A COMPARISON OF HYDROSTATIC WEIGHING WITH OTHER METHODS OF DETERMINING BODY FAT

by

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Chapter 1

INTRODUCTION

Obesity poses a significant health problem for all ages in that susceptibility to chronic disease is enhanced and length of life is decreased (9, 46). Since World War II the danger of obesity has increasingly been recognized. Life insurance mortality tables have shown that in age group 45-50 the death rate increased roughly one percent for each pound of fat (119:967). The importance of the problem is evidenced by the increasing volume of research related to this problem (14, 44). The fact that obesity or excess body fat is associated with increased morbidity and mortality has been well documented (125).

Dawber and his associates (The Farmingham Study, 1957) showed that obese individuals have a three times greater risk of coronary heart disease than normal or underweight individuals. Amad (19) found an increased incidence of cardiovascular disease in the obese which included possible angina pectoris and coronary heart disease. In 1967, Taylor (125) showed a moderate correlation between incidence of coronary heart disease and obesity.

Depending upon the sources used, the differentiation between normal weight, overweight and obesity is difficult to define and delimit. Height-weight tables based on sex, skeletal size and height have been used to determine normal weight (13, 93, 97, 110) and often these are in disagreement. Height-weight tables have been used as an indicator of ideal weight since the turn of the century (110). However, the traditional methods have been found to be inconsistant or unreliable (78). When normal weight is assessed by comparison of an individual's weight to a table of mean weights for same age, sex and height, their measured weight is found to be twenty to forty pounds over the table weight.

In research with live subjects the following methods for determination of body composition have been used: (1) underwater weighing (Buskirk, 1961), (2) body volume (Allen, 1963), (3) helium dilution (Walser and Stein, 1953; Siri, 1956), (4) radiographic analysis (Garn, 1959), (5) potassium - 40 (K-40) (Barter and Forbes, 1963), (6) ultrasound (Sloan, 1967), (7) total body water (Siri, 1956; Mendez et al., 1970) and (8) creatine excretion (Kreisberg, Bowdoin and Meador, 1970). These methods have been shown to produce in varying degrees both valid and reliable results in the determination of body composition. Underwater weighing has probably been the most widely used and accepted indirect method for such determination in humans and has shown to yield excellent results (96). However, these methods have the following problems in common: (1) considerable time for a single determination, (2) relatively elaborate and expensive equipment and (3) rather complex procedures. For these reasons, these methods are not readily applied to field work. Therefore, a method was needed for estimation or prediction of body composition and hence degree of obesity.

Estimation of body composition was first attempted by Matiegka, a Czech anthropologist, who measured the skeleton, muscle and fat.

Since this first attempt, many other investigators have offered equations using (1) height, (2) weight, (3) skinfolds, (4) girths, and (5) bone diameters for the estimation of body composition (7, 10, 24, 25, 26, 40, 101, 127, 128, 130). Many of the first equations were developed using body composition measurements of males. A specific need to develop equations for estimation of the female's body composition has produced volumes of research related to this area. These equations have become too numerous to review. However, some of the more commonly used ones are discussed in detail in Chapter 2.

NEED FOR THE STUDY

Validation of prediction equations for estimation of body composition has become necessary. It is still questionable as to which of the available estimation equations should be used when considering different populations (150). In a recent study by Pollock, et al. data was produced to support the need for different equations for different age groups (105). Thus the problem of defining a population is not limited to age, sex and race, but should also consider the factor of physical activity (99). Zuti's study recommended that physical activity be a factor in defining a population after comparing fat equations to underwater weighing of male adults (151).

In recent years, a greater emphasis has been placed on preventive health measures. The work of a number of investigators over the past fifteen years has demonstrated unequivocally that exercise is an effective agent in either the control or alteration of body composition (2). Many medical and health related associations have encouraged physical activity and weight control as part of preventive medicine. Exercise programs have become very popular and often include physical fitness testing; however, they seldom use any methods to evaluate body composition or to determine ideal weight.

While the accuracy of precise laboratory evaluations of body composition is desirable, it is highly impractical to bring large segments of various populations into the laboratory for mass evaluations or screening. Because of this, and because of the belief that assessment of body composition is valuable and of interest and importance for the general population, methods have been proposed which are applicable to field testing. The non-research organizations who sponsor fitness programs can use estimation equations to provide an easy way to predict body composition and hence ideal weight. Unfortunately, many program leaders trained to take body measurements may not know which prediction equation to use. Most of the current formulas were developed for normal inactive populations and may give results that are not valid estimations of body composition for subjects engaged in regular physical activity, particularly adult fitness participants.

PURPOSE

It was the purpose of this study to determine the validity of the more commonly used body composition equations for females by comparing their results with those obtained by underwater weighing. The subjects in this study were adult females between ages twenty-five and fifty years of age, prior to menopause. They were engaged in some form of regular physical activity.

Physical activity has been shown to have an affect on the body composition of adult females (2:Chapter9; 152). Therefore the population's physical activity may be an important factor, also in muscle tissue atrophy or hypertrophy. The combination of these factors deemed it necessary that physical activity be a factor of the population.

The methods for the estimation of body composition compared to underwater weighing included those by Young et al. (143, 146); Steinkamp (124); Wilmore and Behnke (135); Sloan, Burt, and Blyth (119); Katch and Michael (75); and Pollock et al. (105).

DEFINITION OF TERMS

Nude Land Weight

This is the subject's weight taken nude in a state of normal hydration, after a four hour fast.

Fat Free Weight (FFW)

This is the weight of the body with all fat removed.

Lean Body Weight (LBW)

This is the fat free weight of the body. This is the same as fat free weight.

Total Body Fat (TBF)

This is the total weight of body fat.

Per Cent Body Fat

This is the per cent of body that is made up of fat.

Total Body Water (TBW)

This is the total body water in the body including both intra and extra-cellular.

Underweight

This is weight below normal weight and is not related to fat.

Overweight

This is weight above normal weight and is not related to fat.

Normal Weight

This is weight determined by height-weight tables based on sex, skeletal size and height.

Overfat

This is the excess fat beyond the normal suggested range of sixteen to nineteen per cent for the normal male and nineteen to twenty-three per cent for the normal female.

Obese

This is the classification of adult women who have forty per cent or more body fat (112).

Underwater Weight

This is the weight of the body when it is totally immersed underwater. This weight is corrected for residual volume lift. It may be either positive or negative; if negative, the subject has a buoyant force as opposed to an actual weight. This is expressed as a negative weight.

Body Volume

This is the actual volume of the body, not including lung displacement.

Body Density

This is the body mass (weight) divided by the body volume.

Functional Residual Volume

This is the volume of air remaining in the lungs and associated airways following a normal expiration.

Residual Volume

This is the volume of air remaining in the lungs and associated airways following a maximal expiration. This term, when used in conjunction with underwater procedure, refers to air remaining in the lungs and airways during the underwater weighing and is more correctly Functional Residual Volume.

Minimal Weight

This is the same as lean body weight. This weight refers to anthropometrically calculated lean body weight in girls and women. Minimal weight is equal to lean body weight in men. It is greater than lean body weight by reason of sex-specific 'Essential' fat in mammary glands and other tissues (2:69-71).

Potassium - 40 (K-40)

This is a biochemical approach for determining the basic fat and lean components of the body. The body emits naturally occurring gamma radiation in the form of potassium - 40. Since lean body tissue has a fairly constant potassium content and constitutes the primary source of potassium, the ability to measure potassium - 40 is of great practical significance relative to body composition assessment. The potassium - 40 content of the body is assessed by radioactive counting (2:32).

LIMITATIONS OF THE STUDY

This study was limited to only the equations listed above for the population of adult females twenty-five to fifty years of age engaged in regular physical activity.

It was assumed that the density value obtained from underwater weighing was a valid measurement of body composition. Validation of underwater weighing with live human subjects was not feasible, since such validation methods involve chemical analysis of the body. However, considerable research has been done to show this relationship. After Keys and Brozek (78) developed the Minnesota Reference Man, Brozek *et al.* (44) proposed the calculation of body density on the basis of chemical analysis of cadavers and defined empirically a new reference man with a known fat content. Volumes of research have been contributed by Allen (18), Pitts (103), Mendez (87, 88), Rathbun and Pace (108), and countless others in the densitometric analysis of body composition in regards to validity.

The reliability for all measurements, including underwater weighing, was not determined in this research. These measurements, including underwater weighing, were found to have excellent reliability coefficients in previous research by Zuti (151, 152) and Zuti and Golding (148).

Chapter 2

REVIEW OF LITERATURE

In this chapter studies related to underwater weighing as a means of determining body density, the measurement of residual volume, and the various prediction methods using skinfolds, girths and bone diameters are reviewed.

UNDERWATER WEIGHT

History

The principle of the relationship of weight to volume (W/V = D) was developed by Archimedes. Robertson, as early as 1757, is credited as being the first to apply the density principle to humans. Spivak, in 1915, used the underwater weighing method for humans, but neither of these early workers made correction for residual volume.

In 1942, Behnke *et al*. made the first corrections for residual volume. These investigators found underwater weighing to be a better indicator of relative "fatness or leanness" of an individual than were the contemporary age-height-weight tables (30).

The first to demonstrate a quantitative relationship between whole body density and fat using underwater weighing were Rathbun and Pace (108, 109). From studies on eviserated guinea pigs, they found specific gravity of the carcus to be a good indicator of composition.

Development of Procedure

Behnke's *et al.* procedure in 1942 used two underwater weighings for each subject. The first weighing was made at the completion of a maximum expiration. These two weighings were used as a validation technique (30). In 1945, Rathbun and Pace used guinea pigs to validate an underwater weighing technique similar to Behnke's technique. The specific gravity of the animals was determined; they were then sacrificed and their body composition was measured (108).

Underwater weighing can be divided into two systems--those using a suspended device by which the subject is lowered into the water (78), or the platform type on which the subject is supported (127, 128). Buskirk (45) stated that both systems would result in accurate measurement if an adequate dampening of the scale was available. Most current workers (76, 123, 135, 141, 147) are using variations of these systems.

RESIDUAL VOLUME

Use with Underwater Weighing

The chief difficulty with underwater weighing is the accurate determination of the buoyance resulting from residual volume (151:8). To avoid additional error and necessity for correction the suggestion that underwater weight be recorded at the end of maximum expiration was advised by Buskirk. He further suggested that the determination of the residual volume be made at the time of underwater weighing (45). However, due to the measurement of the volume of air in the lungs for all underwater weighings, this study allowed the subject to take a comfortable breath and hold it during the underwater weighing. This allowed the subject to hold her breath longer with less muscular tension, thus reducing the error due to subject-caused-movement of the system. Carlson and Chen found that as long as residual volume (or any other lung volume) was measured, it essentially made no difference what volume of air remained in the lungs at the moment the underwater weight was observed (47).

Keys and Brozek (78) have emphasized the importance of measuring residual volume. Behnke et al. (30) proposed a method of two weighings with maximum inspiration and maximum expiration with thirty per cent of the subject's vital capacity used as a correction for residual volume. The use of this method would produce an error of ± five hundred milliliters. This error may account for as much as ± four per cent body fat. Thus for density determination from underwater weighing to be reliable, the residual volume must be measured for each subject (78).

Wilmore compared the use of actual, predicted and constant residual volumes in the assessment of underwater weighing data. He concluded that there was enough variation in subject residual volume to necessitate the use of actual residual volume for research (131, 132). Most present research concurs with this.

Residual Volume Measurement

There are several methods for determining residual volume. Not all are applicable for use in underwater weighing. These methods are of two general types--open and closed-circuit--and some of which may include (1) plethysmography, (2) nitrogen washout, (3) oxygen rebreathing, (4) hydrogen rebreathing, (5) helium dilution and the like. Of all the methods, the closed system nitrogen washout and the closed-circuit helium dilution methods are used by most current workers in respiratory studies.

Helium dilution was first introduced in 1941 for the purpose of estimating functional residual capacity by a closed circuit technique. Subsequently closed helium methods were compared with various procedures in existence (91). Fowler (63) concluded that in comparison with other methods in common use, greater precision appeared possible with closed circuit methods using serial helium or nitrogen analysis. The helium dilution technique has proven to be simple, inexpensive, highly reproducible, and not as time-consuming as compared to other more elaborate systems such as the oxygen open-circuit method (91, 95).

Determination of residual volume is most desirable at the time of the underwater weighing. Brozek's et al. (38) and Pascale's et al. (101) seven minute nitrogen washout method, and Goldman's three to four breath oxygen rebreathing method (69) have been used successfully with underwater weighings. These investigators used previously developed methods for determining residual volume. The closed system nitrogen washout method (45, 82, 107) and the closed-circuit helium dilution method (4, 5, 56, 90, 91) also are commonly used in underwater weighing studies.

PREDICTION METHODS: ESTIMATION OF BODY COMPOSITION

Introduction

While accuracy of precise laboratory evaluations of body composition is desirable, they are too complex and time-consuming to be administered to a large population. Simple techniques are needed for widespread use of measurements for clinical, general-evaluative, and some research purposes. A few simple anthropometric diameters (skeletal), circumferences (or girths), and skinfolds have been used to predict or estimate density, weight, relative and absolute body fat, or lean body weight.

The roots of man's first systematic attempt to estimate body composition, can be traced to the work of the Czech anthropologist Matiegka. In 1921 he broke the human body into components: (1) the skeleton, (2) skin and fat, (3) muscle and (4) the remainder (84). Several investigators developed similar systems--Willoughby (130), McCloy (10) and Cureton (7). Since then, innumerable equations and methods have been proposed.

Height-Weight

A variety of height-weight indices were devised using skeleton size as an indicator of the amount an individual should weigh. The standard weight is usually defined as the average weight of an individual of a given sex, height, and age. Life insurance companies were interested in body weight as being a factor of mortality; as a result they have attributed to the development of popular "height-weight" tables.

In the United States the basic tables of standard weights are those developed in the course of Medico-Actuarial Investigations of 1912. The actual tables came several years after the initial report (Davenport, 1923). Rion (110) noted that much of the weight data appeared to have been estimated--not measured--and questioned the accuracy of the tables. In 1943, the Metropolitan Life Insurance Company issued new tables based on data for the younger age groups, which eliminated the middle age weight increase and, in addition, recognized the variability of the human body composition to account for variation in frame sizes. The Metropolitan Life Insurance Company of New York has since published a series of tables in 1959, giving the desirable weights by small, medium and large frames for men and women over the age of 25. The frame sizes were determined by classifying the lightest third as "small frame", the middle third as "medium frame", and the heaviest as "largest frame" (9). There is no simple method for measuring an individual's frame to decide whether it is small, medium or large. Anthropologists must use calipers for measuring skeletal frame accurately. Thus clinical judgment usually must suffice (6).

Although an individual who is markedly overweight is quite likely to be obese, moderate levels of overweight are not necessarily indicative of excess fat. On the basis of normative tables an individual of good muscular development but little fat would be classified as overweight (30, 78).

At present, the use of height-weight tables persists as a quick evaluation of obesity or desirable weight for clinicians (77). As a result, Pierson and Eagle converted height-weight relationship into a nomogram for estimating body composition (102). They proposed that with the use of height and weight, the specific gravity and per cent fat of the body could be determined. This nomogram provided a useful tool for assessing the clinical significance of lean body weight and body fat. The authors specified that the nomogram was restricted to male subjects within the "normal" range of height and weight.

Ideal or Normal Weight

Following the development of normal height-weight tables, more sophisticated work established normal values for human body composition. Keys and Brozek (78) established the Minnesota Reference Man with standards of D = 1.063 and fourteen per cent total body fat for men twenty-five years old. Brozek *et al*. (44) on the basis of chemical composition of adult male bodies reconstructed the 1953 formula and established "reference body" with the standards of D = 1.064 and 15.3 per cent total body fat. Behnke (24, 25), in predicting ideal weight, used sixteen per cent total body fat for men as his standard. However, more recent work has suggested (40, 44, 78, 80) that the normal man should be sixteen to nineteen per cent fat and the normal woman from nineteen to twenty-three per cent fat and some even higher.

Skinfolds and Girths

Execution of any research tool other than the skinfold measurements is often too difficult and too time consuming for the investigator who wants simply to make rapid diagnosis of obesity, obtain a reasonably accurate estimate of its extent, and follow its changes (86:328). Estimation of total body fat from skinfold measurement has been based on the assumption that subcutaneous fat deposits can be indicators of total body fat. Instruments for accurate skinfold measurements, developed in the 1950's (34, 59, 60), made such estimation possible. Recent work (16, 81) comparing skinfold estimates of total body fat with postmortem measurements correlated well. Coefficients of $r = 0.70$ to 0.80 for males and $r = 0.61$ to 0.92 for females were found.

Durnin and Rahaman (57) made assessments of the amount of fat in the human body from measurements of skinfold thickness on one hundred and five men and women, and eighty-six boys and girls. They found skinfolds had a higher correlation than other anthropometric measurements when compared to body fat determined by underwater weighing.

In 1956, specifications for the skinfold caliper were established for general use by the Committee on Nutritional Anthropometry, Food and Nutrition Board of the National Research Council. Caliper pressure at contact surfaces kept at value of ten grams per square millimeter ($10\ gm/mm^2$); contact surface of twenty to forty square millimeters depends on the shape of contact surface (circular, square, rectangular).

It is recommended to lift the skinfold between thumb and forefinger at a distance of about one centimeter from the site at which the caliper is to be placed and skinfold measured (43, 9:31-32).

Damon suggested that the left side of the body be measured for skinfold and the skinfold be lifted with both hands (53). The left side was found to be statistically more reliable than the right side. This slightly altered previously established procedures (12, 78). Recent work of Womersley and Durnin found no statistical difference between skinfold measurements taken on either side of the body (137).

Other problems involved in gaining correct measurements are changes in skinfolds at different sites, and age changes in skinfold compressibility. Brozek and Kinzey reported decreased, but not uniform, skinfold compressibility with an increase in age. They concluded that this decrease in compressibility may be expected to exaggerate somewhat the trends towards an increase in subcutaneous fat with age (41).

Chen (48) and Young et al. (144) found little alteration in the ratio of subcutaneous fat to deep body fat in women up to the age group forty-five to fifty. They also found that for older women the proportions in the subcutaneous tissues became relatively decreased. The older women had a decrease in mean body density and an increase in body fat after the fortieth year, yet the total of the skinfold measured did not increase above that of the young women sixteen to thirty years of age until after the fifth decade. This was interpreted to indicate that more of the fat in older women is central or non-subcutaneous. Also the skinfolds which correlated best with density were different in younger and older women. Hence, prediction euqations for body fatness based on skinfolds probably should be different for younger and older women.

Steinkamp (121, 122, 123, 124) used skinfolds and girths for prediction of body fat and developed regression equations for estimating body fat in healthy adults. These equations for estimation of body fat had excellent correlation coefficients-- r = 0.92 to 0.98 -- when compared to body fat determined by underwater weighing. The correlation coefficient range for the two female equations was -- r = 0.94 and 0.98.

Young and associates (140, 141, 142, 143, 145, 146, 147) have worked with pre-adolescent and adolescent girls aged nine to seventeen years, young women aged sixteen to thirty years, and older women aged thirty to seventy years. From density and skinfold data, they have developed regression equations for predicting density on the basis of the more easily measured skinfold thicknesses. Several are used in this study.

Since the increased enrollment of women in physical fitness courses where weight control was a factor, the development of a testing procedure for estimation of body fat became apparent. Sinning (114) simplified the estimation of fat for women by developing a computation guide and conversion tables from Sloan, Burt and Blyth's skinfold equation, and Wilmore and Behnke's circumference and skeletal diameter equation.

Pollock *et al*. (105) found the best combination of four variables for predicting body density was skinfold thigh, skinfold suprailiac, diameter knee and girth wrist for young women, with a correlation coefficient of r = 0.83. The best combination of cup size, skinfold suprailiac, girth waist and skinfold thigh was found for middle-aged women with a correlation coefficient of r = 0.89. The subjects were eighty-three young women and sixty middle-aged women ranging from eighteen to twenty-two and thirty-three to fifty years of age respectively.

Katch and Michael (75) derived a prediction equation for body density from sixty-four college females, aged nineteen to twenty-three years. Using only skinfolds of triceps and scapula, and girths of buttock and arm, they obtained a correlation coefficient of r = 0.70.

The iliac crest and triceps skinfold were reported by Blyth, Burt and Sloan (119, 35) as the best prediction of body density when compared to other single measurements. Seltzer, Goldman and Mayer (111, 112) explored the relative merits of two skinfolds--triceps and subscapular--as an index of obesity for women. These studies used women clinically diagnosed as obese. They concluded that the triceps skinfold measurement was the best single indicator in classifying obese and non-obese females.

Crook *et al.* (51) and Edwards and Whyte (61) used skinfolds to increase the accuracy of predicting body fat when developing simpler methods for clinical purposes. Crook *et al.* combined the scapula skinfold and height-weight measurements to measure body fat within an average of ± 6.3 per cent of true per cent body fat. Edwards and Whyte derived several formulae for fat mass prediction using skinfold, height and weight as a simple measurement of obesity.

Zwiren *et al.* used a skinfold equation and body density for estimating small reduction in body fatness. It was apparent in this study that to obtain accuracy in assessing small changes in body composition the most accurate, valid, and reliable techniques must be employed (149).

ANTHROPOMETRIC MEASUREMENTS, SKELETAL SIZE AND LEAN BODY WEIGHT

Using a few simple anthropometric measurements for the prediction or estimation of accurate density, weight, relative and absolute body fat, or lean body weight can have practical significance. Because of this and because of the belief that assessing body composition has been important to the general population, methods have been developed which are applicable to field testing.

Skeleton size was the first basic method of assessment which was used as an indicator of the amount an individual should weigh. The Medico-Actuarial Investigation of 1912 used height as an indicator of skeleton size to determine optimum weight. The height-weight tables compiled by Davenport in 1923 have not changed appreciably since that time (78).

In 1959, Behnke, Guttentag, and Brodsky demonstrated that lean body weight can be calculated with remarkable accuracy from a few simple anthropometric measurements, rather than just height. Behnke (24) took skeletal measurements using calipers and validated them using x-rays. He showed that the estimation of lean body weight from skeletal measurements correlated well with total body water and with body density, as determined be underwater weighing. Coefficients in the range of r = 0.80 to 0.90 were reported.

In 1961, Behnke established the uses of eleven body circumferences, divided by a constant, as another method for determination of lean body weight. When this estimation of lean body weight was correlated with underwater weighing values, good results were obtained -- r = 0.8+ (25, 26, 33).

Behnke (27) subsequent refinement of his technique for estimating body weight resulted in work to include children and adolescents (28) and used potassium - 40 to validate lean body weight. He reported good results; r = 0.80.

Wilmore and Behnke reported an excellent correlation coefficient of r = 0.98 between lean body weight determination and underwater weighing values on fifty-four college age males. In 1969, these same authors conducted a similar study taking fifty-two measurements on one hundred and thirty-three young men and fifty-five measurements on one hundred and twenty-eight young women. They found comparable results, but these results have not yet been published. The correlation between predicted and actual body weight was r = 0.976 for men and r = 0.975 for women (2:57). In the original studies (134, 135) these same authors derived twelve estimation equations from the measurements on one hundred and thirty-three college age males and six estimation equations from the measurements on one hundred and twenty-eight young women. These estimations of density or lean body weight had good correlation coefficients when compared to underwater weighing data; r = 0.792 to 0.958 for men and r = 0.676 to 0.929 for women.

The concept of minimal weight as an entity distinct from lean body weight, was proposed by Behnke in his description of the female (29). In an investigation by Wilmore, Girandola, and Moody the estimated lean body weights for the girls were found higher than the actual values (4.47 - 5.24 kg), while the correlations were nearly the same as those reported in the original study (136). This difference between the anthropometrically and hydrostatically determined lean body weights was concluded to be accounted for by Behnke's concept of minimal weight in women (2:69-71).

SUMMARY

Many methods for determination of body composition have been used in various investigations. Underwater weighing for determination of body density, has been used and accepted as a valid procedure. Many methods for estimation of body composition have been developed using height, weight, skinfolds, girths and skeletal measurements.

Chapter 3

METHODOLOGY AND PROCEDURE

Introduction

The purpose of this study was to compare the validity of the more commonly used methods for the estimation of body composition of physically active adult women by correlating them with body density as determined by underwater weighing. The measurement of body density by underwater weighing, bone diameters, girths and skinfolds, were selected because they were required for the various methods for body composition estimation.

Equipment

The equipment used in this study included the following:

1. Homs full capacity beam scale (Model 300T serial no. 5314) Bench scale with blank tare calibration ¼ pound (Douglas Homs Corp., Belmont, California).
2. Health-o-meter (Continental Scale Corp., Chicago, Ill. #400 DGM) was used to measure subject's height.
3. Anthropometry equipment -- (Siber Hegner and Co., Inc., 8 W. 30th Street, N. Y. 1, N. Y.) included the following equipment:
   a) Anthropometer -- calibrated in centimeters
   b) Large sliding compass -- calibrated in centimeters
   c) Small sliding compass -- calibrated in centimeters
   d) Small spreading calipers -- calibrated in centimeters

e) Large spreading calipers -- calibrated in centimeters

f) Steel tape (Lufkin no. 146) -- calibrated in centimeters.

4. Harpenden skinfold calipers -- calibrated in 0.2 millimeters. (John Bull, British Indicator, Ltd., Leeds, England).

5. Underwater weighing equipment included the following:

a) The tank used for weighings was constructed of concrete built within the floor of the Exercise Physiology Research Lab of Kansas State University, Manhattan, Kansas. Its measurements were six feet long by four feet wide by six feet deep (designed by William B. Zuti).

b) The water was tap (or city) water. The temperature was maintained by adding hot water to raise the temperature to 37 degrees centigrade ± 0.5 degrees before each test.

c) Electronic "force cube" tranducers similar to Akers and Buskirk's system (15) were used to measure underwater weight. The weighing platform on which the subject sat, was constructed on aluminum and nylon webbing. The platform was suspended on the four force cubes mounted near the top edge of the tank. The subject's weight caused compression of the strain gages which was electronically transmitted to a servo-recorder (Model Eu-208; Heath Co., Benton Harbor, Michigan) where a graphic record was recorded. The subject wore a weighted jacket of fifteen pounds to help hold them on the platform during the submerged portion of the underwater weighing test.

d) The residual volume analyzer was a helium dilution residual volume analyzer system distributed commercially by Warren E. Collins, Inc., 220 Wood Rd., Braintree, Mass. The modification of the analyzer included lengthening the hoses and weighting them so that they would reach the subject in the tank and would remain submerged at the time of the underwater weighing, and offer no buoyancy.

Subjects

The subjects were fifty-one adult women volunteers, twenty-five to fifty years of age (premenopausal) in good general health. The mean age of the fifty-one subjects was 33.86 years. For the purposes of recruitment, notification and a description of the study was sent to all female participants in the Kansas State University's adult fitness program (Appendix A). The volunteers were women engaged in some form of regular physical activity. They had an average height of 64.94 inches and an average weight of 132.72 pounds.

Pre-Test Procedure

Prior to testing, subjects were asked to refrain from eating any gas-forming food for a forty-eight hour period, to completely fast four hours prior to testing, and to drink no fluids two hours before the test. The restriction of food and fluids prior to testing was to help eliminate any possible adverse affect on the underwater weighing. These variables could affect the calculation of fat and density in either a positive and negative way. The restriction on gas-forming foods was intended to reduce the error due to gas in the gastrointestinal region. Because this variable is hard to control, Buskirk (45) has recommended a correction of one hundred milliliters, due to gastrointestinal air (21, 22) in calculating density.

Prior to testing, the subjects signed informed consent forms (Appendix B). The subject's personal data was recorded and all possible body wastes were excreted. The subject's land weight and height were recorded while clothed only in a nylon or knit swim suit which she wore for the remainder of testing.

Procedure for Anthropometric Measurements

Body weight and anthropometric measurements were taken prior to the underwater weighing. The measurements taken included the following:

1. Body weight -- This measurement of nude land weight was taken to the nearest ounce on a Homs full capacity balance beam scale.
2. Skeletal measurements -- These measurements were taken with the anthropometric equipment according to the procedure described by Montagu (12), Behnke (26), Steinkamp (123, 124), Wilmore and Behnke (135), von Dobeln (127), and Zuti and Golding (148). These measurements and their locations taken to the nearest .05 centimeters included the following:
   a) Bi-acromial width was measured with a sliding compass across the most lateral aspect of the acromion processes of the scapula, with the arms at the side.

b) Chest breadth was measured with a sliding compass across the angle of the sixth rib with the arms at the side. The mean was taken between inspiration and expiration measurements.

c) Thorax diameter (chest depth) was measured with spreading calipers from the mesosternal position to the spine of the thorax vertebrae at a corresponding height. The mean was taken between inspiration and expiration measurements.

d) Bi-iliac diameter (hip breadth) was measured with a sliding compass across the most lateral aspects of the iliac crests.

e) Bi-trochanter diameter was measured with spreading calipers across the most lateral portion of the great trochanters of the femur. Measurement was taken with the feet placed together.

f) Elbow width (both right and left) was measured with a small sliding compass across the epicondyles of the humerus. Measurement was taken with the elbow flexed.

g) Wrist width (both right and left) was measured with a small sliding compass between the styloid processes of the radius and ulna.

h) Knee width (both right and left) was measured with a small sliding compass across the condyles of the femur. Measurement was taken with knee flexed.

i) Ankle width (both right and left) was measured with a small sliding caliper at the greatest distance between the malleoli.

j) Upperarm length was measured with a sliding compass from the lateral margin of the acromial process of the scapula to the tip of the olecranon process with the arm relaxed but slightly flexed at the elbow.

k) Lower arm length was measured with a sliding compass from the tip of the olecranon process to the styloid process with the arm relaxed but slightly flexed at the elbow.

3. Skinfold measurements -- These measurements of subcutaneous fat were taken on the left side of the body using harpenden calipers by the methods described by Pascale (101), Steinkamp (123, 124), Wilmore and Behnke (135), Young (143, 146), and Zuti and Golding (148). These measurements and their locations taken to the nearest 0.2 millimeters included the following:

a) Chin was taken under the mandible as a vertical fold, running between the chin and neck.

b) Cheek was taken as a vertical fold, midway between the corner of the mouth and the temporalis of the mandible.

c) Pectoral was taken on the pectoral line about two-three inches below the anterior axillary fold toward the nipple. The measurement is taken with the fold parallel to the pectoral tendon line.

d) Mid axillary was taken as a vertical fold on the mid axillary line at the mid sternum level.

e) Umbilicus (abdominal) was taken as a vertical fold adjacent to the umbilicus.

f) Iliac crest was taken as an oblique fold on the iliac crest at the mid axillary line.

g) Suprailiac was taken as a vertical fold on the crest of the ilium at the mid axillary line.

h) Pubic was taken as a horizontal fold midway between the pubic symphysis and the umbilicus.

i) Waist was taken as a vertical fold on the mid axillary line midway between the twelfth rib and the iliac crest.

j) Scapula was taken on the inferior angle of the scapula with the fold parallel to the vertebral border of the scapula.

k) Mid triceps was taken as a vertical fold midway between the acromion and olecranon processes on the posterior side of the arm hanging relaxed.

l) Front thigh was taken as a vertical fold on the anterior side of the thigh midway between the knee and the hip joint.

m) Rear thigh was taken as a vertical fold opposite the anterior thigh measurement.

n) Lateral thigh was taken as a vertical fold at the level of the gluteal furror on the lateral mid line.

o) Interior thigh (groin) was taken as a vertical fold just below the pubis on the interior mid line of the thigh.

p) Calf was taken as a vertical fold at the largest portion of the posterior lower leg.

q) Knee was taken as a vertical fold at the midpoint of the patella.

4. Body circumference -- These measurements of the trunk and limb girths were taken using a steel tape measure on the right side according to the methods described by Behnke (26), Montagu (12), Steinkamp (123, 124), Wilmore and Behnke (135), Young _et al_. (143, 146), and Zuti and Golding (148). These measurements and locations to the nearest 0.1 centimeters included the following:

a) Neck was measured just below the larynx.

b) Maximum upper arm (biceps flexed) was measured at the point of the greatest circumference with the elbow in a flexed position.

c) Upperarm (biceps extended) was measured at the maximal girth of the mid arm when the elbow is locked in maximal extension with the underlying muscles fully contracted.

d) Forearm was measured at the maximal girth with the elbow extended and the hand supinated.

e) Chest (normal, minimum, maximum). All three of these chest girth measurements were taken at the nipple line in a horizontal plane: minimum girth, at the point of maximum exhalation; maximum girth, at the point of maximum inhalation; and, normal girth, at the midpoint of normal inhalation and exhalation.

f) Chest (above the bust line) was measured in the horizontal plane just above the bust line in the axillary folds, and recorded at the midpoint of normal respiration.

g) Chest (below the bust line) was measured in the horizontal plane just below the bust line and recorded at the midpoint of normal respiration.

h) Waist was measured in the horizontal plane positional at the narrow part of the waist.

i) Hips at the iliac crest were measured in the horizontal plane positioned on the iliac crest.

j) Maximum hip was measured in the horizontal plane at the maximal protrusion of the gluteal muscles, subject's legs together.

k) Maximal diameter around both thighs was measured in the horizontal plane with the tape at the greatest lateral protrusion of the upper thigh, subject's legs together.

l) Thigh at groin level was measured in the horizontal plane at groin, measurement taken just on the right leg with subject supporting her weight on that leg.

m) Mid thigh was measured with subject in same position as thigh at groin with tape positioned midway between the level of the pubic symphysis and the patella.

n) Thigh (two inches above patella) was measured in the horizontal plane with the tape positioned two inches above the patella with the subject's weight on that leg.

o) Maximum lower leg (calf) was measured in the horizontal plane with the tape positioned at the largest portion of the calf and the subject standing with her weight on the leg.

p) Knee (both right and left) was measured in the horizontal plane at the mid patellar level, with weight on the measured leg.

q) Ankle (both right and left) was measured at the minimal girth, superior to the malleoli.

r) Elbow (both right and left) was measured at the minimal girth, just proximal to the condyles of the humerus.

s) Wrist (both right and left) was measured at the minimal girth just distal to the styloid processes of the radius and ulna.

Procedure for Underwater Weighing

This was the last measurement in the battery of tests. Prior to testing the weighing platform and the weighted vest were placed in the tank at least one hour before starting the test to allow complete saturation of porous material, and to allow the water to settle and become as quiet as possible. The chart recorder for underwater weighing was calibrated to zero with the jacket and weighted hoses of the analyzer in the water on the platform. The residual volume analyzer was checked for leaks and was primed with a mixture of room air and a known amount of helium (usually 1000 cc ATPS). The per cent of helium of this mixture was read and recorded.

A "dry run" on the testing procedures was given before the subject entered the tank. The subject was fitted with a noseclip and mouthpiece after which the procedure for breathing into the analyzer was practiced. Then an explanation of the tank was made prior to lowering the subject into the tank. Before being seated on the platform in chin deep water, a fifteen pound weighted jacket was put on the subject. The subject was then allowed to practice submerging from this position to become more familiar with the procedure.

The mouthpiece of the analyzer was handed to the subject seated on the platform chair. On instructions to take a breath, the valve on the mouthpiece was turned from snorkle to the residual volume analyzer prior to the subject's leaning forward to submerge. This breath was held throughout the underwater weighing. Observation of the kymograph

graph assured that the subject retained a constant breath while leaning forward during the underwater weighing. After the underwater weight was recorded the subject was instructed to raise her head, but to remain seated while breathing into the analyzer for the determination of the functional residual volume.

Once the residual volume was recorded the mouthpiece was removed and then the subject was removed from the platform to a standing position in the tank. The jacket was removed and placed on the platform with the weighted hoses of the analyzer. The subject was instructed to stand very quietly while the underwater weighing chart recorder was checked for electronic drift before repeating the test. This procedure was repeated four to five times for all subjects to insure consistency in the underwater weighing. Density was determined as the mean of the last three weighings.

Residual Volume

The procedure used for the determination of residual volume is similar to that described by Motley (95). After calibration of the analyzer, a measured quantity of helium (about 1000 cc) was added, along with several liters (usually 4-5) of additional room air. The per cent helium of this mixture was read and recorded before the start of the underwater weighing.

After the underwater weight was determined, the subject remained in a sitting position and breathed the mixture of room air and helium in the analyzer for three to four minutes. The subject's expired air was force-circulated through baralyme ($Ca(CO_3)_2$) to remove the carbon dioxide (CO_2) before it was returned to the system and oxygen was added to keep the end total volume the same. The kymograph tracing of analyzer bell indicated when equilibrium was reached, by showing a horizontal base line and no change in the percentage of helium. At this point, the second reading of per cent helium was taken and recorded along with the temperature of the air in the bell.

The calculation of the residual volume was based on the reduction of the relative concentration of helium when the subject's lung volume was added to the system. The total volume of the analyzer was calculated from the known quantity of helium (1000 cc) and its relative concentration (@ 8%). When the subject's lung volume was added to the system, the percentage of helium dropped due to the increase in the total system. This larger system volume minus the smaller system volume gives the volume of the system contributed by the lung volume of the subject. This was the functional residual volume. The buoyancy force caused by the quantity of air was corrected for when the subject's density was calculated (45).

Prediction Methods

Data for this study was used in both raw and calculated forms. The raw data included all measurements taken. Calculated data included the estimations from equations and underwater weight data. The methods and procedures for the estimation of body composition for the various methods studied included the following:

1. Young et al. (143) proposed a practical equation for predicting specific gravity of young women. The equation was proposed for women seventeen to thirty years of age and based on a single pubic skinfold and percentage of standard weight.

$$SG\ 17\text{-}30 = 1.0884 - 0.0004231 \times \text{pubic} - 0.0003401 \times \text{percentage "standard" weight (average weight per height and age)}\ (13).$$

2. Young et al. (146) proposed three equations for the prediction of specific gravity in eighty-eight "older" women. The first was proposed for women forty to seventy years of age and used three skinfold measurements. The other two equations used the anthropometric measurement of the deltoid diameter which was not measured in this study.

$$SG_{40-70} = 1.05555 - 0.0007109 \times \text{abdominal} - 0.0012239 \times \text{chin} - 0.0007728 \times \text{chest (axillary border pectoral major)} + 0.0004196 \times \text{suprailiac}.$$

3. Ruth Steinkamp (124) developed five equations for estimation of body fat, two of which may be used here. The first is for females twenty-five to thirty-four years of age and the second for females thirty-five to forty-four years.

Fat_{25-34} = upper arm (C) x 0.354 + mid thigh (C) x 0.403 + abdominal (S) x 0.159 + weight (pounds) x 0.083 - 26.189.

Fat_{35-44} = Weight (pounds) x 0.300 - wrist (C) x 1.855 + triceps (S) x 0.169 - upper arm length x 0.511 + 23.173.

4. Wilmore and Behnke (135) proposed six new equations for the estimation of lean body weight or density. Three are reviewed in this study. The first was proposed for females eighteen to forty-eight years of age and used three simple skinfold measurements for the prediction of density.

D_{18-48} = 1.06234 - 0.00068 x scapula - 0.00039 x triceps - 0.00025 x thigh.

5. Wilmore and Behnke (135) proposed a second equation using weight and three skinfold measurements for the prediction of lean body weight.

LBW_{18-48} = 8.629 + 0.680 x weight (kilograms) - 0.163 x scapula - 0.100 x triceps - 0.054 x thigh.

6. Sloan, Burt and Blyth (119) using only two skinfold measurements, predicted density for females seventeen to twenty-five years of age.

D = 1.0764 - 0.00081 x suprailiac - 0.00088 x triceps.

7. Katch and Michael (75) using two skinfold and two girth measurements, predicted density for young women nineteen to twenty-three years of age.

D = 1.12569 - 0.001835 x triceps (S) - 0.002779 x maximum hip (inches) (C) + 0.005419 x upperarm (biceps flexed, inches) (C) - 0.0007167 x scapula (S).

8. Wilmore and Behnke (135) proposed a third equation for the prediction of lean body weight using weight, skeletal diameter and three circumference measurements.

LBW = 8.987 + 0.732 x weight (kilograms) + 3.786 x wrist (D) - 0.157 x maximum abdominal (iliac) (C) - 0.249 x maximum hip (C) + 0.434 x forearm (C).

9. Pollock _et al_. (105) proposed two equations for the prediction of density in females. The first was proposed from a combination of measurements for young women eighteen to twenty-two years of age.

D_{18-22} = 1.0836 - 0.0007 x suprailiac (S) - 0.0007 x thigh (S) + .0048 x wrist (C) - 0.0088 x knee (D).

10. Pollock _et al_. (105) proposed a second equation for women thirty-three to fifty years. Cup size was considered a factor not used in previous research, and was found to be

a good predictor variable for middle-aged women. The best combination of four variables for predicting density was cup size, waist girth, and two skinfold measurements.

$$D_{33-50} = 1.1023 - 0.0005 \times \text{suprailiac (S)} - 0.0003 \times \text{thigh (S)} - 0.0005 \times \text{waist (C)} - 0.0033 \times \text{cup size.}$$

Four equations for comparison of per cent fat variation from the same density were compared. The equations included the following:

1. Siri (115)

$$\% \text{ fat} = 100 \frac{4.95}{(\text{ D } - 4.50 \text{ })}$$

2. Rathbun and Pace (108)

$$\% \text{ fat} = 100 \left(\frac{5.548}{SG} - 5.044\right)$$

3. Keys and Brozek (40)

$$\% \text{ fat} = 100 \left(\frac{4.201}{D} - 3.813\right)$$

4. Allen (18)

$$\% \text{ fat} = 100 \left(\frac{4.834}{D} - 4.336\right)$$

For this study, the equation of Brozek *et al*. (44) was used to estimate per cent fat from density obtained from underwater weighing.

$$\% \text{ fat} = 100 \left(\frac{4.570}{D} - 4.142\right)$$

Statistical Treatment of Data

The data collected from underwater weighing and residual volume for each subject's tests was computed on the Olivetti Underwood electric desk programmable calculator in the Exercise Physiology Laboratory of Kansas State University. The calculations included the residual volume for underwater weighing, residual volume lift, body volume, density, specific gravity, per cent fat, total body fat and lean body weight.

All laboratory calculations, raw data, and estimation equations were sent to the university's computer center. The calculation of estimation equations, as well as the statistical calculations, were accomplished by the center. Pearson Product Moment correlations were computed for the raw and calculated data for all equations. Interpretation of the validity for each equation was determined by its correlation with the corresponding variable from the underwater weighing.

Chapter 4

RESULTS AND DISCUSSION

Introduction

Descriptive statistics were computed for the raw and calculated data from the equations. The mean values, standard deviations and ranges for all measurements and estimation equations were calculated by the computer center and are shown in Table 1.

Pearson Product Moment correlations were computed for the raw and calculated data from the equations. A simple matrix of ten variables correlated to all measurements and estimation equations was produced, which included underwater weighing (Appendix C). The measurements and estimation equations which were correlated with density determined by underwater weighing are shown in Table 2. The mean values (Table 1) for estimation equations were correlated to mean values of underwater weighing to determine accuracy. The estimation equations predicting density could be compared directly. For other measurements underwater weighing values were converted to per cent fat, specific gravity, total body fat or lean body weight by Brozek *et al*. equation (44).

Results

Several prediction equations correlated well with the underwater weighing values. The best correlations were obtained by the methods of Steinkamp and Wilmore and Behnke. These methods did not

Table 1.1

Age and Physical Characteristics of 51 Women

Variable	Mean	SD	Range
Age, year	33.863	8.139	25.000 - 50.000
Height, inches	64.939	2.248	60.500 - 69.000
Weight, pounds	132.722	19.112	104.190 - 186.500
Body volume	126.004	19.414	97.130 - 180.680
Specific gravity	1.0517	0.0137	1.025 - 1.079
Fat, percent*	22.1545	5.6923	11.200 - 33.410
Total Body Fat, pounds	30.1623	11.3022	12.230 - 59.050
Total Body Fat, kilograms	13.57	5.086	5.504 - 26.573
Lean Body Weight, pounds	102.5602	10.5300	84.030 - 130.650
Lean Body Weight, kilograms	46.15	4.7385	37.814 - 58.793
Body Density, g/ml (underwater weighing)	1.0549	0.0138	1.028 - 1.082
Cup size	1.902	0.671	1.000 - 3.000
Standard Per Cent Weight**	.9803	0.1210	.734 - 1.371

* Brozek (44): $\% \text{ fat} = 100 \left(\frac{4.570}{D} - 4.142\right)$

** Calculated on basis of average weights in Build and Blood Pressure Study, 1959 (13).

Table 1.2

Means, Standard Deviations and Range for
Selected Bone Measurements (N = 51)

Variable	Units	Means	SD	Range
Wrist Right	mm	4.9657	0.3006	4.50 - 5.80
Wrist Left	mm	4.8402	0.2693	4.30 - 5.70
Elbow Right	mm	6.0363	0.3100	5.40 - 6.80
Elbow Left	mm	5.9559	0.3038	5.20 - 6.70
Knee Right	mm	8.5608	0.6129	6.00 - 9.90
Knee Left	mm	8.5667	0.6052	6.05 - 9.60
Ankle Right	mm	6.1912	0.3129	5.50 - 6.80
Ankle Left	mm	6.3020	0.2816	5.70 - 6.90
Bi-acromial Bdth	mm	35.9921	2.2497	27.40 - 40.40
Bitrochanteric Bdth	mm	31.1941	2.4844	27.00 - 40.80
Chest	mm	26.9902	2.3601	23.80 - 36.70
Chest depth	mm	17.8725	1.7757	12.90 - 22.80
Bi-ilium	mm	29.0863	2.0323	25.40 - 35.00
Arm length upper	mm	31.1127	1.626	27.50 - 34.00
Arm length lower	mm	24.1882	2.0850	20.40 - 35.60

Table 1.3

Means, Standard Deviations and Range for Selected Body Circumferences (N = 51)

Variable	Units	Means	SD	Range
Neck	cm	30.5314	1.5380	27.80 - 34.20
Biceps Flexed	cm	27.1941	2.3165	23.00 - 33.80
Biceps Extended	cm	25.2912	2.3231	21.00 - 30.30
Chest Nipple	cm	89.4961	6.0513	80.00 - 106.50
Chest Exhale	cm	86.9529	6.2555	76.00 - 104.50
Chest Inhale	cm	92.5118	6.1543	80.50 - 111.00
Chest Above	cm	84.4118	4.8882	75.00 - 95.50
Chest Below	cm	75.6804	5.9436	66.50 - 93.50
Waist Minimum	cm	68.3470	6.2371	59.20 - 83.50
Iliac	cm	82.8402	7.1279	67.50 - 98.00
Hip Maximum	cm	95.4333	6.6800	85.00 - 112.00
Thigh Maximum	cm	95.5863	6.9268	85.00 - 115.00
Groin	cm	57.8451	4.7927	51.00 - 70.60
Thigh Mid	cm	48.4255	4.4773	36.00 - 61.00
Ht. above patella	cm	13.3529	0.9343	12.00 - 16.00
2" above Patella	cm	38.0372	3.0929	31.00 - 46.00
Calf Maximum	cm	34.3922	2.3013	29.50 - 39.20
Forearm Extended Supinated	cm	23.1461	1.3932	20.80 - 26.60
Knee Right	cm	33.6363	2.0534	29.00 - 38.50

Table 1.3 (Continued)

Variable	Units	Mean	SD	Range
Ankle Right	cm	21.2010	1.1677	18.50 - 23.80
Elbow Right	cm	23.0980	1.3748	20.00 - 26.70
Wrist Right	cm	14.7627	0.7820	13.20 - 16.30
Knee Left	cm	33.6843	2.0898	28.00 - 38.00
Ankle Left	cm	20.9225	1.1622	18.00 - 23.10
Elbow Left	cm	22.9000	1.2248	20.80 - 26.00
Wrist Left	cm	14.5745	0.6911	13.40 - 16.50

Table 1.4

Means, Standard Deviations and Range for
Selected Skinfold Measurements (N = 51)

Variable	Units	Means	SD	Range
Chin	mm	7.7412	2.0490	4.00 - 13.00
Cheek	mm	9.8765	2.0205	5.50 - 15.00
Pectoral	mm	11.6667	4.3597	5.00 - 22.50
Scapular	mm	13.6039	5.0808	6.00 - 30.50
Triceps	mm	15.8706	5.3556	7.00 - 33.50
Mid Axillary	mm	12.1333	5.4541	4.50 - 34.00
Abdominal	mm	17.2314	8.0630	7.00 - 42.00
Iliac Front	mm	13.1765	5.6212	4.00 - 27.50
Suprailiac	mm	16.3431	7.7888	5.50 - 37.00
Pubic	mm	24.8098	9.5643	6.00 - 47.00
Lower rib	mm	11.7059	5.6207	4.50 - 28.00
Groin	mm	16.8431	7.1088	6.00 - 35.00
Thigh Front	mm	24.7353	6.5760	13.50 - 44.00
Thigh Rear	mm	22.3235	5.2952	13.00 - 35.00
Thigh Lateral	mm	28.7451	7.4172	11.00 - 48.00
Calf	mm	16.4510	4.3844	6.50 - 26.00
Knee	mm	8.5392	2.2380	4.00 - 15.00

Table 1.5

Means, Standard Deviations and Range for Estimation Equations (N = 51)

Variable	Units	Mean	SD	Range
Young 16-30	Specific Gravity	1.0776	0.0043	1.068 - 1.085
Young 40-70	Specific Gravity	1.0317	0.0077	1.008 - 1.045
Steinkamp 25-34	Total Body Fat (kg)	17.2402	4.9441	7.517 - 28.468
Steinkamp 35-44	Total Body Fat (kg)	22.3881	5.1341	14.073 - 36.180
Wilmore & Behnke 18-48	Density	1.0407	0.0060	1.024 - 1.051
Wilmore & Behnke -S-	Lean Body Weight	44.4265	4.9265	36.794 - 57.088
Sloan, Burt & Blyth	Density	1.0492	0.0097	1.025 - 1.064
Katch & Michael	Density	1.0404	0.0138	1.008 - 1.065
Wilmore & Behnke -CD-	Lean Body Weight	45.1319	5.2216	35.629 - 60.568
Pollock 18-22	Density	1.0504	0.0116	1.024 - 1.078
Pollock 33-50	Density	1.0462	0.0090	1.026 - 1.060
% Fat Siri	Per Cent	19.3384	6.1180	7.448 - 31.424
% Fat Rathbun & Pace	Per Cent	23.2288	6.8759	9.856 - 36.815
% Fat Brozek & Keys	Per Cent	17.0213	5.1923	6.930 - 27.278
% Fat Allen	Per Cent	24.7398	5.9746	13.128 - 36.542

Table 2.1

The Correlation of Density Determined by Underwater Weighing with Selected Bone Measurements in Descending Order (N = 51)

Variable	Correlation Coefficient (r)
Chest	0.51
Trochanter Breadth	0.47
Bi-ilium	0.45
Chest Depth	0.42
Knee Right	0.42
Knee Left	0.39
Bi-acromial Breadth	0.35
Elbow Left	0.22
Arm Length Upper	0.21
Ankle Right	0.20
Ankle Left	0.18
Wrist Right	0.18
Wrist Left	0.17
Elbow Right	0.16
Arm Length Lower	0.14

Table 2.2

The Correlation of Density Determined by Underwater Weighing with Selected Body Circumference Measurements in Descending Order (N = 51)

Variable	Correlation Coefficient (r)
Biceps Extended	0.78
Groin	0.78
Thigh Maximum	0.78
Hip Maximum	0.78
Biceps Flexed	0.73
2" Patella	0.64
Knee Left	0.63
Chest Exhale	0.62
Thigh Mid	0.60
Knee Right	0.60
Chest Nipple	0.59
Calf Maximum	0.58
Iliac	0.58
Waist Minimum	0.57
Elbow Left	0.56
Elbow Right	0.54
Chest Above	0.54
Forearm Extended Supinated	0.53

Table 2.2 (Continued)

Variable	Correlation Coefficient (r)
Chest Inhale	0.53
Chest Below	0.51
Wrist Left	0.50
Ankle Right	0.48
Ankle Left	0.48
Wrist Right	0.41
Neck	0.38

Table 2.3

The Correlation of Density Determined by Underwater Weighing with Selected Skinfold Measurements in Descending Order (N = 51)

Variable	Correlation Coefficients (r)
Thigh front	0.76
Thigh lateral	0.70
Thigh rear	0.69
Groin	0.68
Suprailiac	0.66
Triceps	0.65
Abdominal	0.64
Iliac Front	0.59
Mid Axillary	0.59
Pubic	0.59
Chin	0.54
Lower Rib	0.53
Pectoral	0.52
Calf	0.48
Scapula	0.48
Cheek	0.42
Knee	0.41

Table 2.4

The Correlation of Corresponding Variables Determined by Underwater Weighing with Estimation Equations in Descending Order (N = 51)

Equation	Variable	Correlation Coefficients (r)
Steinkamp 35-44	Total Body Fat	0.8952
Wilmore and Behnke -S-	Lean Body Weight	0.8869
Wilmore and Behnke -CD-	Lean Body Weight	0.8853
Steinkamp 25-34	Total Body Fat	0.8798
Pollock 33-50	Density	0.7760
Katch and Michael	Density	0.7449
Sloan, Burt and Blyth	Density	0.7397
Wilmore and Behnke	Density	0.7304
Pollock 18-22	Density	0.6733
Young 40-70	Specific Gravity	0.5992
Young 16-30	Specific Gravity	0.5778

predict density but instead estimated either total body fat or lean body weight. Steinkamp's equation for age group thirty-five to forty-four years correlated the highest with a correlation coefficient of r = 0.90. Wilmore and Behnke's skinfold and circumference-diameter prediction equations were next with a correlation coefficient of r = 0.89 for both equations. Steinkamp's second equation for age group twenty-five to thirty-four had a correlation coefficient of r = 0.88. It can be noted that Steinkamp (124) and Wilmore and Behnke (135), in their original work, reported correlations of r = 0.98, r = 0.92, and r = 0.94, respectively with underwater weighing values.

Equations for estimating density all correlated lower than Steinkamp's total body fat or Wilmore and Behnke's lean body weight methods. Pollock's et al. (105) regression equation for age group thirty-three to fifty years of age had the highest correlation coefficient of r = 0.78. Pollock's equation for age group eighteen to twenty-two years correlated the lowest with a correlation coefficient of r = 0.67, but predicted a mean value that was nearest to density determined by underwater weighing. These were the only two prediction equations for density which correlated lower than the results from their original studies. Pollock's thirty-three to fifty method reported a correlation coefficient of r = 0.89, and an r = 0.83 for the younger age group.

The equations of Wilmore and Behnke; Sloan, Burt and Blyth and Katch and Michael all correlated as well or higher than their original work. Correlation coefficients of r = 0.73, r = 0.74 and r = 0.74, respectively were found in the present study and r = 0.68, r = 0.74, and r = 0.70, respectively in their original work.

Young's prediction equations which estimated specific gravity had the lowest correlation values as compared to underwater weighing values. The prediction method for the age sixteen to thirty group had a correlation coefficient of r = 0.58. The original work reported a correlation of r = 0.70. Young's second method for age group forty to seventy had a correlation coefficient of r = 0.60 in the present study and a correlation of r = 0.78 in the original study.

Discussion

The data would indicate that if the estimation equation using other anthropometric measurements could include body weight, the prediction might be more accurate. The best correlations with underwater weighing values in the present study all included body weight in each of the regression equations. Body weight had a correlation of r = 0.72 with density for underwater weighing. Body weight had a correlation of r = 0.88 with total body fat from underwater weighing. In Steinkamp's original study for thirty-five to forty-four age group equation, body weight had a correlation of r = 0.96 with total body fat and a correlation of r = 0.87 for the younger age group. Body weight in Steinkamp's equation for older group correlated higher with total body fat than density. The equation also included a combination of skinfold, girth and diameter variables. The triceps skinfold was the only predictor variable which did not correlate better than those predictor variables of the original regression equation.

The body weight predictor variable did not correlate as high with density as total body fat. This factor may have been an influence on Wilmore and Behnke's regression equations correlations. The predictor variables in these equations showed no distinct pattern of prediction. Although Wilmore and Behnke's best skinfold predictors were subscapula and mid axillary, the best skinfold predictor in this study was thigh front. The predictor variable of body weight was the second best value in both equations.

Steinkamp's equation for the younger age group had the highest predictor variable of r = 0.88 for body weight. The other predictor variables of biceps extended girth (r = .84), mid thigh girth (r = .72), and pubic skinfold (r = .63) were lower than the original predictor variables. The original predictor variables were r = .88, r = 0.88, and r = 0.80, respectively.

Pollock's thirty-three to fifty years of age group was the best predictor for density. The thigh skinfold (r = 0.76) was the best predictor variable but the suprailiac skinfold (r = 0.66) and waist girth (r = 0.57) predictor variables were very low as compared to Pollock's original variables of r = 0.82 and r = 0.83, respectively. These two variables were Pollock's best single predictors for skinfolds and girths of middle-aged women.

Pollock's eighteen to twenty-two year age group was the lowest in correlation values as compared to underwater weighing values. Yet the equation predicted a body density mean value nearest to the actual predicted value. Pollock's equation had a mean value of 1.0504, and the value determined by underwater weighing was 1.0549. The predictor variables were suprailiac skinfold, thigh skinfold, wrist girth, and knee diameter. The predictor variables were $r = 0.66$, $r = 0.76$, $r = 0.51$ and $r = 0.50$, respectively for this study. The original values were $r = 0.66$, $r = 0.73$, $r = 0.19$ and $r = 0.42$, respectively.

Individual Measurements

Several individual body measurements had good correlations with density as shown in Tables 2.2 and 2.3 (biceps extended girth, groin girth, thigh maximum girth, hip maximum girth, thigh front skinfold, biceps flexed girth, and thigh lateral skinfold). Other investigators (135, 143, 105, 75) have found results correlating with density to produce much lower correlations. Pollock's (105) study found results for biceps extended girth, hip maximum girth and thigh skinfold nearest to the present study's correlations.

Factors Affecting Estimation

The sex, race, age and amount of physical activity engaged in by an individual can greatly influence anthropometric data (100). In a recent study on young and middle-aged women, the data supported the need for different regression equations for different age groups (105). The present study used adult Caucasian females in some form of physical activity. Many of the estimation equations used in this study considered age, but not physical activity. It is generally agreed that increasing age sometimes causes muscle atrophy, while physical activity may prevent atrophy, or even cause hypertrophy. When used with older population, the equation based on younger women should show a consistently higher density prediction; this may result from the lesser muscle mass of the older women. On the other hand, physically active women may not have as much muscle atrophy as the inactive women of the same age, giving the reverse effect of predicting lower density values. The higher specific gravity estimation obtained by using Young's method for sixteen to thirty years of age may be due to this age and physical activity explanation since this equation was developed on young women. Yet, the density values for the methods of Sloan, Burt and Blyth; Katch and Michael and Pollock's eighteen to twenty-two years of age, did not produce higher estimations. Instead Sloan, Burt and Blyth's and Pollock's methods predicted mean values of density that were very near to density determined by underwater weighing. Although Steinkamp used subjects of same age as the present study, her higher total body fat values may be due to the fact that the subjects were sedentary. Wilmore and Behnke's methods for determining lean body weight predicted mean values that were near to underwater weighing determined values even though the subject's may not have been physically active.

Recommended Methods

Steinkamp's equation for thirty-five to forty-four years of age had the highest correlation with underwater weighing values of total body fat, but predicted mean values which were higher than underwater weighing. The equations by Wilmore and Behnke for lean body weight prediction had a high correlation with underwater weighing values, but both consistently predicted lower lean body values than the underwater weighing. However, the predicted mean values were only one or two kilograms different from the actual mean values of underwater weighing. The actual values were higher than the predicted values. These methods would be the most valid estimations of lean body weight for the population.

Steinkamp's second equation for twenty-five to thirty-four years of age had a high correlation with underwater weighing values of total body fat and predicted mean values which were nearer to the underwater weighing mean values of total body fat than her equation for the older age group. The mean values had a difference of three to four kilograms of total body fat between the equation's mean values and underwater values.

Chapter 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

In this study, a comparison was made of the some commonly used body composition equations for females by comparing their results with those obtained by underwater weighing. The fifty-one subjects in this study were adult females between the ages of twenty-five and fifty years of age prior to menopause. They were all engaged in some form of regular physical activity. The mean age of the subjects was 33.9 years. They had an average height of 64.94 inches and an average weight of 132.72 pounds. The female volunteers were participants in the Kansas State University's adult fitness program.

Body weight, height and anthropometric measurements of girths, skinfolds and diameters were taken prior to the underwater weighing. The subject was clothed only in a nylon or knit swimsuit which was worn for the remainder of testing. The underwater weighing was measured by electronic "force cube" tranducers system similar to Akers and Buskirk's (15). The residual volume was measured following the underwater weighing by a helium dilution residual volume analyzer system similar to that described by Motley (95).

The data calculated in the laboratory included the residual volume for underwater weighing, residual volume lift, body volume, density, specific gravity, per cent fat, total body fat and lean body weight. All statistical calculation and Pearson Product Moment correlations were computed for the raw and calculated data from the equations. Interpretations of the validity for each equation was determined by its correlation with the corresponding variable from the underwater weighing.

Several prediction equations correlated well with underwater weighing values. The best correlations were obtained by the methods of Steinkamp and Wilmore and Behnke. These methods did not predict density but instead estimated either total body fat or lean body weight. Steinkamp's equation for age group thirty-five to forty-four years correlated the highest with a correlation coefficient of $r = 0.90$. Wilmore and Behnke's skinfold and circumference-diameter prediction equations were next with a correlation of $r = 0.89$ for both equations. Steinkamp's second equation for age group twenty-five to thirty-four had a correlation coefficient of $r = 0.88$. The reported correlations in the original studies all reported higher underwater values.

Equations predicting density all correlated lower than Steinkamp's total body fat or Wilmore and Behnke's lean body weight methods. Pollock's regression equations predicting body density for age group thirty-three to fifty had the highest correlation coefficient of $r = 0.78$. Pollock's second equation for the younger age group predicted a mean value that was nearest to mean density value determined by underwater weighing. The other density equations by Wilmore and Behnke, Sloan, Burt and Blyth, and Katch and Michael all correlated as well or higher than their original work. The equations predicting specific gravity by Young both correlated very low with underwater weighing values as compared to their original studies.

Conclusions

Conclusions based on the results of this study included the following.

1. Of the estimation equations studied, the methods by Wilmore and Behnke for determining lean body weight for women eighteen to forty-eight years of age were the most accurate estimation for the population. The standard error of estimation for Wilmore and Behnke's skinfold equation was ±0.690 and the circumference-diameter equation's standard error of estimation was ±0.731. Although the method by Steinkamp for thirty-five to forty-four years of age had a slightly higher correlation than Wilmore and Behnke, the equation consistently estimated higher total body fat values than were obtained from underwater weighing. Steinkamp's standard error of estimation for this equation was ±0.692.

2. The method by Steinkamp for twenty-five to thirty-four years of age, due to its high correlation with underwater weighing values, is a good equation to use for estimating body composition; however, the actual values may over-estimate total body fat. While the mean value for this study's subjects was 13.57 kilograms of total body fat, Steinkamp's equation predicted a mean value of 17.2402 kilograms

of total body fat. The standard error of estimation for this equation was ±0.719.

3. Seven individual measurements had fairly high correlations with density determined by underwater weighing (biceps extended girth, groin girth, thigh maximum girth, hip maximum girth, thigh front skinfold, biceps flexed girth, and thigh lateral skinfold).

4. Although none of the equations had exceptionally high correlations with density determined by underwater weighing, a few could be used with confidence. However, if a study has body composition of density as its main experimental variable, no equation could be substituted for actual underwater weighing of the subjects.

5. The variable of body weight was found included in each of the recommended equations. The data would indicate that if equations using anthropometric measurements could include body weight, the prediction might be more valid.

Recommendations

Recommendations based on the results of this study are as follows.

1. This study did not evaluate all the equations proposed by Wilmore and Behnke (135) and Young (143, 146); future studies should consider this work.

2. The results of this study recommend the use of Wilmore and Behnke's estimation equations for lean body weight and Steinkamp's

estimation equations for total body fat for the estimation of body composition if underwater weighing is not feasible, or when body composition is not the main experimental variable.

3. The selection of the prediction equation should consider the age, sex, race and physical activity of the population being studied.

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APPENDIX A

RECRUITMENT LETTER

Dear Ms.

I am writing to ask your help. We, in the Exercise Physiology Research Lab, have undertaken a research project to assess methods for estimating body composition of adult women engaged in regular physical activity. Since you are a regular participant in the adult fitness program or related activities here at Kansas State University, we would ask you to assist us in our research by donating one hour of your time. The project involves a method of estimating the percentage of fat in the human body using simple skinfold, girth or bone measurements. We will be taking about 40 such measurements on you, as well as doing underwater weighing which is a more accurate and complicated method of determining body composition. The study would require you to report to our laboratory for a one-hour testing session. During this test, you would be clad in a swimsuit. We would take skinfold measurements, body circumference or girth measurements, and several bone measurements, along with height and weight. After these measurements are taken, you would then be immersed in an underwater weighing tank and we would measure the amount of air you had in your lungs while you were under water to accurately measure your body density. The testing procedure for underwater weighing does not require you to be a swimmer, since you are able to stand up in this tank with your head out of the water. The procedure, however, does require that you do not have such a great fear of the water so that you are able to immerse yourself completely (head under). This research is necessitated by the lack of accurate measures for estimating body composition with adult women. Many of the women who have undergone the fitness testing have been very dissatisfied with the present method used to estimate their percent fat and give them a recommended ideal weight. The completion of this research will provide you with the most accurate measurement of body density, percent fat, lean body weight, and recommended ideal weight. Your help in this matter would be greatly appreciated. I or my associate, Bev Yenzer, will be contacting you by phone in the next several weeks. If you do not receive a phone call from us and are extremely interested, please call us here at 532-6765. Thank you for your time.

Sincerely,

William B. Zuti, Ph.D.
Assistant Professor

WBZ/bm

APPENDIX B

INFORMED CONSENT FORM

EXERCISE PHYSIOLOGY LABORATORY

Kansas State University

Date ______________________

I ______________________________ have volunteered to participate in the exercise physiology study of body composition. In volunteering to participate in the body composition tests, I waive any possibility of personal damage which may be blamed upon such a study in the future and accept the responsibility. To my knowledge, I am not infected with a contagious disease or limiting physical condition or disability, especially with respect to my heart, that would preclude any testing. I understand that I may withdraw from the project at any time.

Signed ____________________

APPENDIX C

KEY TO ABBREVIATIONS IN APPENDIX C

ABBREVIATED FORM	NON ABBREVIATED FORM
Ht In	Height Inches
Wt Lb	Weight Pounds
Body Vol	Body Volume
SG	Specific Gravity
% Fat	Per Cent Fat
TBF	Total Body Fat
LBW	Lean Body Weight
D	Density
Wrist R	Wrist Right
Wrist L	Wrist Left
Elbow R	Elbow Right
Elbow L	Elbow Left
Knee R	Knee Right
Knee L	Knee Left
Ankle R	Ankle Right
Ankle L	Ankle Left
Bi-Ac	Bi-Acromial
Chest Bdth	Chest Breadth
Chest Dpth	Chest Depth
Bi-Il	Bi-Ilium
Bi-Tro	Bi-Trochanter
Arm Length Up	Arm Length Upper

KEY (Continued)

ABBREVIATED FORM	NON ABBREVIATED FORM
Arm Length Lo	Arm Length Lower
Biceps Ext	Biceps Extended
Forearm Ex Sup	Forearm Extended Supinated
Standard Per Cent Wt	Standard Per Cent Weight
Young 16-30 SG	Young 16-30 Specific Gravity
Young 40-70 SG	Young 40-70 Specific Gravity
Stein 25-34 TBF	Steinkamp 25-34 Total Body Fat
Stein 35-44 TBF	Steinkamp 35-44 Total Body Fat
W & B Density	Wilmore and Behnke Density
W & B -S-	Wilmore and Behnke -S-
K & M	Katch and Michael
W & B -CD-	Wilmore and Behnke -CD-
% Fat Siri	Per Cent Fat Siri
% Fat R & P	Per Cent Fat Rathbun and Pace
% Fat K & B	Per Cent Fat Keys and Brozek
% Fat Allen	Per Cent Fat Allen

INTER-CORRELATION OF BODY COMPOSITION
ESTIMATES AND SELECTED MEASUREMENTS
SECTION C-1

	Age	Ht In	Wt Lb	Body Vol	SG	% Fat	TBF	LBW	D	Cup Size	Wrist R	Wrist L	Elbow R	Elbow L
Age	1.00	.09	.02	.01	.17	.16	.11	.16	.17	.08	.17	.15	.10	.10
Height Inches	.09	1.00	.62	.60	.29	.27	.42	.67	.29	.32	.52	.45	.52	.45
Weight Pounds	.02	.62	1.00	.99	.72	.71	.88	.87	.72	.54	.56	.53	.52	.57
Body Volume	.01	.60	.99	1.00	.76	.75	.91	.84	.75	.54	.54	.51	.50	.55
Specific Gravity	.17	.29	.72	.76	1.00	.99	.95	.28	.0002	.50	.18	.17	.16	.22
Per Cent Fat	.16	.27	.71	.75	.99	1.00	.95	.27	.99	.49	.18	.17	.17	.22
Total Body Fat	.11	.42	.88	.91	.95	.95	1.00	.53	.95	.52	.35	.33	.32	.39
Lean Body Weight	.16	.67	.87	.84	.28	.27	.53	1.00	.28	.41	.64	.61	.60	.61
Density	.17	.29	.72	.75	.0002	.99	.95	.28	1.00	.50	.18	.17	.16	.22
Standard Per Cent Weight	.33	.24	.85	.85	.63	.63	.77	.72	.62	.48	.35	.36	.32	.41

INTER-CORRELATION OF BODY COMPOSITION
ESTIMATES AND SELECTED MEASUREMENTS
SECTION C-2

	Knee R	Knee L	Ankle R	Ankle L	Bi-Ac	Chest Bdth	Chest Dpth	Bi-Il	Bi-Tro	Arm Length Up	Arm Length Lo	Neck	Biceps Flexed	Biceps Ext
Age	.19	.20	.19	.28	.04	.11	.08	.11	.02	.25	.03	.05	.10	.12
Height Inches	.29	.28	.48	.49	.57	.29	.49	.56	.55	.71	.43	.34	.22	.30
Weight Pounds	.55	.54	.46	.45	.54	.62	.68	.62	.71	.53	.28	.66	.80	.81
Body Volume	.55	.53	.45	.44	.54	.63	.67	.62	.71	.52	.25	.65	.81	.82
Specific Gravity	.42	.39	.20	.18	.35	.51	.42	.45	.47	.22	.14	.37	.73	.78
Per Cent Fat	.42	.40	.18	.16	.35	.49	.39	.45	.46	.21	.13	.37	.73	.78
Total Body Fat	.49	.47	.29	.27	.44	.59	.54	.56	.59	.35	.02	.52	.81	.84
Lean Body Weight	.47	.47	.52	.54	.51	.50	.66	.53	.66	.59	.48	.64	.57	.56
Density	.42	.39	.20	.18	.35	.51	.42	.45	.47	.21	.14	.37	.73	.78
Standard Per Cent Weight	.44	.43	.26	.21	.32	.50	.54	.37	.56	.34	.12	.63	.78	.75

INTER-CORRELATION OF BODY COMPOSITION
ESTIMATES AND SELECTED MEASUREMENTS
SECTION C-3

	Chest Nipple	Chest Exhale	Chest Inhale	Chest Above	Chest Below	Waist Minimum	Iliac	Hip Maximum	Thigh Maximum	Groin	Thigh Mid	Inches Above	2" Patella	Calf Maximum
Age	.02	.05	.06	.03	.08	.003	.15	.09	.0002	.11	.05	.11	.003	.04
Height Inches	.43	.41	.42	.42	.34	.29	.51	.51	.41	.31	.29	.11	.52	.37
Weight Pounds	.86	.85	.83	.80	.74	.75	.83	.93	.86	.87	.75	.22	.88	.78
Body Volume	.86	.85	.83	.80	.73	.75	.82	.94	.87	.88	.75	.22	.88	.78
Specific Gravity	.59	.63	.53	.54	.52	.57	.58	.78	.78	.78	.60	.06	.64	.58
Per Cent Fat	.58	.62	.51	.52	.50	.57	.57	.78	.78	.78	.61	.08	.64	.58
Total Body Fat	.73	.75	.68	.67	.62	.68	.71	.90	.87	.89	.72	.15	.79	.70
Lean Body Weight	.78	.73	.79	.74	.67	.63	.74	.72	.62	.62	.59	.25	.75	.66
Density	.59	.62	.53	.54	.51	.57	.58	.78	.78	.78	.60	.06	.64	.58
Standard Per Cent Weight	.76	.75	.72	.71	.70	.72	.65	.79	.79	.81	.70	.26	.75	.73

INTER-CORRELATION OF BODY COMPOSITION
ESTIMATES AND SELECTED MEASUREMENTS
SECTION C-4

	Forearm Ex Sup	Knee Right	Ankle Right	Elbow Right	Wrist Right	Knee Left	Ankle Left	Elbow Left	Wrist Left	Chin	Cheek	Pectoral	Scapula	Triceps
Age	.09	.002	.15	.09	.04	.01	.18	.06	.0001	.14	.02	.09	.04	.21
Height Inches	.28	.40	.36	.34	.34	.44	.47	.40	.37	.19	.08	.26	.23	.11
Weight Pounds	.78	.67	.52	.77	.59	.70	.57	.85	.70	.54	.34	.57	.67	.51
Body Volume	.77	.67	.52	.77	.59	.71	.57	.84	.70	.55	.35	.58	.67	.53
Specific Gravity	.53	.60	.48	.55	.41	.63	.48	.56	.50	.54	.42	.52	.48	.65
Per Cent Fat	.52	.60	.48	.54	.42	.63	.47	.56	.49	.53	.43	.53	.48	.65
Total Body Fat	.66	.66	.51	.67	.52	.69	.52	.71	.62	.56	.40	.56	.59	.62
Lean Body Weight	.70	.51	.40	.68	.52	.54	.49	.77	.60	.38	.18	.43	.58	.26
Density	.53	.60	.48	.54	.41	.63	.48	.56	.50	.54	.42	.52	.48	.65
Standard Per Cent Weight	.80	.58	.49	.77	.57	.60	.51	.80	.65	.49	.36	.55	.68	.46

INTER-CORRELATION OF BODY COMPOSITION
ESTIMATES AND SELECTED MEASUREMENTS
SECTION C-5

	Mid Axillary	Abdominal	Iliac Front	Iliac Side	Pubic	Lower Rib	Groin	Thigh Front	Thigh Rear	Thigh Lateral	Calf	Knee	Standard % Wt	Young 16-30 SG
Age	.04	.08	.21	.01	.37	.003	.22	.24	.21	.08	.12	.28	.33	.36
Height Inches	.10	.21	.05	.36	.18	.25	.20	.23	.21	.24	.09	.22	.24	.18
Weight Pounds	.66	.64	.57	.67	.57	.58	.72	.64	.65	.68	.42	.49	.85	.58
Body Volume	.67	.65	.58	.69	.59	.58	.73	.67	.67	.70	.43	.50	.85	.59
Specific Gravity	.59	.64	.59	.66	.59	.53	.68	.76	.69	.71	.48	.41	.63	.58
Per Cent Fat	.60	.64	.60	.67	.59	.53	.69	.77	.70	.72	.48	.41	.63	.59
Total Body Fat	.67	.70	.64	.73	.63	.57	.75	.78	.74	.77	.49	.47	.77	.63
Lean Body Weight	.48	.41	.34	.44	.37	.43	.49	.33	.38	.42	.23	.39	.72	.37
Density	.59	.64	.59	.66	.59	.53	.68	.76	.69	.70	.48	.41	.62	.59
Standard Per Cent Weight	.71	.62	.56	.61	.46	.57	.65	.55	.58	.70	.48	.57	1.00	.46

INTER-CORRELATION OF BODY COMPOSITION
ESTIMATES AND SELECTED MEASUREMENTS
SECTION C-6

	Young 40-70 SG	Stein 25-34 TBF	Stein 35-44 TBF	W & B Density	W & B -S-	Sloan Density	K & M Density	W & B -CD-	Pollock 18-22	Pollock 33-50	% Fat Siri	% Fat R & P	% Fat K & B	% Fat Allen
Age	.07	.15	.06	.12	.06	.10	.15	.06	.19	.03	.18	.18	.18	.18
Height Inches	.18	.41	.50	.24	.67	.29	.33	.63	.29	.39	.28	.29	.28	.28
Weight Pounds	.61	.91	.95	.76	.98	.69	.75	.95	.64	.83	.72	.72	.72	.72
Body Volume	.62	.91	.96	.77	.98	.70	.76	.95	.66	.84	.75	.75	.75	.75
Specific Gravity	.60	.76	.77	.73	.65	.74	.74	.60	.67	.78	.99	.99	.99	.99
Per Cent Fat	.60	.76	.75	.73	.64	.75	.75	.59	.68	.78	.99	.99	.99	.99
Total Body Fat	.64	.88	.90	.79	.83	.77	.79	.79	.72	.85	.95	.95	.95	.95
Lean Body Weight	.43	.70	.77	.53	.89	.41	.51	.89	.39	.59	.28	.28	.28	.28
Density	.60	.76	.76	.73	.65	.74	.74	.60	.67	.78	.99	.99	.99	.99
Standard Per Cent Weight	.60	.79	.82	.72	.82	.62	.65	.81	.53	.76	.62	.63	.62	.62

APPENDIX D

ILLEGIBLE DOCUMENT

THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

THIS IS THE BEST COPY AVAILABLE

```
//XPRS7069      JOB    (XXXXXXXXX,XXXXXXXX,,2,1000),'I618-ARHEART',         JOB 202
//                TIME=(,6)
//STEP1   EXEC FORTGCLG
//FORT.SYSIN  DD  *

KSU003I PARTITION SIZE -  256K, MAXIMUM CORE USED -   92K,  TIME =  15.02.36
KSU004I EXCP COUNT - UR 345       64,  UR 380       0,  DA 252        2,  UR 300       42
KSU001I STEP   1 FORT      EXECUTION TIME =          1.56 SEC     RETURN CODE =      0

KSU003I PARTITION SIZE -  256K, MAXIMUM CORE USED -  156K,  TIME =  15.03.00
KSU004I EXCP COUNT - DA 250       56,  DA 253       0,  DA 254        0,  DA 252       16,  DA 251       0,  UR 345       32
KSU004I EXCP COUNT - DA 252        3,       DUMMY
KSU001I STEP   2 LKED      EXECUTION TIME =          0.73 SEC     RETURN CODE =      0

//GO.SYSIN  DD  *

KSU003I PARTITION SIZE -  256K, MAXIMUM CORE USED -   28K,  TIME =  15.03.15
KSU004I EXCP COUNT - DA 252        0,  UR 302     410,  UR 345        0,  UR 380      102,  DA 252       0,  DA 251        0
KSU004I EXCP COUNT - UR 346        0
KSU001I STEP   3 GO        EXECUTION TIME =          2.01 SEC     RETURN CODE =      0

KSU002I JOB XPRS7069 EXECUTION TIME =          4.30 SEC

 HASP-II V3.1 JOB STATISTICS --    454 CARDS READ --     123 LINES PRINTED --    102 CARDS PUNCHED --   COPY   1 OF   1
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0001          DIMENSION X(73),Y(17)
0002       10 READ(5,1,END=9)ID,CARD,X
0003        1 FORMAT(I3,I1,F2.0,F6.0,F4.0,F1.0,F6.0,2F1.0,F6.0,F7.0,F5.0,2F6.0,
             1F7.0,T80,F1.0/12F6.0/12F6.0/12F6.0/12F6.0/11F6.0//)
0004          ISW=0
0005          DO 100 I=30,55
0006          N=X(I)
0007          DEC=(X(I)-N)*100.
0008          IF(DEC.GT.5.0.OR.DEC.EQ.0.0) GO TO 100
0009          ISW=1
0010          X(I)=X(I)+.45
0011      100 CONTINUE
0012          IF(ISW.EQ.1)WRITE(7,3)(X(I),I=27,38),ID,(X(I),I=39,50),ID,
             *(X(I),I=51,62),ID
0013        3 FORMAT(12F6.2,T77,I3,'3'/12F6.2,T77,I3,'4'/12F6.2,T77,I3,'5')
0014          Y(1)=1.0884-.0004231*X(65)-.0003401*X(73)
0015          Y(2)=1.05555-.0007109*X(62)-.0012239*X(56)-.0007728*X(58)+
             1.0004196*X(64)
0016          Y(3)=.354*X(32)+.403*X(43)+.159*X(65)+.083*X(5)-26.189
0017          Y(4)=.3*X(5)-1.855*X(51)+.169*X(60)-.511*X(28)+23.173
0018          Y(5)=1.06234-.00068*X(59)-.00039*X(60)-.00025*X(68)
0019          Y(6)=8.629+.680*X(5)*.4536-.163*X(59)-.1*X(60)-.054*X(68)
0020          Y(7)=1.0764-.00081*X(64)-.00088*X(60)
0021          Y(8)=1.12569-.001835*X(60)-.002779*.3937*X(40)+.005419*.3937*X(31)
             1-.0007167*X(59)
0022          Y(9)=8.987+.732*X(5)*.4536+3.786*X(15)-.157*X(39)-.249*X(40)+
             1.434*X(47)
0023          Y(10)=1.0836-.0007*X(64)-.0007*X(68)+.0048*X(51)-.0088*X(19)
0024          Y(11)=1.1023-.0005*X(64)-.0003*X(68)-.0005*X(38)-.0033*X(14)
0025          Y(12)=((X(23)+X(27)+X(15)+X(16)+X(19)+X(20))/54.8)**2*X(3)
0026          Y(13)=(X(5)-Y(12))/X(5)*100.
0027          Y(14)=(4.95/X(13)-4.5)*100.
0028          Y(15)=(5.548/X(9)-5.044)*100.
0029          Y(16)=(4.201/X(13)-3.813)*100.
0030          Y(17)=(4.834/X(13)-4.336)*100.
0031          WRITE(7,2)(Y(I),I=1,09),ID,(Y(I),I=10,17),ID
0032        2 FORMAT(9F8.4,T77,I3,'7'/8F8.4,T77,I3,'8')
0033          GO TO 10
0034        9 STOP
0035          END
```

```
                                   SUBPROGRAMS CALLED
SYMBOL    LOCATION       SYMBOL    LOCATICN       SYMBOL    LOCATION       SYMBOL    LOCATION       SYMBOL    LOCATION
IBCOM#       C8

                                   SCALAR MAP
SYMBOL    LOCATION       SYMBOL    LOCATION       SYMBOL    LOCATION       SYMBOL    LOCATION       SYMBOL    LOCATION
ID           CC          CARD         D0          ISW          D4          I            D8          N            DC
DEC          E0

                                   ARRAY MAP
SYMBOL    LOCATION       SYMBOL    LOCATION       SYMBOL    LOCATION       SYMBOL    LOCATION       SYMBOL    LOCATION
X            E4          Y            208

                                   FORMAT STATEMENT MAP
SYMBOL    LOCATION       SYMBOL    LOCATION       SYMBOL    LOCATION       SYMBOL    LOCATION       SYMBOL    LOCATION
     1       24C              3       29C              2       2C4

      *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,MAP
      *OPTIONS IN EFFECT*  NAME = MAIN     , LINECNT =       60
      *STATISTICS*    SOURCE STATEMENTS =       35,PROGRAM SIZE =      2320
      *STATISTICS*  NO DIAGNOSTICS GENERATED.
```

```
F128-LEVEL LINKAGE EDITOR OPTIONS SPECIFIED LET,LIST,MAP
         DEFAULT OPTICN(S) USED -  SIZE=(157596,24576)

                                             MODULE MAP

  CONTROL SECTION                   ENTRY

    NAME     ORIGIN  LENGTH           NAME   LOCATION     NAME   LOCATION     NAME   LOCATION     NAME   LOCATION

  MAIN           00     910
  IHCECOMH*     910     F61
                                    IBCOM#       910   FDIOCS#       9CC   INTSWTCH     1856
  IHCCOMH2*    1878     65D
                                    SEQDASD     1BF0
  IHCFCVTH*    1ED8    119D
                                    ADCON#      1ED8   FCVAOUTP     1F82   FCVLOUTP     2012   FCVZOUTP     2162
                                    FCVICUTP    2510   FCVECUTP     2A12   FCVCOUTP     2C2C   INT6SWCH     2F13
  IHCEFNTH*    3078     542
                                    ARITH#      3078   ADJSWTCH     3414
  IHCEFIOS*    35C0     F28
                                    FIOCS#      35C0   FIOCSBEP     35C6
  IHCFIOS2*    44E8     52E
  IHCUOPT *    4A18     300
  IHCERRM *    4D18     504
                                    ERRMON      4D18   IHCERRE      4D30
  IHCUATBL*    52F0     208
  IHCETRCH*    54F8     28E
                                    IHCTRCH     54F8   ERRTRA       5500

 ENTRY ADDRESS        00
 TOTAL LENGTH       5788

****MAIN      DOES NOT EXIST BUT HAS BEEN ADDED TO DATA SET
```

A COMPARISON OF HYDROSTATIC WEIGHING WITH OTHER METHODS OF DETERMINING BODY FAT

by

BEVERLY M. YENZER

B. S., Kansas State Teacher's College, 1969

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Health, Physical Education and Recreation

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

Yenzer, Beverly M. "A Comparison of Hydrostatic Weighing with Other Methods of Determining Body Fat." Unpublished Master's thesis, Kansas State University, Manhattan, Kansas, 1976.

The purpose of this study was to determine the validity of the more commonly used body composition estimation equations for females by comparing their results with those obtained by underwater weighing. A hydrostatic weighing technique was used to determine body density on fifty-one volunteer females aged twenty-five to fifty years. The variables measured included seventeen skinfolds, twenty-six girths, fifteen bone or skeletal diameters, age, height, weight and breast cup sizes. The mean body density for the subjects was 1.0549 g/ml (standard deviation ± 0.138) and per cent fat, 22.15 (standard deviation ± 5.692). Per cent fat was calculated by the formula of Brozek. Statistical calculations and Pearson Product Moment correlations were computed for the raw and calculated data from the estimation equations. Interpretation of the validity for each equation was determined by its correlation with the corresponding variables from the underwater weighing such as density with density, per cent fat with per cent fat. Highest correlations were obtained by methods of Steinkamp and Wilmore and Behnke for total body fat and lean body weight. The total body fat estimation equation by Steinkamp for thirty-five to forty-four years of age group correlated slightly higher than Wilmore and Behnke's estimation equations for lean body weight as determined by underwater weighing. Steinkamp estimation equation had a correlation coefficient of $r = 0.90$. Wilmore and Behnke's skinfold and circumference-diameter methods for

determining lean body weight was the most valid estimation for the population with correlation coefficients of r = 0.89 for both equations. Individual measurements correlating high with density were biceps extended girth, groin girth, thigh maximum girth, hip maximum girth, thigh front skinfold, biceps flexed girth and thigh lateral skinfold. The variable of body weight was found included in each of the recommended regression equations. This predictor variable correlated high with density (r = 0.72) and total body fat (r = 0.88) values obtained by underwater weighing.