Determination of Body Density in Prepubescent Males, Age 7-11

A Thesis Presented

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Master of Science Degree

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Abstract

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The purpose of this investigation was to develop a reliable technique for determining body density in prepubescent males, age 7-11. Reliability was assessed by test-retest of 41 prepubescent males ($\bar{X}$ age 9.3 years, SD ± 1.2). A mean body density value of 1.053 gm/cc (SD ± .011) was found during both trials. A correlated t test revealed no significant difference (P > .05) between the two trials. A correlation of .99 was also observed between body density values of trial one and trial two. Validity was established by hydrostatically weighing 21 college-age students ($\bar{X}$ age 20.7 years, SD ± 1.4) both the standard technique and proposed modification. Mean body density values of 1.056 gm/cc (SD ± .017) and 1.057 gm/cc (SD ± .017) were found by these two techniques. A correlated t test revealed no significant difference between the two methods. A correlation of 1.00 between the body density values obtained by the two techniques was also reported.

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Chapter I

INTRODUCTION

The problem of obesity in children is a growing health concern. As will be discussed in subsequent pages, the presence of obesity during childhood greatly increases the risk of adult obesity (Johnson, Burke, & Mayer, 1956). A review of the literature, however, reveals that neither an accurate estimation or definition of the magnitude of this problem has been thoroughly researched. Garn, Clark, and Guire (1975) reported that two pertinent aspects of this problem must be considered: first is the accurate and objective identification of the individual cases of obesity; and second, is the estimation of the incidence of obesity in this population.

Much of the previous research conducted in the area of body composition has investigated the problem of obesity after the onset of puberty (Garn et al., 1975). Relatively few attempts have been made to quantify or qualify body composition in prepubescent children.

Anthropometric measurements, somatotyping, and height-weight tables are the tools most investigators have used to assess the body build of children. Although these studies have provided us with valuable information, they have not been successful in accurately determining the body composition of this population.

The inability of most children to satisfactorily perform the respiratory maneuvers, mandated by the h drostatic weighing technique, is the predominant factor inhibiting investigations of children's body composition (Zuti, 1978; Pollock, 1979; personal communication). There are other methods which can be used to study this problem such as: potassium-40, gas dilution, isotopic dilution, etc. Compared to hydrostatic weighing, however, these techniques are more expensive and require a greater degree of technical expertise to operate, therefore, it is proposed that a modification of the standard hydrostatic weighing technique (Goldman & Buskirk, 1961) be utilized to assess the body composition of children.

Statement of the Problem

As a result of the inability of most children to properly perform the procedures dictated by hydrostatic weighing, an alternate method must be established. It was the purpose of this study to develop a reliable technique for determining body density in prepubescent males age 7-11.

Subproblem

Validity of the technique was established by hydrostatically weighing college age subjects by the standard and proposed modified hydrostatic weighing technique.

Delimitations

The population studied to determine reliability was delimited to males age 7-11 who resided in the La Crosse County area. The population studied to determine validity was delimited to college age students between the ages of 19-24 years who resided in the La Crosse County area. The subjects chosen were not on a random basis.

Limitations

In reference to this study, the following limitations must be recognized:

1. The subjects chosen were not selected on a random basis.
2. There was a relatively small number of subjects chosen to determine the validity (21) and reliability (41) of the proposed modified hydrostatic weighing procedures.
3. It was difficult to determine if the breathing maneuvers mandated by the proposed modified technique were performed correctly.

Assumptions

Within the limits of this study, it was necessary to make the following assumptions:

1. No significant body composition changes occurred between test 1 and test 2.
2. All subjects performed the necessary respiratory maneuvers to the best of their ability.
3. All subjects fasted for the required period of time prior to the test (4-6 hours).

Definition of Terms

Archimedes Principle: A body submerged in a fluid is buoyed up by a force equal the weight of the fluid displaced.

Densitometry: The science of assessing the density of the body.

Density: The mass per unit volume of a body (D=M/V), expressed as gm/cc.

Hydrostatic Weighing: The process of weighing a body underwater to determine the volume of the body.

Percent Body Fat: The percentage of total body weight that consists of adipose tissue or fat.

Prepubescent: Period in life before one becomes functionally capable of generation.

Residual Volume: The volume of air remaining in the lungs following maximal expiration.

Chapter II

REVIEW OF LITERATURE

Introduction

As discussed earlier, the standard technique for hydrostatic weighing described by Goldman and Buskirk (1961) is impractical for assessment of body composition in children. Accurate data could probably be obtained by this technique if a large number of trials were conducted. This would be necessary because as Katch (1968) demonstrated, there is a great amount of learning necessary to properly perform the standard hydrostatic weighing procedures. It is doubtful if there is always sufficient time to allow this learning to occur. Some of the alternate methods utilized by researchers have enabled us to make gross estimation of body composition in children as well as approximate the incidence of obesity at this age. These studies as well as other pertinent topics are reviewed in this chapter.

Review of Literature

Utilizing the Wetzel Grid classification of obesity (channel A_4 or over), Johnson et al. (1956) reported 10% of the 3,600 children studied to be "obese." It must be emphasized that the Wetzel Grid (Wetzel, 1941) requires only age, height, and weight to plot physical status. Garn et al. (1975) emphasized that these parameters may not accurately reflect the status of an individual.

One third of the overweight girls and almost half the overweight boys in the study conducted by Johnson et al. (1956) demonstrated a continued obesity throughout the course of their school years. This, one of the major findings of the study, lends support to the concept of persistent obesity. A child who is obese will have a propensity for continued obesity later in life.

A nine year study of the heights and weights of 98 obese children was conducted by Lloyd and Wolf (1961). These children attended a hospital for the obese for one year. Thereafter, yearly examinations were conducted. Supporting the data of Johnson et al. (1956), these researchers reported less than 25% of the original group had achieved a near normal weight within a 9 year period.

A consistent weight gain during the winter months was another observation noted by Johnson et al. (1956). They indicated this to be a result of decreased physical activity. This is supported by Parizkova (1963), who studied dynamic fluctuations in body composition with changes in physical activity. The primary conclusion of her investigation also indicated that intensity and duration of physical activity have a great influence on body composition of all age groups.

These studies have provided some insight into the problem of childhood obesity, however, they made no attempt to describe the true body composition of this population. De^cribed below are studies which address this topic.

Hydrostatic weighing of 214 healthy children age 9-16 years enabled Parizkova (1961) to determine their body density. No conversion was made from body density to percent body fat. This topic will be discussed in detail later. To estimate body fat, Parizkova (1961) proposed a correlation between skinfold thickness and body density. A scale of percent body fat was included to facilitate orientation and a nomogram was also constructed. However, the author did not indicate the formula used to obtain these values, nor did she present means or standard deviations for her data. This makes it difficult to generalize as to the body composition of her sample. She also did not describe the procedures followed to determine body density.

Despite the limitations of the above study, research conducted by Lohman, Boileau, and Massey (1975) supported Parizkova's findings. Utilizing potassium 40 (^{40}K) technique, these investigators found a mean value of 20.2% body fat in 162 boys age 6-13 years. Applying the nomogram developed by Parizkova (1961) to estimate percent fat for their subjects, these researchers reported a mean value of 19.5% for their subjects. This value closely approximates the 20.2% body fat obtained by their ^{40}K technique, thus lending support to the findings of Parizkova (1961). In close agreement with these results, Slaughter and Lohman

(1977) used the ^{40}K technique to measure the body composition of 45 boys age 7-12. A mean value of 22% body fat was reported.

Finally, in 1975 a comparison of densitometric, ^{40}K, and skinfold estimates of body composition was conducted (Cureton, Boileau, & Lohman) in 49 prepubescent boys. The calculated mean percent body fat for densitometric, ^{40}K, and skinfolds were reported to be 20%, 19.2%, and 21.5% respectively. Correlations ranging from .74 to .77 were found between these three methods. The authors attributed much of the discrepancy between methods to be due to technical rather than biological variation. It is interesting to note that these researchers followed the standard hydrostatic weighing procedures described by Goldman and Buskirk (1961). No modifications of the technique were reported. They also used the formula developed by Brozek, Grande, Anderson, and Keys (1963) to convert body density to percent fat.

Development of the Formula

Body Volume

Archimedes was the first to state the significance of the relationship of weight (W) to volume (V) ($\frac{W}{V}$ = Density). His principle stated that a body immersed in a fluid is acted on by a buoyancy force equal to the weight of the displaced fluid (Behnke, 1961). Stated another way, an object displaces a volume of water equal to volume of the object itself. Body volume can be calculated by utilizing the method of hydrostatic weighing. This is accomplished by subtracting the underwater weight from the dry weight, therefore:

(equation 1)

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

Density of the Water

Goldman and Buskirk (1961) pointed out that a correction factor must be determined for the density of the water at the time of the underwater weighing. This is necessary to obtain the exact volume corresponding to the mass of the water displaced by the body.

It was recommended by Goldman and Buskirk (1961) that the temperature of the water approximate that of the body (35-36° C). They also emphasize that adjustments could be made if this range was not comfortable for the subjects. Recording the water temperature and application of the corresponding density value result in the following equation:

(equation 2)

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

where:

D= Density

M_A = Mass in air

M_W = Mass in water

D_W = Density of water

Residual Volume

Contributing to the measured volume is the quantity of air that remains in lungs after a maximal exhalation. This volume is referred to as residual volume (RV).

There exists a number of different methods for assessing RV. These include: 1) the pneumatometric approach, using some form of whole-body plethysmograph, 2) the closed-circuit approach, where there is dilution followed by equilibration of an inert tracer gas; and 3) the open-circuit technique, where nitrogen is "washed out" of the lungs during a period of oxygen breathing.

The technique utilized in this study is a modified version of the closed-circuit oxygen dilution method described by Wilmore (1969). The modifications employed in this study are discussed in Chapter III.

With the ability to determine RV, the formula becomes:

(equation 3)

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

Air in Gastrointestinal Tract

The quantity of air in the gastrointestinal (G.I.) tract at the time of the underwater weighing is the final volume of air that must be compensated for when body volume is calculated for adults. Citing the research of Bedell, Marshall, DeBois, and Harris (1956), the value of 100 ml. is often used. Although this volume is quite variable, one can approximate this by having subjects fast for twelve hours (Goldman and Buskirk, 1961).

This value of 100 mls is valid for adults but may not be accurate for children. Since the subjects in the present study were children who fasted 4-6 hours prior to testing, no compensation for air in the G.I. tract was made.

Subtraction of One Liter of Air

The technique required the administration of one liter of air to the subjects' lungs. It was therefore necessary to compensate for this volume of air, resulting in the following equation:

(equation 4)

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

Prediction of Percent Body Fat from Body Density

There exist a number of formulas for predicting percent body fat from the obtained body density value. Basically, these formulas are different from another as a result of the inability of the researchers to agree as to the exact density of lean body mass or adipose tissue. The different values have been obtained through the analyzation of relatively few adult cadavers or through animal studies. None of the equations have been derived through investigation of the density of lean body mass or adipose tissue in children.

Before discussing these formulas, it is necessary to make clear the definitions of specific gravity and body density. Density is defined as mass per unit volume ($D = M/V$). Specific gravity is the ratio of the density of the substance to the density of water (Keys & Brozek, 1953).

The development of four popular formulas is presented below.

Rathburn and Pace (1945)

These researchers studied the fat content of male and female guinea pigs. Using .918 and 1.10 as the specific gravity of fat and fat-free tissue respectively, they derived the following formula for predicting fat percentage in man:

(equation 5)

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

Keys and Brozek (1953)

These investigators refuted the findings of Rathburn and Pace (1945). The substance of their argument was based on the derivation of the specific gravity values used to determine the above formula. Keys and Brozek (1953) felt it was inappropriate to apply an equation derived from eviscerated guinea pigs to adults. They also criticized the methodology employed in the analyzation of the pigs.

Measuring the density of fat at various temperatures of men and women and various animals, these researchers reported a density value .90074 for human fat at a temperature of 36° C. From this information, a "reference man" was developed with an estimated 14% fat. They then derived the following conversion formula:

(equation 6)

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

Siri (1961)

The concept of a "reference man" was not in agreement with the investigations of Siri (1961). He felt that one should use a fat-free body in the development of a formula. Values of 1.100 (lean body mass) and .900 (fat) were used to develop his formula:

(equation 7)

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

Brozek, Grande, Anderson, and Keys (1963)

The final formula to be considered was developed by Brozek et al. (1963). Utilizing a "reference body", they derived a more accurate estimate of the chemical composition of the human body. They achieved this by dividing the body into compartments and chemical components and analyzing each. A new fat density of .915 was obtained. The fat content of the "reference body" was calculated to be 15.3%, resulting in the following formula:

(equation 8)

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

These investigators pointed out that this formula is most valid when applied to those who have not experienced great fluctuations in body weight. In conclusion, Brozek et al. (1963) also stated that as a consequence of the great amount of variability in adipose tissue, it appears very difficult to establish a generally valid formula.

Despite the disagreement among researchers, the percent body fat values obtained from these formulas are not greatly different. In fact, a study conducted by Wilmore and Behnke (1969) revealed a correlation of 0.995-0.999 between the values obtained from the different formulas.

Conversion of Body Density to Percent Fat in Children

It was previously stated that Parizkova (1961) did not convert her data from body density to percent fat. She reported that although the composition of adipose tissue in children is probably very similar to adults, no research had been conducted to validate the use of these formulas in converting the body density of children to percent fat.

An early investigation by Moulton (1923) reported that fat free protoplasm reaches a constant chemical composition early in childhood. Friis-Hansen (1961) stated that intracellular water remains fairly constant throughout life, while there are alterations in extracellular fluid. A small but statistically significant difference in intracellular water of lean tissue has been demonstrated by Lesser, Kumar, and Steele (1963). No difference, however, was observed in the ratio of total body water to fat-free lean mass. Heald, Hunt, Schwartz, Cook, Elliot, and Vajda (1963) and Novak (1966) contended that chemical maturity occurs prior to puberty.

The thorough review presented by Malina (1969) concluded that data is lacking in this area and that direct analysis of adipose tissue of children is needed to resolve the problem. For this reason, both body density and percent fat are presented in this paper.

Standard Error in Hydrostatic Weighing

Limits have been placed on the standard error (S_e) in relation to repeated measurements of hydrostatic weighing. Values ranging from .0004 gm/cc to .0026 gm/cc have been suggested (Buskirk, 1961). A S_e of .001 gm/cc will alter the percent fat value approximately .4%.

Determination of residual volume at the time of underwater weighing or outside the hydrostatic weighing tank may be the source of additional error. Some investigators have found no difference (Graig & Ware, 1967; Prefaut, Lupi, & Anthonisen, 1976) while Bondi, Young, Bennett, and Bradley (1976) reported a decrease. A recent investigation by Girondola, Wiswell, Mohler, Romero, and Barnes (1977) revealed a 6.7% increase in residual volume when determined in the water.

Each of these reports presents some physiological justification for the conclusions. Those investigators explaining an observed decrease in residual volume maintain that the increase in thoracic pressure (approximately 20 mm Hg) increase intrathoracic blood volume, compressing small airways thereby increasing the volume of air expired. Those demonstrating increases in residual volume claim an increased pulmonary pressure causes difficulty in compressing alveoli at low lung volumes.

As a result of these disagreements, it appears there is no clear evidence to support one position over the other, therefore this study determined residual volume outside of the hydrostatic weighing tank. The subjects were seated in similar positions during both the residual volume determination and the underwater weighing.

Chapter III

METHODS

Subject Selection

A total of 21 subjects (12 females; 9 males) volunteered to establish the validity of the proposed modification of the standard underwater weighing technique. These subjects ranged in age from 18-24 years. They were all considered to be in good physical condition.

The 41 prepubescent boys participating in the reliability phase of the study ranged in age from 7-11 years. The boys resided in the La Crosse, Wisconsin area and were considered to be in excellent health. Due to the nature of the study, it was necessary to select individuals who were comfortable in a water environment. For this reason 44% of these subjects were members of the YMCA swim team. The remaining 56% were volunteers who stated that they were also comfortable in a water environment. The subjects and parents were informed of the procedures (Appendix A) and of the potential hazards (Appendix B). The parents signed the informed consent form (Appendix B).

Instrumentation

Residual Volume - The method utilized to determine residual volume employed modification of the procedures outlined by Wilmore (1969). The modifications were designed to reduce the total amount of dead space.

Preliminary testing during this study indicated that the vital capacity of boys age 7-11 years ranged from 1.5 liters to 3.5 liters. Since the dead space of the system reported by Wilmore (1969) was 1.085 liters, it was evident that the volume closely approximated the vital capacity of some of the smaller children. This caused great difficulty in the attainment of an equilibrium, thus the following modifications were made.

A six liter Collins Vitalometer was employed to measure the volume of oxygen to be used during the trials. This volume of oxygen was then introduced to a five liter rubber breathing bag by opening a previously closed two-way stop-cock valve located at the base of the vitalometer, and depressing the tissot. The oxygen passed through this valve into the rubber bag which had been previously vacuumed free of air. The valve was then shut. These modifications reduced the dead space from 1.085 liters to .04 liters as calculated by geometric estimation. The reduction in the dead space of the total system enabled a much faster clearance of nitrogen prior to the test, faster equilibration, and increased accuracy of the subsequent determinations by reducing the total volume of the system.

A Collins Nitrogen Analyzer Head (model number 21232) was placed at the distal end of the breathing bag between the two-way breathing valve and the subject's mouthpiece

(Fig. 1). This system provided continuous analysis of inspired and expired air. The resolution of the system was +.1% N_2 with a readout accuracy of +0.2% N_2.

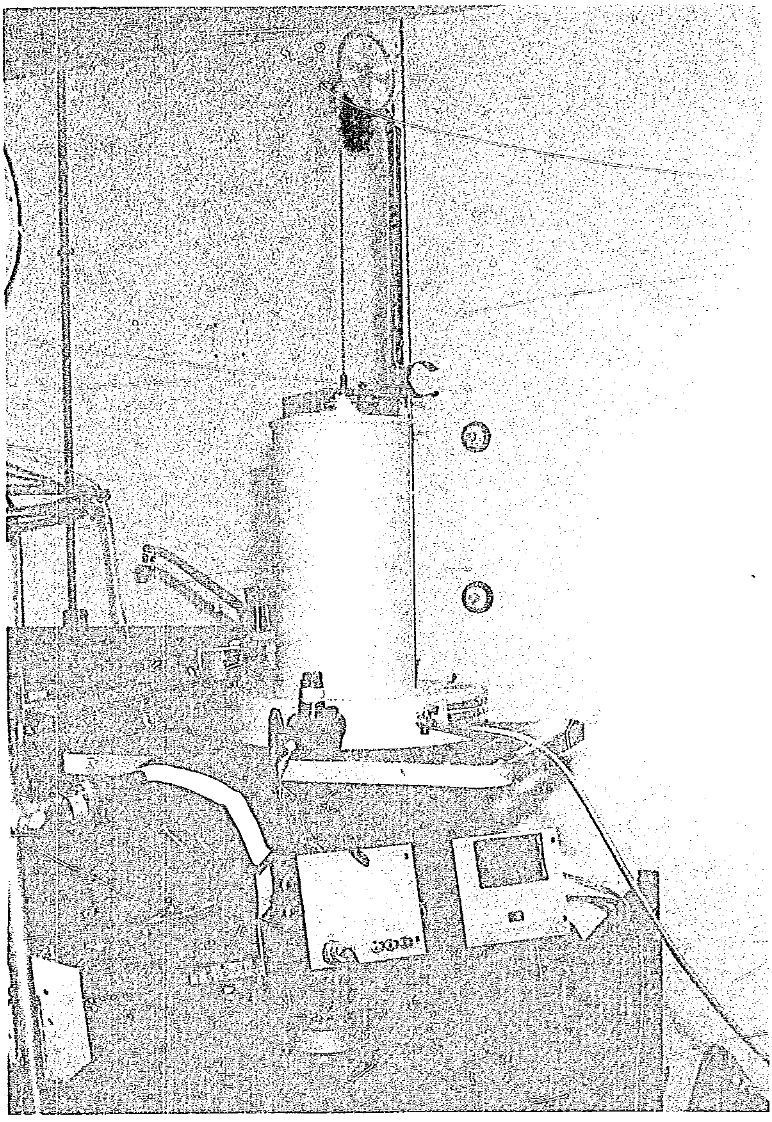
Hydrostatic Weighing - The equipment employed to modify the standard hydrostatic weighing technique was designed to enable the technician to introduce a precise volume of air to the subject's lungs prior to submersion.

Originally, the proposed modification was going to allow subjects to inspire a comfortable volume of air, submerge (underwater weight recorded), and then upon surfacing perform a maximal expiration into a respirometer. This, when combined with residual volume, would allow the investigator to subtract the total volume of air in the subjects at the time of the underwater weighing. This is theoretically possible since body density should not be influenced by the volume of air when this volume is measured (Welch & Crisp, 1958). However, preliminary data indicated great intra-individual variation between successive trials.

Possible explanations for these discrepancies include the following. Behnke, Feen, and Welham (1942) were the first to recognize that if a subject was submerged with a large volume of air, a correction for the mean hydrostatic pressure on the thoracic volume was needed. This theory is supported by the investigations of Welch and Crisp (1958) who demonstrated a significant difference between body density values obtained through maximal exhalations when compared

Figure 1

Modified Residual Volume Equipment



to one half exhalation. Another plausible explanation for the differences obtained concerns the possibility of increased internal air pressure after inspiration of large volumes of air. This greater pressure compresses the molecules within the lungs at increased levels of inspiration. Thus, during exhalation, these molecules will occupy a larger volume due to the lower atmospheric pressure. This will result in measuring a greater volume than was present during the underwater weighing and thus reduce the total volume. Varying the levels of inspiration from trial to trial may have altered the extent to which this influence affects the underwater weight.

The final possibility for the observed discrepancies concerns the relationship between level of inspiration and underwater weight. It is generally accepted that as the level of inspiration increases, there is a proportional decrease in underwater weight. This is partially based on the fact one must increase the body volume, by expansion of the thoracic cavity as he inspires greater volumes of air. However, it has not been shown that this proportional relationship exists at high levels of inspiration. It is possible that to inspire large quantities of air, one must increase his thoracic cavity (body volume) by a greater proportion than at lower levels of inspiration. If this theory is valid, techniques requiring high levels of inspiration during the underwater weighing might not be entirely accurate.

Further investigation is needed to identify the relationship between the level of inspiration and change in body volume.

To minimize these potential sources of error, equipment was developed which would allow the subject to first perform a maximal expiration, then receive a small known volume of air (one liter), submerge and have an underwater weight recorded. The apparatus consisted of a three liter rubber breathing bag which was fastened to a two-way stopcock valve. One end of the bag was attached by way of a hollow plastic tube, to a rubber stopper with a small hollow center continuous with the tube (Fig. 2). The final piece of equipment modified was a nine liter Collins Respirometer. The only alteration consisted of removing all hosing and attaching a two-way valve at the base (Fig. 3). This enabled investigators to introduce a known volume of air to the breathing bag.

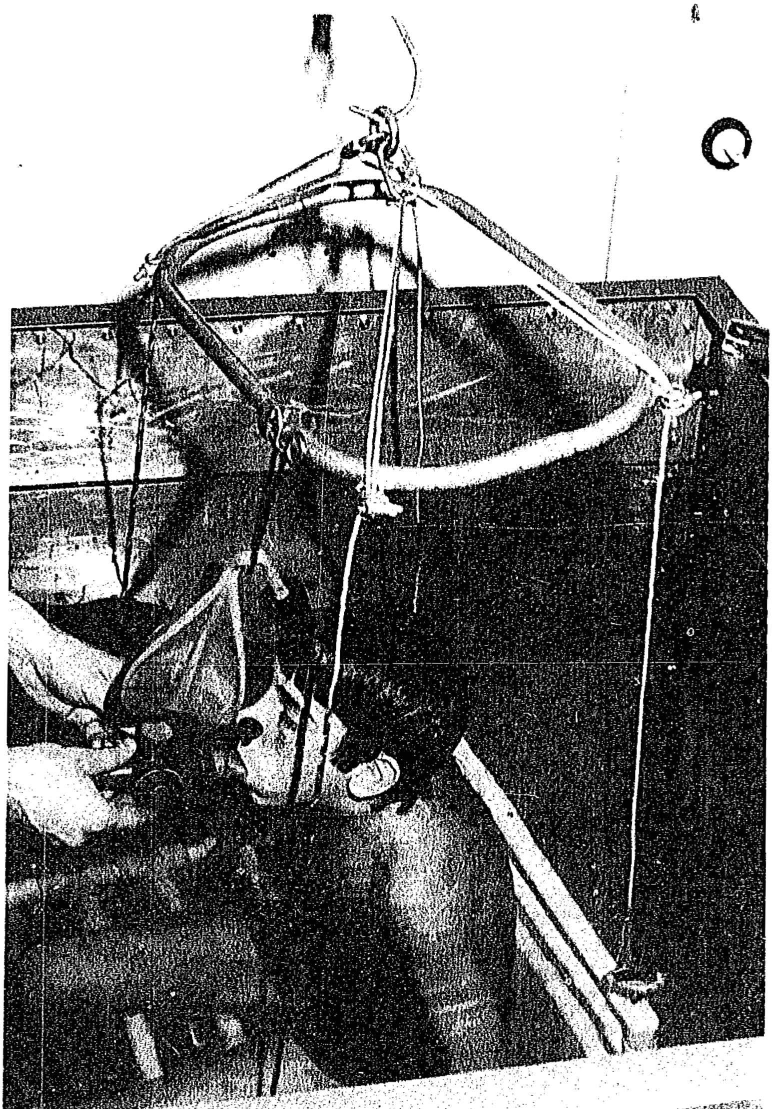
Procedures

The 41 prepubescent boys which were studied to determine the reliability of the modified technique visited the laboratory on three or four occasions. The first visit was designed to orientate the subject to the residual volume and modified hydrostatic weighing procedures. On the day the subject demonstrated consistency in both procedures, usually the second of third visit, he was asked to return once again. The data collected during the last two visits was used in the statistical analysis.

Figure 2

Equipment Employed to Administer One

Liter of Air to Subject's Lungs



Validity was established by hydrostatic weighing 21 subjects who performed both the standard procedures and the proposed modifications. Upon visiting the laboratory, residual volume was determined first. This was followed by the standard hydrostatic weighing. When a "true" underwater weight was obtained, the subjects were given a short rest and asked to perform the modified hydrostatic weighing procedures.

Standard Hydrostatic Weighing Procedure

On the day of testing, the subjects reported to the Human Performance Laboratory at the University of Wisconsin-La Crosse. They had been previously instructed not to eat for 12 hours to achieve the post-absorbative state.

A dry weight was obtained on a Health-O-Meter scale (Continental Scale Corporation) and measured to the nearest .25 lb. with the subjects clothed in their swimming attire. They were then instructed to take a warm shower and wash with a neutral soap, thus removing any excess debris or oil. They were outfitted with a weighted belt (10 lbs.) and noseclip and then asked to descend into the 4'x4'x4' hydrostatic tank. After manually removing air bubbles trapped within the swimming attire, the subjects were seated on a light-weight polyethelyne chair. The chair was suspended from a 15 kg cadaver scale (Chatillion and Sons, New York, N.Y.), which was graduated in increments of 25 grams and fastened to the ceiling. The subjects then performed the following procedures.

First they inspired deeply followed by a long, slow maximal expiration. At the end of this expiration, the subjects bent at the waist and completely submerged. Expelling any air that was left in the mouth or lungs while underwater signalled the technician that an underwater weight could be recorded. This was done to the nearest ·25 grams.

Tapping the subjects lightly on the shoulder informed them that they could surface. These procedures were performed about 8 times or until a consistent reading was obtained (Katch, 1968). Although Katch used an average of the last three trials to obtain the "true" underwater weight, this criterion was not utilized in the present study because of the early fatigue demonstrated by the subjects. The young subjects also did not demonstrate the high degree of intra-individual consistency as those tested by Katch. As an alternative, Katch (1968) mentioned that the heaviest weight that is repeated could represent the "true" underwater weight also. This criterion was followed in the present study for both the standard and modified hydrostatic weighing procedures.

Modified Hydrostatic Weighing Procedure

The subjects followed the same procedures described above until they entered the tank. It was after the subjects were seated and noseclip secured that the following modifications were instituted.

To accurately administer one liter of air to the subjects, the technician utilized the equipment previously described. First, the rubber stopper was inserted tightly into the two-way valve at the base of the respirometer. This valve was opened to the respirometer, hence closed to the stopper and rubber bag. On the distal end of the rubber breathing bag, the two-way stopcock valve was opened to the bag. This enabled the technician to manually vacuum the air out of the bag. Turning the stopcock valve closed the system. The respirometer was then set for the administration of one liter of air into the bag. This was accomplished by setting the recording pen at a predetermined point, opening the two-way valve at the base of the respirometer and depressing the oxygen bell manually. This forced the air from respirometer into the rubber bag. A clamp was then secured at the neck of the bag, between the stopper and inflated portion of the bag, thus sealing the system.

A mouthpiece was attached to the stopcock valve and given to the subjects. With the mouthpiece properly positioned in their mouth, the subjects were instructed to perform a maximal exhalation. At the end of this maneuver, they raised their hand and the valve was turned, allowing inspiration of the one liter of air. The subjects were then instructed to bend at the waist and submerge. As they submerged the stopcock valve with the attached rubber bag were removed from the mouthpiece and the underwater weighing apparatus. The underwater weight was therefore recorded with the mouthpiece in position and one liter of air in excess of residual volume, in the subjects' lungs.

Residual Volume Procedures

As stated earlier, the method adopted for residual volume assessment in this study utilized a modified closed-circuit oxygen dilution technique (Wilmore, 1969).

Prior to the start of each trial, the respirometer was flushed with pure oxygen and filled to a predetermined level. The stopcock valve was closed as was the breathing valve as the 5 liter rubber breathing bag was mechanically vacuumed of all air. The stopcock valve was then opened to the respirometer. When the tissot was depressed, the pure oxygen flowed through the valve into the breathing bag. Closing the valve sealed the oxygen in the bag.

The subjects were asked to be seated in a position which closely approximated the one adopted during the underwater weighing. After a noseclip and mouthpiece were positioned, the subjects were instructed to perform the following maneuvers to the best of their ability.

They were asked to inhale deeply followed by a maximal expiration. At the end of this expiration, the initial alveolar nitrogen concentration (AN_2) was recorded. The breathing valve was closed, thus connecting the subjects to the breathing bag and allowing them to inspire the oxygen. The concentration of nitrogen in the oxygen was recorded at this time (IN_2). This reflected the impurity of the oxygen.

The subjects were then instructed to breathe fairly deeply, approximately 2/3 vital capacity, and rapidly, one respiration approximately every 3 seconds. As a consequence of this rebreathing, a nitrogen equilibrium was reached between the bag and the lungs. Since a single value was not obtained, the mid-point between the equilibrium range was recorded (EN_2).

Another inspiration followed by a maximal expiration was then performed. The final reading was recorded at the end of this expiration (FN_2).

After two minutes of normal respiration, the entire procedure was repeated. If a difference greater than 50 mls was observed between the trials, a third trial was performed. The mean of the lowest 2 trials was used.

The formula for calculating residual volume is presented below:

(equation 9)

$$RV = \frac{VO_2 \ (EN_2 - IN_2)}{(AN_2 - FN_2)} - D.S.$$

R.V. = Residual Volume

VO_2 = Initial volume in system

EN_2 = Percent nitrogen at equilibrium

IN_2 = Impurity of oxygen

AN_2 = Percent nitrogen initially in alveolar air

FN_2 = Percent nitrogen in alveolar air at end of test

D.S. = Dead space of mouthpiece, sensing element and small portion of breathing valve

Statistical Treatment

The Pearson Product Moment Correlation and correlated *t* test were the statistical tools utilized to determine the reliability and validity of the proposed modification of the standard hydrostatic weighing technique. Means and standard deviations were also provided.

Chapter IV

RESULTS AND DISCUSSION

The purpose of this study was to develop a technique for determining body density in prepubescent males age 7-11 years. Both validity and reliability tests were applied to assess the accuracy of this technique.

Subjects

The subjects selected for participation in this study were residents of the La Crosse County area. The 41 subjects studied to determine reliability were males between the ages of 7-11 years ($\bar{x}$ age 9.3 years). A total of 21 subjects (male N=9; female N=12) between the ages of 18-24 years ($\bar{x}$ age 20.7 years) were chosen to determine the validity of the technique.

Validity of the Modified Technique

The validity of the technique was determined by the hydrostatic weighing of 21 subjects. These subjects performed both the standard hydrostatic weighing procedures as described by Goldman and Buskirk (1961) and the modified procedures presented in this study. A correlated *t* test was used to determine if there was a significant difference between body density values obtained by the two different techniques. The Pearson Product Moment correlation was also employed to determine the correlation between different variables.

The mean body density for the males was 1.073 gm/cc and females 1.044 gm/cc (Table 1). The combined scores for males and females demonstrate a body density value of 1.056 gm/cc and 1.057 gm/cc for trials I and II respectively. This resulted in a difference of .001 gm/cc. Table II reflects the correlations observed between the different variables. It should be noted that a correlation of 1.00 was found between the body density values obtained from the two different techniques. A correlated *t* test revealed a *t* value of .246. At 20 degrees of freedom, a *t* value must exceed 2.086 to be significant at the .05 level. Therefore this indicated no significant difference between the density values obtained by the two methods.

The percent body density values obtained for this college age population are similar to those reported by other investigators. Durnin and Womersley (1974) found a mean density of 1.040 gm/cc in 29 females and 1.066 in 24 males. Katch and McArdle (1973) reviewed the results of fourteen studies reporting on the body composition of males and females. The mean body density values reported for males ranged from 1.064 gm/cc to 1.075 gm/cc. Those reported for females ranged from 1.031 gm/cc to 1.049 gm/cc. These values are consistent with the densities of 1.044 gm/cc for females and 1.073 gm/cc for males reported in the present study.

The difference of .001 gm/cc observed between the two trials is well within the range of acceptability. Values ranging from .0004 gm/cc to .0026 gm/cc have been suggested by Buskirk (1961).

As stated earlier, there was a high correlation (1.00) observed between the body density values obtained by the two different techniques. A number of factors have probably contributed to this observation. First, the potential influence of hydrostatic forces on body density measurements which has been previously discussed. It was stated that these influences may be manifested when large volumes of air are allowed to be present in the subject's lungs as the underwater weight is recorded. The hydrostatic influence may also occur when varying volumes of air from trial to trial are allowed to be present in the subject's lungs, and subsequent measurement of this volume is made. It is believed that the development of the modified hydrostatic weighing technique outlined in this study has minimized the influence of hydrostatic forces as evidenced by the high correlation noted between the modified and standard techniques.

Another plausible explanation for this high correlation is based on the fact that many measurement errors had been eliminated. Buskirk (1961) presented a number of variables that should be controlled when assessing body composition through densitometry. He emphasized that repeat measurements may be inconsistent with previous data if density of

Table 1

Means and Standard Deviations for Age and Physical Characteristics of 21 College-Age Students

Variable	$\bar{X}$	S. D.
Age (yrs)	20.7	1.4
Weight (kg)	67.9	11.8
Height (cm)	171.2	8.8
Residual Volume (Ltrs)	.971	.181
Density Males (gm/cc)	1.073	.011
Density Females (gm/cc)	1.044	.007
Density Total trial #1	1.056	.017
Density Total trial #2	1.057	.017

Table 2

Correlations for Variables Measured

in 21 College Age Students

	Age	Ht.	Wt.	RV	Density 1	Density 2
Age (yrs)						
Height (cm)	.06					
Weight (kg)	.25	.81**				
Residual Volume (Ltrs)	.17	.54*	.35			
Density trial 1	.04	.57**	.45*	.21		
Density trial 2	.03	.57**	.47*	.22	1.00**	

* Correlations above .433 are significant at the .05 level of probability

** Correlations above .549 are significant at the .01 level of probability the water, residual volume, air in gastrointestinal tract, air bubbles on skin surface were not effectively controlled. The procedures followed in this study eliminated many of these influences. By having the subjects perform the standard procedures, rest, and then perform the modified procedures, the investigator controlled these potential sources of error.

Table 2 demonstrates the correlations observed during the testing of the 21 college-age subjects. It was observed that there was not a high correlation between residual volume and height (r=.54). Using the equation developed by Polgar and Promadhat (1971) to predict residual volume in the present study, a value of 1.04 liters was obtained. This is only 69 ml more than was actually obtained. This equation was derived from a large population using height as the independent variable. The ability of the equation to accurately predict residual volume in the present study, when in fact only a .54 correlation was observed between height and residual volume, is unclear. Possible sample bias or methodology difference could account for this phenomenon.

A high correlation (r=.81) was obtained between height and weight. Sinclair (1969) has demonstrated that because of this high correlation, prediction tables can often be constructed.

There were also significant intercorrelations among the variables height, weight, and density. This was not unexpected since height and weight are important variables in defining lean body mass. Keys and Brozek (1953) have noted the consistent relationship between lean body mass and density.

Reliability of the Modified Technique

Reliability was determined by a test-retest of 41 pre-pubescent males. Body density was determined by following the modified hydrostatic weighing procedures. The subjects were then retested within one week of the initial assessment. A correlated *t* test was employed to determine the difference between the density values obtained. Correlations between other variables were determined by the Pearson Product Moment correlation formula.

The means for age and physical characteristics are presented in Table 3. Also shown are the mean body density values obtained from the two trials. It should be emphasized that the mean body density for both trials was 1.053 gm/cc and that the correlation between both trials was .99. A *t* test revealed a *t* value of -.267. At 40 degrees of freedom, a *t* value greater than 2.021 is significant at the .05 level. Therefore this demonstrates no significant difference in body density values between the two trials.

The rationale for not converting body density to percent fat is based on the lack of evidence demonstrating the validity of the known equations when converting body density to percent fat in children. For this reason, body density

Table 3

Means and Standard Deviations for Age and Physical Characteristics of 41 Prepubescent Males

Variable	$\overline{X}$	S. D.
Age (yrs)	9.3	1.2
Weight (kg)	33.7	7.7
Height (cm)	139.5	9.7
Residual Volume (Ltrs)	.459	.089
Density trial 1 (gm/cc)	1.053	.011
Density trial 2 (gm/cc)	1.053	.011

Table 4

Correlations for Variables Measured

in 41 Prepubescent Males

	Age	Ht.	Wt.	RV	Density 1	Density 2
Age (yrs)						
Height (cm)	.77**					
Weight (kg)	.67**	.86**				
Residual Volume (Ltrs)	.21	.36*	.36*			
Density trial 1	-.30	-.36*	-.66**	-.01		
Density trial 2	-.32	-.41*	-.69**	-.02	.99**	

* Correlations above .325 are significant at the .05 level of probability

** Correlations above .418 are significant at the .01 level of probability values have been recalculated, utilizing the appropriate equation, for those studies which have reported percent fat.

There have been relatively few attempts to assess body composition in children through hydrostatic weighing. The body density values obtained in this study are consistent with these reports.

In 1975 Cureton et al. reported a mean body density value of 1.053 gm/cc for 49 prepubescent males ($\bar{x}$ age 9.5 years). A retest demonstrated a reliability correlation coefficient of .83. These researchers recorded the underwater weight at the end of maximal expiration. Residual lung volume was determined at the time of the underwater weighing using a closed-system, nitrogen dilution procedure. The present study obtained the same mean body density value of 1.053 gm/cc. These results are plausible if one observes the samples obtained from each study. Cureton et al. (1975) selected their population from a sports fitness program. Forty-three percent of the subjects in the present study were members of the YMCA swim team. The mean height (141.6 cm) and weight (34.9 kg) of Cureton's subjects are comparable to the values of 139.5 cm and 33.7 kg obtained in this report.

The large discrepancy noted in the retest correlations may be the result of a number of factors. First, Cureton et al. (1975) recognized their low correlation and attributed it to the technical difficulties encountered as residual volume was obtained at the time of the underwater weighing.

However, it is doubtful if the entire difference was due to that problem. Comparing the research design, one notes that Cureton et al. (1975) had their subjects visit the laboratory on two occasions. The present study required three to four visits. Other reasons for the high correlation in this report include comfort of the subjects in a water environment, all were in a post-absorbative state following a 4-6 hour fast, greater time to read underwater weight due to subject comfort with one liter of air, and a constant residual volume used in the calculation.

The only other published study which attempted to hydrostatically weigh children was conducted by Parizkova (1961). It must be emphasized that the author did not present means or standard deviations for the data, thus making it difficult to generalize as to body composition of the sample. However, Lohman et al. (1975) have supported Parizkova's findings by utilizing the nomogram developed by Parizkova for their own subjects. They found a mean percent fat of 20.2 utilizing the ^{40}K technique and a comparable 19.5% fat utilizing Parizkova's (1961) nomogram. It is recognized that it is not entirely accurate to compare ^{40}K to hydrostatic weighing (Cureton et al., 1975), but it is done here to facilitate comparison of different studies.

An unpublished investigation by Zavalata (1976) also utilized the standard hydrostatic weighing procedures to determine body density in males. The mean body density value of the subjects age 9, 10, and 11 years was reported to be 1.073 gm/cc, 1.068 gm/cc and 1.061 gm/cc respectively. These values are much higher than obtained in the present report. Possible explanation for this discrepancy could be sampling error, methodology differences, and socio-economic status.

Two other studies which have assessed the body composition of children were conducted by Slaughter and Lohman (1977) and Forbes (1972). Both utilized the ^{40}K technique to determine percent fat in their subjects. For this reason, it was necessary to convert the 1.053 gm/cc density value obtained in the present report to 19.9% fat utilizing the equation developed by Brozek et al. (1963).

The subjects studied in the research conducted by Slaughter and Lohman (1977) were of the similar age and physical characteristics as the subjects in this study. Their mean age, height and weight were 10.0 years, 141.8 cm, and 35.2 kg, respectively. The percent fat obtained had a mean value of 22.0%, which is comparable to the 19.9% found in the population in this report.

A total of 134 males between the ages of 7-11 years were found to have a mean percent fat of 18.4% by Forbes (1972) utilizing the ^{40}K technique.

Table 4 reveals the correlations among the other variables measured during the reliability assessment. Presented below is a brief discussion of some of these correlations.

It is interesting to note that there was only a .38 correlation between height and residual volume. Polgar and Promadhat (1971) have developed an equation (RV = -919.2123 + 11.4193 X HtCm) based on the relationship between height and weight for individuals between the ages of 4-19 years. Utilizing their equation to predict RV in our subjects, a mean value of 673.8 ml was obtained. This is 214.8 ml more than was observed by actual measurement. This would be reflected as approximately .0033 gm/cc decrease in density or 1.2% increase in percent fat. This large difference may be attributed to methodology or the wide age range of the subjects from which Polgar and Promadhat (1971) obtained their data. As pointed out by Sinclair (1969), the height in children around age 7 is subject to great variation due to possible growth spurts. The capability of establishing an accurate equation for variable scores predicting RV based on height measurement is doubtful.

A correlation of .86 was observed between height and weight. This value is supported by the investigations of Lohman et al. (1975) who demonstrated a correlation of .83. Their measurements were obtained on 162 boys with a mean age of 10.1 years. This correlation has been previously recognized in that tables have been constructed to predict weight from height (Sinclair, 1969). However, Sinclair (1969) also pointed out that children often exhibit a transitory growth spurt around the age of 7 years which may affect the accuracy of these tables.

Table 4 also revealed a .67 correlation between weight and age and .77 correlation between height and age. Similar values of .62 and .80 respectively have been reported (Lohman et al., 1975). The only discrepancy noted between the data in the present study and those of Lohman et al. (1975) is their .43 correlation observed between weight and percent fat compared to the .66 value in the present study. The fact that they observed a percent fat retest reliability of only .83 using the ^{40}K technique compared to the reliability of .99 obtained in this study could account for the difference.

Chapter V

CONCLUSIONS

Summary

A valid and reliable technique has been developed to predict body density in prepubescent males age 7-11. The body density values obtained in this study were compared to studies that have investigated similar populations. It was also emphasized that there have been relatively few attempts to quantify or qualify body composition in children.

Conclusions

The results of this investigation indicated the following conclusions:

1. The modified hydrostatic weighing technique described in this study is a valid measure of body density in prepubescent males age 7-11. This was evidenced by the high correlation (1.00) observed by comparing body densities obtained from hydrostatic weighing 21 subjects the standard method (Goldman and Buskirk, 1961) and the proposed modification. Further support for this conclusion was based on the agreement observed between the mean body density value of the children tested in this study as compared to those values obtained in other studies.

2. The reliability of the modified technique (r=.99) has been shown to be superior to other techniques reported

in the literature. A number of explanations were proposed to elucidate this observation.

3. An estimation incidence of childhood obesity in the La Crosse County area cannot be made from this study. This was due to the lack of random sample and the small number of children evaluated.

4. A technique has been developed that will allow the accurate and objective identification of the individual cases of obesity. This could then facilitate attempts to estimate the incidence of obesity in children.

Recommendations

Based on the conclusions, the following recommendations are made:

1. A trained group of children should have body density determined by hydrostatic weighing both the standard and modified techniques. This would allow the assessment of validity of the modified technique in children.

2. A large random sample of children should have body density determined, allowing an estimate of the incidence of childhood obesity in that population. This would incorporate body density assessment in females.

3. Direct body composition analysis in post mortem children should be conducted to determine the accuracy of existing equations which predict percent body fat from body density.

Appendix A

Dear Parent/Guardian: RE: Subjects for determination of body composition for males age 7-11

Obesity among children continues to be a major health concern. Effectively dealing with this problem requires early identification and accurate assessment of the child's body composition. David Jensen and Roxanne Reed, graduate assistants in the La Crosse Exercise Program at the University of Wisconsin-La Crosse, are conducting research in the area of body composition in children. This study will enable health and physical educators in the elementary schools to more accurately monitor the growth patterns of children. This study has been approved and supported by the medical advisory committee of the La Crosse Exercise Program.

The study determines body density and percent body fat using the technique of hydrostatic weighing and anthropometric measurements. Hydrostatic weighing requires that the participant be submerged underwater for a period of 4-6 seconds. It is therefore necessary for your child to be comfortable in going underwater for this short period of time. If you feel that your child fits this criterion, and is a male between the ages of 7 and 11, we would like your cooperation and your son's participation in this research.

Participation is totally voluntary and will require three or four visits to the Human Performance Laboratory on the University of Wisconsin-La Crosse campus. Each session will be approximately one hour long. We encourage you to attend the first session to better acquaint yourself with the equipment and procedures of the study.

The following is a brief description of the tests to be conducted:

1. Hydrostatic weighing. This procedure entails submerging the subject underwater, while seated on a chair for a period of 4-6 seconds.

2. Lung volume: Non-invasive breathing maneuver used to measure residual volume.

3. Anthropometric measurements. The use of skinfolds, body circumferences, and bone diameters to estimate percent body fat.

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It should be emphasized that the Human Performance Laboratory has the most modern equipment available, and that both Mr. Jensen and Miss Reed are highly trained laboratory technicians. They are both former YMCA professionals with considerable experience in aquatics. They are both currently certified as water safety instructors by the American Red Cross.

At the conclusion of this investigation the results will be explained to both you and your child. If you are interested in having your child involved in this study, or have any questions, please call Mr. Jensen or Miss Reed at the Human Performance Laboratory, 785-8685, between the hours of 8:00-12:00 or 1:00-4:00, Monday through Friday. Please leave a message if they are not there and your call will be promptly returned.

Thank you for your time and consideration. We hope that you will take this opportunity to assist us in this valuable research effort.

Sincerely,

Raymond F. Moss, Ph.D.
Director of Research
La Crosse Exercise Program

Appendix B

PARENTAL CONSENT FORM--BODY COMPOSITION

I, ________________________________, the parent/guardian of ________________________________, give my permission for my son to participate in the body composition investigation conducted in the Human Performance Laboratory at the University of Wisconsin-La Crosse. I understand that participation will consist of three or four visits to the lab, in which my child will be underwater weighed, have residual volume determined, and anthropometric measurements taken.

As in any testing situation there exists some risk. In working in a water environment the risks include infection, accident, and possible drowning. However, there has never been an accident or report of infection as a result of hydrostatic weighing at the Human Performance Laboratory.

The potential risks have been explained to me, and I fully understand their implications. I hereby acknowledge that no representations, warranties, guarantees, or assurances of any kind pertaining to the procedure have been made to me by the University of Wisconsin-La Crosse, the officers, administrators, employees, or by anyone acting on behalf of any of them.

Signed:______________________________ Date:_______________

Subject's Name:______________________________

Witnessed by:______________________________

Appendix C

Name:____________________________________ Age:__________

IMMERSION TANK TEMP.__________ ^{o}C. DENSITY OF WATER (D_W) 0.____
(from conversion chart)

MASS IN AIR (M_A)__________kg.

MASS IN WATER (M_X)__________kg.

MASS OF WEIGHING APPARATUS (M_Y)________kg.
(in water)

MASS OF WATER (M_W) = M_X - M_Y = ________kg.

VOLUME OF AIR ADMINISTERED = 1 LITER

BODY DENSITY (D_B) = $$\frac{M_A}{\left(\frac{M_A - M_W}{D_W}\right) - RV - 1.0L.}$$ = _______

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

Appendix D

RESIDUAL VOLUME DATA SHEET

NAME: ______________________________ AGE: ________
First Last

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

$$\text{RESIDUAL VOLUME} = \frac{VO_2\ (EN_2 - IN_2)}{(AN_2 - FN_2)} - DS$$

$$= \underline{\qquad\qquad\qquad} \text{L.}$$

Personal Information

David G. Jensen was born and raised in New Britain, Connecticut. He attended local public schools and received his B.S. degree in Physical Education from Central Connecticut State College in December 1978. Employed by the New Britain YMCA, he served as Assistant Director of Physical Education with emphasis in cardiac rehabilitation. He attended the University of Wisconsin-La Crosse from the spring of 1978 to spring of 1979 and received his M.S. degree in Cardiac Rehabilitation/Adult Fitness in December 1979.

Parents address: 25 Wilna Street; New Britain, Connecticut, 06053.

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