume in individuals suffering from pulmonary dysfunction. When a subject, because of weakness or respiratory disturbance cannot increase depth of respiration, considerable time is needed for complete mixture of the gases in the lungs. The volume of the lungs subsequently changes, due primarily to the difference between releasing of carbon dioxide and absorption of oxygen. Therefore, only persons not suffering from respiratory disorders should be assessed for residual volume by the closed circuit method (Hackney & Deutsch, 1985; and Sloan & Bredell, 1973).

The physical characteristics mentioned which are related to residual volume, are age (Boren et al., 1966; Brozek, 1960; Crapo et al., 1985; Goldman & Becklake, 1959; Grimby & Soderholm, 1963; and Jones et al., 1978), height (Aitken et al., 1985; Boren et al., 1966; Crapo et al., 1982; Goldman & Becklake, 1959; Grimby & Soderholm, 1963), weight (Boren et al., 1966; Crapo et al., 1982; Goldman & Becklake, 1959; Grimby & Soderholm, 1963; and Petersen, Lapp & Amandus, 1975), smoking history (Boren et al., 1966; Webster et al., 1979; and York & Jones, 1981), and vital capacity (Boren et al., 1966; Brozek, 1960; and Wilmore, 1969a). A correlation between FEV-1 and residual volume was not reported in the literature reviewed. The characteristics that are correlated with residual volume can be placed in a multiple regression equation for the prediction of residual volume. The S.E.E. and correlation coefficients for the regression equations to predict residual volume in females that have been developed (Boren et al., 1966; Crapo et al., 1982; Goldman & Becklake, 1959; and Grimby & Soderholm, 1963) are presented in Table 2.

In conclusion, a prediction formula, developed using multiple regression, to estimate residual volume from physical characteristics of females is needed. The formula would hopefully correlate well with the actual residual volume calculated using the closed circuit oxygen dilution technique.

CHAPTER III

METHODS

Introduction

Included in this chapter is a description of the process of subject selection, and vital statistics. Details of the instrumentation, and the procedures used to collect the measurements, and processing of the data are included. Also, the statistical analysis of the data is described in this chapter.

Subjects

One hundred twenty female volunteers from Wisconsin, Minnesota, and Iowa were subjects in this study. Their ages ranged from 10 to 69 years. The subjects were divided into six groups, of twenty persons each based on age;

Group 1 = 10 to 19 years of age
Group 2 = 20 to 29 years of age
Group 3 = 30 to 39 years of age
Group 4 = 40 to 49 years of age
Group 5 = 50 to 59 years of age
Group 6 = 60 to 69 years of age

The subjects used in this study were of varying heights and body weights. Subjects suffering from respiratory dysfunction were excluded from this study using FEV-1 measurements as a screening criterion.

Instruments

The instruments used for data collection in this study were:

Anthropometer: A GPM Model 101 anthropometer (Seritex Inc., Carlstadt, NJ) was used for height determination in centimeters of the subjects standing without shoes.

Questionnaire: All subjects were required to complete a personal questionnaire (Appendix B) inquiring about date of birth, respiratory and/or cardiac disorders, and smoking habits.

Single beam balance scale: A Health-O-Meter scale (Continental Scale Corp., Bridgeview, IL) was used to weigh subjects to the nearest pound. Subjects were wearing street clothes without shoes.

Spirometer: A 13.5 liter, water-filled spirometer (W.E. Collins Corp., Braintree, MA) was used in measuring vital capacity and forced expiratory volume to the nearest .01 liters.

Residual Volume Apparatus: A closed circuit oxygen dilution method (Wilmore, 1969b) was used to measure residual volume. The model 505D Nitralyzer (Med-Science St. Louis, MO) was used to determine the percentage of nitrogen. An Omniscribe (Houston Instruments, Houston TX) chart recorder, which graphically recorded the nitrogen fractions during rebreathing was attached to the Nitralyzer A 6-liter spirometer (W.E. Collins, Braintree, MA) was used to measure a volume of oxygen which was then transferred into a rubber bag for rebreathing. Oxygen volumes of approximately 5 liters were used for each subject and were measured to the nearest .01 liter for every trial.

Procedures

Subjects filled out an informed consent form (Appendix A) which was read and signed upon entering the laboratory. The consent form explained the procedures involved, expectations of the participant, possible risks involved, and an option to withdraw at anytime. The investigator answered all questions posed by the subject before initiation of the testing.

The volunteer was instructed to stand and take two to three normal breaths into a 13.5 liter water-filled spirometer. The subject was then requested to maximally inspire followed by maximally expiring that same breath as completely as possible for vital capacity and FEV-1 determinations. The two trials were calculated, by converting to liters from the number of millimeters of vertical deflection of the pen which recorded the movement of the spirometer bell. Each volume was then corrected to body temperature, total water vapor saturation and was then recorded on the data sheet (Appendix C).

For residual volume determination, a 6 liter spirometer bell was filled with approximately 5 liters of oxygen by an electronic dispensing valve. The spirometer and bag were filled and emptied at least 2 or 3 times to flush all gases out between trials. The spirometer was then filled with a final oxygen volume which was recorded for the subject's trial. The volumes of oxygen varied from 4.5 to 5.7 liters, depending on the trial, but were measured to the nearest .01 liter in all cases.

The spirometer volume was then emptied into a 6 liter rebreathing bag, thus filling the bag with the recorded amount of oxygen from the spirometer.

During residual volume determination each subject was seated with a noseclip and disposable mouthpiece in place. The subject was instructed to take two to four normal breaths and when ready, to deeply inhale. When she could no longer inspire air she was instructed to expire to her fullest possible capability. The investigator coached the subject during each phase. The subject was to raise an index finger when she felt she could no longer expire, indicating that only residual volume remained in the lungs. The tester then switched a valve which connected the subject to the rebreathing bag, full of oxygen, and instructed her to breathe in and out rapidly and deeply (with emphasis placed on "deeply"), until a nitrogen equilibrium between the subject's lungs and the rebreathing bag was attained. Equilibrium is never absolutely reached between the lungs and the rebreathing bag because nitrogen is always available from the bloodstream (Wilmore, 1969b). For purposes of this study, nitrogen equilibrium was said to be reached as soon as the difference between equilibrium nitrogen and final nitrogen was indistinguishable on the graphic printout. The values obtained from the test were inserted into a formula equivalent to that proposed by Wilmore (1969b) for the determination of residual volume:

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

Definition of terms:

RV = residual volume.

BV = rebreathing bag volume of oxygen.

AN = % of alveolar nitrogen.

IN = % of impurity nitrogen in oxygen of rebreathing bag before the onset of rebreathing.

EN = % of nitrogen in the rebreathing bag at equilibrium.

FN = % of nitrogen in expired air at equilibrium.

DS = .05 liters of dead space in tubes of the system and analyzer head.

1.1 = BTPS correction.

A minimum of three trials were measured for residual volume. The first trial was for training purposes. The succeeding trials were repeated until two trials had final nitrogen values within one and one-half percent of each other. No more than five trials were performed because of potential adverse affects due to fatigue and/or boredom. Between trials, the subject was asked to move around for at least three minutes to allow for the elimination of any excess oxygen remaining in the lungs after rebreathing. After the first trial, the subject filled out the personal questionnaire (Appendix B). Between the second and third trial the subject's height (anthropometer) and weight (single beam balance scale) were recorded without shoes. The values were recorded on the data recording form (Appendix C). All the residual volume trials were recorded on graph paper but only the two residual volume trials that came within one and one-half percent of each other were used for data analysis.

Statistical Analysis

Since the dependent variable in this study (residual volume) was expected to be influenced by several independent variables such as age, height, weight, smoking history, vital capacity, and FEV-1, the data collected in this study was processed using stepwise multiple regression using SPSSx software on a VAX-11/780 computer. To determine the importance of one or a group of independent variables, the following stepwise technique was used. A prediction formula was derived using only the independent variable which contributed the most to the accuracy of the model. One additional independent variable was added at each step, until no significant increase in R squared occurred. Any significant increase in the multiple coefficient of determimation, R squared, due to the inclusion of an independent variable, indicates the importance of including that variable into the prediction equation.

The resulting formula excluded the independent variables which did not significantly improve the equation for predicting residual volume. T-tests were used to determine whether a significant difference

($p < .05$) existed between the results obtained from applying the new formula and the previously published formulae to the sample data obtained in this study. Similar tests were used to compare all formulas to the actual residual volume.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The data collected for the prediction of residual volume are presented in this chapter. The data was processed using a stepwise multiple regression formula. The previously published formulas were compared to the prediction formula developed from this study. In addition, prediction residual volumes from all the prediction formulas were compared to the actual residual volume obtained from the volunteers who participated in this study.

Subject Characteristics

One hundred twenty-four females from the age of 10 to 82 years were participants in this investigation. Six groups of 20 subjects per age decade were studied. Four additional women, who were 70, 71, 72, and 82 years old, were included in the study even though they were older than the highest age group (60-69 years of age). The characteristics of age, height, weight, FEV-1, vital capacity , smoking history, and residual volume for the subject population are summarized in Table 3. Dismissing the first trial for all subjects as a training trial, a mean residual volume was obtained by averaging two residual volume values per subject. These replicate trials were required to be within 10% of each other.

Table 3

CHACTERISTICS OF THE SUBJECT POPULATION

Variable	Mean	Standard Deviation	Standard Error of the Mean
Age(years)	40.86	18.20	1.634
Height(cm)	163.36	8.76	.787
Weight(kg)	65.71	13.84	1.243
Forced Expiratory Volume-1(liters)	2.43	.71	.064
Vital Capacity (liters)	3.37	.74	.066
Smoking History (pack-years)	2.61	8.70	.782
Residual Volume (liters)	1.82	.74	.067

Note n=124

Table 4 depicts the correlation of the independent variables with each other and with the dependent variable. Independent variables with high positive or negative correlations to the actual (measured) residual volume are good candidates for inclusion in a reduced prediction formula.

Table 4

INTERCORRELATION MATRIX OF VARIABLES

	Residual Volume	Forced Expiratory Volume-1	Vital Capacity	Age	Height	Weight	Smoking History
Residual Volume	1.00	-.15	-.14	.66	.31	.21	.28
Forced Expiratory Volume-1	-.15	1.00	.69	-.34	.45	-.00	-.16
Vital Capacity	-.14	.69	1.00	-.36	.59	-.01	-.12
Age	.66	-.34	-.36	1.00	.09	.46	.15
Height	.31	.45	.59	.09	1.00	.30	.12
Weight	.21	-.00	-.01	.46	.30	1.00	.02
Smoking History	.28	-.16	-.12	.15	.12	.02	1.00

Note n=124

The Prediction Formula

The raw data obtained in this investigation was reviewed comprehensively and singularly to establish the effects of the independent variables on the dependent variable using a stepwise regression form of analysis. Age, FEV-1, VC, height, weight, and smoking history were evaluated to determine their effects on the prediction of residual volume. The results are listed in Appendix D. The results of the stepwise regression steps are summarized in Table 5.

The increasing values of adjusted R squared quantify the degree of effectiveness of the prediction equation as more independent variables are included.

R squared (Table 5), when expressed as a percentage, describes the percentage of variance accounted for by the independent variable(s) in the prediction of residual volume. The inclusion of vital capacity and FEV-1 did not significantly increase ($p < .05$) the accuracy of the prediction equation.

Table 5

SUMMARY OF STEPWISE REGRESSION STEPS

Step	Multiple R	Multiple R squared	*Adjusted R square	Standard Error
1	.66	.43	.43	.562
2	.70	.50	.49	.532
3	.73	.53	.52	.515
4	.74	.55	.54	.505

* Note: R squared modified to recognize # of independent variables

Table 6 presents the results calculated when the raw data accumulated in this study is substituted into the new regression equations using from one to four predictor variables.

Table 6

NEW PREDICTION EQUATION WITH ONE, TWO, THREE, OR ALL FOUR OF THE PREDICTOR VARIABLES

Equation	Multiple Correlation Coefficient	Standard Error of Estimation
.028(Age)+.718	.66	.420
.026(Age)+.021(HT)-2.742	.70	.373
.030(Age)+.026(HT)-.012(WT)-2.926	.73	.349
.029(Age)+.025(HT)-.011(WT)+.013(SM)-2.689	.74	.332

Note: ($p<.05$)
Age = (years)
HT = height (cm)
WT = weight (kg)
SM = smoking history (pack-years)

Comparing the Prediction Formulas

Table 7 depicts the prediction equations and the reported standard error of estimation for the formulas of Crapo et al. (1982), Goldman and Becklake (1959), and Grimby and Soderholm (1963) compared to the equation developed in this study. The information provided in Grimby and Soderholm's (1963) investigation was insufficient for the determination of a standard error of estimation. Crapo et al. (1982), Goldman and Becklake (1959), and Grimby and Soderholm (1963) used men and women subjects thus developing separate prediction equations for the estimation of residual volume for each sex.

Table 7

STANDARD ERROR OF ESTIMATION FOR PREDICTION EQUATIONS FOR FEMALES

FORMULA		Standard Error of Estimation
Crapo et al. (1982)	0.0201(Age)+0.0197(HT)-2.421	.381
Goldman & Becklake (1959)	0.009(Age)+0.032(HT)-3.90	.360
Grimby & Soderholm (1963)	0.007(Age)+0.0268(HT)-3.42	*
Russell (1987)	0.029(Age)+0.025(HT)-0.011(WT)+0.013(SM)-2.689	.332

Note: ($p<.05$)
* value reported as the residual standard deviation, 320 mls
Age = (years)
HT = (cm)
WT = (kg)
SM = smoking history (pack-years)

The results of using the physical measurements obtained from this study in each of the previously published prediction equations to predict residual volume is compared to the actual measured residual volume (Table 8). A low standard error of estimation was observed when the prediction equation of Crapo et al. (1982) was applied to the data obtained in this study. This indicates that Crapo's (1982) equation predicts as well for the raw data obtained in this study (S.E.E. = .386) as it did for the raw data of their study (S.E.E. = .381).

Table 8

COMPARISON OF PREVIOUSLY PUBLISHED EQUATIONS
USING THE DATA OBTAINED IN THIS STUDY

Formula		Standard Error of Estimation
Crapo et al. (1982)	0.0201(Age)+0.0197(HT)-2.421	.386
Goldman & Becklake (1959)	0.009(Age)+0.0197(HT)-3.90	.505
Grimby & Soderholm (1963)	0.007(Age)+0.0268(HT)-3.42	.522

Note: ($p<.05$)
HT = height (cm)
Age = age (years)
WT = weight (kg)
SM = smoking history (pack-years)

The predicted residual volumes derived from the formulas of Crapo et al. (1982), Goldman and Becklake (1959), and Grimby and Soderholm (1963) were all significantly different ($p < .05$) from the predicted residual volumes derived from the prediction equation developed from this investigation (Table 9).

Table 9

PAIRED DIFFERENCE T-TEST COMPARING PREDICTIONS OBTAINED FROM NEW AND PREVIOUS EQUATIONS

	(Difference) Mean	Standard Deviation	Standard Error of the Mean	T
Crapo et al. (1982)	-.201	.209	.019	-10.68*
Goldman & Becklake (1959)	-.124	.362	.033	-3.80*
Grimby & Soderholm (1963)	-.575	.389	.035	-16.48*
Russell (1987)	----	----	----	-----

*Note: significant difference at p<.05

The predicted residual volumes from the new prediction equation and the previously published prediction equations were compared to the actual measured residual volumes of the subjects. The results summarized in Table 10 establish that the predicted residual volumes of Crapo et al. (1982), Goldman and Becklake (1959), and Grimby and Soderholm (1963) were all significantly different ($p < .05$) from the actual measured residual volumes. The predicted residual volume values of the new prediction formula was not significantly different from the actual residual volume at the .05 level.

Table 10

PAIRED DIFFERENCE T-TEST COMPARING ACTUAL AND PREDICTED RESIDUAL VOLUME

	(Difference) Mean	Standard Deviation	Standard Error of the Mean	T
Crapo et al. (1982)	-.201	.539	.048	-4.14*
Goldman & Becklake (1959)	-.124	.615	.055	-2.24*
Grimby & Soderholm (1963)	-.575	.631	.057	-10.15*
Russell (1987)	.000	.497	.045	0.00
Residual Volume	----	----	----	-----

*Note: significant difference at $p<.05$

<u>Summary</u>

Using the results obtained from the representative sample group tested in this investigation, a prediction equation for the estimation of residual volume in females was developed using age, height, weight, and smoking history as predictors. Vital capacity and FEV-1 did not significantly affect the prediction of residual volume; therefore, those variables were not used in the prediction equation. The residual volume predictions from the equations developed by Crapo et al. (1982), Goldman and Becklake (1959), and Grimby and Soderholm (1963) were significantly different from the residual volume predictions of the formula developed in this study when the raw data obtained from this study were used. The previously published formulas of Crapo et al. (1982), Goldman &

Becklake (1959), and Grimby & Soderholm (1963) resulted in predicted residual volumes that were also significantly different ($p < .05$) from the actual measured residual volumes. The standard error of estimation for Crapo et al. (1982) calculated using data obtained in this study was similar to that reported when using their own data. There was no significant difference found between the actual residual volume and the residual volume estimated from the new prediction formula. The standard error of estimation was lower for the prediction formula developed from this study when all four variables were used, than the prediction formulas of Crapo et al. (1982), Goldman and Becklake (1959), and Grimby and Soderholm (1963), all of which used only two variables.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of this study was to develop a formula, using stepwise regression, to predict residual volume in females over a wide age range, using the physical characteristics of age, height, weight, smoking history, vital capacity, and FEV-1. This investigation also used the data obtained in this study in three previously published prediction equations to determine differences in the standard error of the estimate as compared to the prediction equation developed in this study. The residual volumes predicted using the previously published formulas differed significantly ($p < .05$) from residual volumes predicted using the newly developed formula. There was no significant difference between the actual and predicted residual volumes derived from the formula developed in this study. There was a significant difference between the actual residual volume and the residual volume estimated by the previously published equations. The prediction formulas of Crapo et al. (1982), Goldman and Becklake (1959), and Grimby and Soderholm (1963) were observed to have higher standard errors of estimation than the formula developed in this study.

The regression equation developed in this investigation to predict residual volume is as follows:

$$
\begin{aligned}
RV\ (liters) = \ & 0.0289(age) \\
& +0.0247(height) \\
& -0.0112(weight) \\
& +0.0126(smoking\ history) \\
& -2.6890
\end{aligned}
$$

Conclusions

1. Age, height, weight, and smoking history were the only significant ($p < .05$) predictors of residual volume. The null hypothesis was rejected. Vital Capacity and FEV-1 were not predictors of residual volume. The null hypothesis could not be rejected for these characteristics.
2. There was a significant difference ($p < .05$) between the residual volumes obtained from the previously published prediction equations (Crapo et al., 1982; Goldman & Becklake, 1959: Grimby & Soderholm, 1963) and the prediction equation derived in this study. The null hypothesis was rejected.
3. There was no significant difference between the actual residual volume and the estimated residual volume determined by the prediction formula developed in this study. The null hypothesis could not be rejected.

Recommendations

Based upon the conclusions derived in this study, the following recommendations are suggested:

1. Using a more uniform distribution sample of female smokers and non-smokers to test the accuracy of this new formula.
2. Test the accuracy of this new formula using sedentary and trained athletes as subjects.
3. Using this new formula to predict residual volume and by using actual residual volume values placed in body density equations, compare calculated body percentage differences.
4. Develop a prediction formula for residual volume using the closed circuit oxygen dilution method with pregnant females as the subjects.
5. Develop a specific prediction formula or test the accuracy of this study's formula for females 69 years of afe and older.

REFERENCES CITED

Aitken, M. L., Schoene, R. B., Franklin, J., & Pierson, D. J. (1985). Pulmonary function in subjects at the extremes of stature. American Review of Respiratory Disease, 131, 166-168.

Behnke, A. R., Feen, B. G., & Welham, W. C. (1942). The specific gravity of healthy men. The Journal of the American Medical Association, 118(7), 495-498.

Boren, H. G., Kory, R. C., & Syner, J. C. (1966). The vererans administraion-army cooperative study of pulmonary function: II. The lung and its subdivisions in normal men. The American Journal of Medicine, 41, 96-114.

Brozek, J. (1960). Age differences in residual lung volume and vital capacity of normal individuals. Journal of Gerentology, 15, 155-160.

Campbell, J. A., & Hill, L. (1931). Concerning the amount of nitrogen gas in the tissue and its removal by breathing almost pure oxygen. Journal of Physiology, 71, 310-322.

Christie, R. V. (1932). The lung volume and its subdivision: I. Methods of measurement. Journal of Clinical Investigation, 11, 1099-1118.

Cournand, A., Baldwin, E. D., Darling, R. C., & Richards, P. W. (1941). Studies on intrapulmonary emptying rate and a simplified open circuit measurement of residual air. Journal of Clinical Investigation, 20, 681-689.

Crapo, R. O., Morris, A. H., Clayton, P. D., & Nixon, C. R. (1982). Lung volumes in healthy nonsmoking adults. Bulletin of European Physiopathology of Respiration, 18(1-4), 419-425.

Darling, R. C., Cournand, A., & Richards, P. W. (1940). Studies on the intrapulmonary mixture of gases: III. An open circuit method for measuring residual air. Journal of Clinical Investigations, 19, 609-618.

Goldman, H. I., & Becklake, M. R. (1959). Spirometric studies in normal Subjects: III. Static lung volumes and maximum voluntary ventilation in adults with a note on physical fitness. Acta Medica Scandinavica, 173, 199-206.

Grimby, G. & Soderholm, B. (1963). Spirometric studies in normal subjects: III. static lung volumes and maximum voluntary ventilation in adults with a note on physical fitness. Acta Medica Scandinavica, 173, 199-206.

Guyton, A. C. (1986). Textbook of Medical Physiology, (7th Ed.) Philadelphia: N. B. Saunders Company.

Hackney, A. C., & Deutsch, D. T. (1985). Accuracy of residual volume prediction - effects on body composition estimation in pulmonary dsyfunction. Canadian Journal of Applied Sport Sciences, 10(2), 88-93.

Jones, R. L., Overton, T. R., Hammerlindl, D. M., & Sproule, B. J. (1978). Effects of age on regional residual volume. Journal of Applied Physiology, 44(2), 195-199.

Lundsgaard, C., & Van Slyke, D. D. (1918). Studies of lung volumes: I. Relationship between thorax size and lung volume in normal adults. Journal of Experimental Medicine, 27, 65-86.

McMichael, J. (1939). A rapid method of dtermining lung capacity. Clinical Science, 4, 167-173.

Meneely, G. R., & Kaltrieder, N. L. (1949). The volume of the lung determined by helium dilution. Description of the method and comparison with other procedures. Journal of Clinical Investigation, 28, 129-139.

Motley, H. L. (1957). Comparison of a simple helium closed-circuit method with an oxygen open-circuit method for measuring residual air. American Review of Tuberculosis, 76, 601-615.

Petersen, M. R., Lapp, N. L., & Amandus, H. E. (1975). The relationship of several ventilatory capacities and lung volumes to age, height, and weight. Journal of Occupational Medicine, 17, 355-356.

Rahn, H., Fenn, W. O., & Otis, A. B. (1949). Daily variations of vital capacity, residual air, and expiratory reserve including a study of the residual air method. Journal of Applied Physiology, 1, 725-736.

Sloan, A. W., & Bredell, G. A. G. (1973). A comparison of two simple methods for determining pulmonary residual volume. Human Biology, 45, 23-29.

Van Slyke, D. D., & Binger, C. A L. (1923). The determination of lung volume without forced breathing. Journal of Experimental Medicine, 37, 457-470.

Webster, P. M., Lorimer, E. G., Man, S. F. P., Woolf, C. R., & Zomel, N. (1979). Pulmonary function in identical twins: Comparison of nonsmokers and smokers. <u>American Review of Respiratory Disease</u>, <u>119</u>, 223-228.

No Luth.

Weidman, D. A., (1986). A new formula for the prediction of residual volume. M.S. (P. J. Buckenmeyer) 44pp.

Wilmore, J. H. (1969). The use of actual, predicted, and constant residual volumes in the assessment of body composition by underwater weighing. <u>Medicine and Science in Sports</u>, <u>1</u>(2), 87-90.

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

Wilmore, J. H., & Behnke, A. R. (1968). Predictability of lean body weight through anthropometric assessment in college men. <u>Journal of Applied Physiology</u>, <u>25</u>(4), 349-355.

York, E. L., & Jones, R. L. (1981). Effects of smoking on regional residual volume in young adults. <u>Chest</u>, <u>79</u>(1), 12-15.

micro

APPENDICES

APPENDIX A

INFORMED CONSENT FORM

A New Formula for the Prediction of Residual Volume in Females

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 spirometer device used for measuring lung volume. This device will measure the amount of air remaining in my lungs after a maximal expiration. My height and weight will be measured and I will complete a questionnaire regarding respiratory and cardiac disorders, age, and smoking history. The purpose of this thesis is to see if there is any correlation between the values for residual volume obtained from the spirometer device and those obtained from using age, height, weight, smoking history, vital capacity, and FEV-1 in a prediction equation for residual volume.

The potential risks that may occur are light headedness, neausousness, or possible electrocardiographic (EKG) changes due to forced respiration. With all types of spirometry devices there is the chance of infection. Instruments will be sterilized and replaced prior to testing to insure safety and health.

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 the study at anytime.

In giving my informed consent by signing this document, I hereby release the University of Wisconsin-La Crosse, the La Crosse Exercise and Health Program, the Human Performance Laboratory and employees and students engaged in the 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 perform in this study.

Signed ______________________________ Date ______________________

Witness _____________________________ Date ______________________

I, ____________________________ (parent or guardian) of the above-named subject, have read the informed consent stated above and I hereby consent to said procedure.

Signed ____________________________ Witness ______________________

APPENDIX B

QUESTIONNAIRE

QUESTIONNAIRE

NAME ______________________ DATE ______________________

1. DATE OF BIRTH ______________________

2. YOU WERE ____ YEARS AT YOUR LAST BIRTHDAY.

3. DO YOU CHRONICALLY SUFFER FROM ANY RESPIRATORY DISORDERS SUCH AS ASTHMA, TUBERCULOSIS, OR BRONCHITIS? YES ___ NO ___

   IF YES WHICH ONE AND WHEN WAS IT DIAGNOSED. ______________

   ____

4. HAVE YOU EVER EXPERIENCED A CARDIAC INCIDENT, HEART SURGERY, OR ANGIOPLASTY? YES ___ NO ___

5. DO YOU OR HAVE YOU EVER SMOKED? YES ___ NO ___

   IF YES, WHEN DID YOU HAVE YOUR LAST CIGARETTE? ______________

   HOW MANY PACKS PER DAY DO/DID YOU SMOKE? ______________

   THE NUMBER OF YEARS YOU HAVE/HAD SMOKED. ______________

APPENDIX C

DATA RECORDING FORM

DATA RECORDING FORM

Subject ______________________ Date ________________________

A. Dry weight _____lb. _____kg. Height _____in. ______cm.

B. Age ______years.

C. Vital capacity #1____mm #2____mm FEV-1 #1____mm #2____mm

____L ____L ____L ____L

D. Residual volume	Trial 1	Trial 2	Trial 3	Trial 4
Volume of oxygen used	______L	______L	______L	______L
Alveolar nitrogen(AN)	______%	______%	______%	______%
Impurity nitrogen(IN)	______%	______%	______%	______%
Equilibrium nitrogen(EN)	______%	______%	______%	______%
Final nitrogen(FN)	______%	______%	______%	______%

E. Smoking history: smoker ____ non-smoker ___ ex-smoker ___

Packs smoked/day ____ # years smoked ____ Packs x years ____pack years

F. Results:

Residual lung volume (average) ______________________L(to .01)

FEV-1 (average) ______________________L(to .01)

Vital capacity average ______________________L(to .01)

Age ______________________years

Height ______________________cm

Weight ______________________kg

Smoking history ______________________pack-years

APPENDIX D

STEPWISE REGRESSION OF VARIABLES FOR THE PREDICTION OF RESIDUAL VOLUME

STEPWISE REGRESSION OF VARIABLES FOR THE PREDICTION OF RESIDUAL VOLUME

VARIABLE	B	S.E. B	BETA	T	SIG T
step 1					
Age	.026945	.002786	.658779	9.672	.0000
Constant	.717970	.124515	-----	5.766	.0000
step 2					
Age	.026045	.002647	.636791	9.839	.0000
HT	.021406	.005498	.251976	3.893	.0002
Constant	-2.741989	.896499	-----	-3.059	.0027
step 3					
Age	.030037	.002878	.734378	10.435	.0000
HT	.026369	.005565	.310401	4.738	.0000
WT	-.012013	.003953	-.223345	-3.039	.0029
Constant	-2.926453	.869580	-----	-3.365	.0010
step 4					
Age	.028921	.002865	.707089	10.096	.0000
HT	.024664	.005510	.290335	4.476	.0000
WT	-.011189	.003895	-.208018	-2.872	.0048
Smoke	.012614	.005350	.147499	2.358	.0200
Constant	-2.689415	.859415	-----	-3.129	.0022