This is to certify that the

thesis entitled

THE EFFECTS OF FOOD INGESTION AND EXERCISE
ON BODY COMPOSITION ESTIMATIONS AS
MEASURED BY HYDROSTATIC WEIGHING PROCEDURES

presented by

Chester J. Zelasko

has been accepted towards fulfillment
of the requirements for

M.A. degree in Physical Education

William W. Heusner

Major professor

William W. Heusner

Date August 8, 1984

THE EFFECTS OF FOOD INGESTION AND EXERCISE ON BODY COMPOSITION ESTIMATIONS AS MEASURED BY HYDROSTATIC WEIGHING PROCEDURES

By

Chester J. Zelasko

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of
MASTER OF ARTS

Department of Health and Physical Education

1984

ABSTRACT

THE EFFECTS OF FOOD INGESTION AND EXERCISE ON BODY COMPOSITION ESTIMATIONS AS MEASURED BY HYDROSTATIC WEIGHING PROCEDURES

By

Chester J. Zelasko

The purpose of this study was to determine the effects of food ingestion and a moderate bout of exercise on estimates of body composition obtained by hydrostatic weighing.

The sample consisted of 12 men and 12 women volunteers who were between 20 and 30 years of age. The subjects were healthy and neither emaciated nor grossly obese. Body composition was estimated by hydrostatic weighing with the underwater lung volume determined at the time of underwater weighing. All subjects were weighed under the following experimental conditions: before and after breakfast, before and after lunch and before and after a bout of moderate exercise.

There were statistically significant differences in land body weight ($P < .01$) before and after the ingestion of food and before and after a moderate bout of exercise. There were no significant differences in body density related to food ingestion. There were significant differences ($P < .05$) between the pre-breakfast body densities and the post-exercise body densities. The conclusions drawn from the study were that food ingestion does not affect estimates of body composition but that standard body composition determinations should be made prior to exercise or exercise testing.

To the loving memory of my grandfather, Leo J. Rogacki

ACKNOWLEDGEMENTS

The more that we learn, we realize that there is ever so much more to learn. I am indebted to Dr. W.W. Heusner and Dr. W.D. VanHuss for revealing this to me. I am also indebted to them for their assistance with this paper. Thanks also to Mr. Bob Wells for his time and expertise. Finally, thanks to my wife for her belief in me and her help in data collection.

TABLE OF CONTENTS

APPENDICES

Appendix

LIST OF TABLES

CHAPTER I

INTRODUCTION TO THE PROBLEM

The evaluation of an individual's physical condition often includes an estimate of body composition. Body composition estimates consist of body density which then is converted into percentage of body fat. The need for the analysis of body composition is to be able to compare individuals or groups of subjects and to observe changes in a given individual in a way that has more metabolic significance than do simple body weight or body size comparisons. Further, the measurement of body composition in individuals provides valuable information in a wide variety of biomedical contexts. Body fat content influences morbidity and mortality, changes the efficiency of physical performance, alters responses to drugs and anesthetics, and influences the tolerance to cold and starvation (28).

The criterion measure to determine body composition in vivo for over 40 years has been hydrostatic (underwater) weighing. The basic materials necessary (a pool or container of water, a scale to measure the underwater weight and a method of estimating residual lung volume) are available to most scientists. Therefore, hydrostatic weighing has proven to be a popular method for body composition estimations.

Critical to the hydrostatic weighing method are the accurate measurement of an individual's weight underwater and the determination of lung volume when the underwater weight is recorded. Underwater weight is typically measured by an autopsy scale secured to a support system. Due to the fluctuation of the scale pointer, the average of the pointer swing must be used to estimate the underwater weight. Akers and Buskirk (1) developed a method of measuring underwater weight using a load cell (strain gauge). The advantage of using a load cell is that the resulting graphic record provides a more precise determination of the weight (the averaging is done electronically) of an individual underwater.

Residual lung volume, measured on land, is used most often in body composition calculations. However, due to subject fear and apprehension, the maximal exhalation necessary to reproduce residual volume may not be achieved underwater and, therefore, the lung volume at the time of underwater weighing may not be a true residual volume. In fact, it is not critical that residual volume be achieved if the actual volume of gas in the lungs is measured at the time the underwater weight is determined (3). A lung volume that is somewhere between end-tidal volume and residual volume is perfectly acceptable. The term underwater lung volume will be used in this report to refer to such lung volumes which were used throughout the current study.

Hydrostatic weighing to estimate body composition often is used as one of a battery of tests to assess an individual's physical condition or to measure changes in an individual's physical condition

after a dietary or exercise program. The assessment of an individual's physical condition also may include a treadmill stress test, anthropometric data, strength tests, flexibility tests, motor coordination, tests and dietary, sociological and psychological surveys.

When body composition is the primary variable to be examined, there is little difficulty. The subjects usually are required to report to the testing location in a post-absorptive state (following a 12-hour fast) and to avoid flatulent causing foods prior to the fast (2). The subjects void the bowel and bladder, change into swimming apparel, and then are weighed on land and underwater. However, a problem may arise when hydrostatic weighing is used as one of a battery of tests. Little consideration has been given to the establishment of a protocol for the administration of a series of tests. This may be due to limited subject availability on a given day, large numbers of subjects to be tested, staffing limitations, or facility limitations. Regardless of these practical considerations, adherence to a set protocol may be necessary to ensure valid and reliable data. Factors such as food ingestion and exercise may affect body composition estimates and, therefore, may have to be taken into consideration when planning a testing protocol for a complex investigation.

The present study was conducted to evaluate the effects of food consumption and exercise on body composition estimates as quantified by hydrostatic weighing. Several underwater measurements were taken

on subjects in the preprandial and postprandial states and before and after a bout of moderate exercise. If one or a combination of these factors significantly changes body composition estimates, this information should be used to establish a protocol for administering hydrostatic weighing during the day and/or in conjunction with other tests.

Need for the Study

There have been many studies conducted which have used hydrostatic weighing to estimate body composition. Hydrostatic weighing was used as the criterion measure in deriving regression equations for use with skinfold measurements by Jackson and Pollack (17), Satwanti, Bharadwaj and Singh (27), Wilmore and Behnke (38) and Wilmore, Girondola and Moody (39). Body composition estimated by the hydrostatic weighing procedure was one of a battery of tests used to identify group characteristics by Cureton and Sparling (8), Fahey, Rolph, Mounmee, Nagel and Mortara (11) and Leighton, Shapiro, Crawford and Huenemona (20). Webb (35) studied the correlation between energy expenditure and fat-free mass while Slaughter (31) examined the relationship of body composition to somatotype in human subjects. Body composition changes as the result of a physical training program were examined by Moody, Wilmore, Girondola and Royce (24) and Buskirk, Franklin, Hodgson, Gahagan, Kollias and Mendez (6). These are just a few examples of the many studies that have used hydrostatic weighing to quantify body composition estimates. The studies cited did not describe a protocol for hydrostatic weighing in relation to the other tests administered. The lack of a standard testing protocol may have resulted in errors in the body composition estimations and, consequently, the conclusions drawn regarding body composition may not be valid.

There have been few studies conducted which have examined the effects of food ingestion or exercise on body composition estimates as quantified by hydrostatic weighing. Durnin found statistically significant differences in percentage of body fat after ingestion of light and heavy meals (10). One investigator examined the effects of hyper-hydration and dehydration on body composition estimations and found statistically significant but not necessarily physiological important differences in percentage of body fat (14). Acute bouts of exercise have been shown to yield statistically significant differences in body composition estimations (32). It must be noted, however, that in most studies, the residual lung volume has been measured in air and not at the time the underwater weight was taken.

Purpose of the Study

This investigation was designed to determine the effects of food ingestion and a bout of moderate exercise on body composition estimations as quantified by hydrostatic weighing.

Research Hypothesis

The study was designed to test the following hypothesis:

1. There will be a significant difference in body composition estimates as quantified by hydrostatic weighing before and after the ingestion of food.

2. There will be a significant difference in body composition estimates as quantified by hydrostatic weighing before and after a moderate bout of exercise.

3. Hydrostatic weighing procedures will require a precise protocol relative to food ingestion and exercise to limit intraindividual variability.

RESEARCH PLAN

The sample consisted of 12 male and 12 female volunteers from the staff and students at Michigan State University. The subjects were between 20 and 30 years of age, in good health, and neither emaciated nor grossly obese. The subjects were tested under the following conditions:

1. Preprandial and postprandial in the morning and at noon.

2. Before and after a bout of moderate exercise in the afternoon.

The subjects were weighed on land and underwater, and the underwater lung volume was measured at the time the underwater weight was taken under each experimental condition. The underwater weight was measured by a strain gauge with a graphic recording provided by a

pen recorder. Underwater lung volume was measured using the closed circuit procedure originally outlined by Lundsgaard and Van Slyke (22) which was modified by Rahn, Fenn and Otis (26) and then further modified for use in the Center for the Study of Human Performance at Michigan State University (36). Body density was calculated as described by Buskirk (5), and the percentage of body fat was calculated according to the Siri (30) formula. Data analysis was performed using a mixed-effects anova with fixed Factor A being the test condition and random Factor B being subject.

Rationale for the Research Plan

The research plan of the present study was constructed to simulate a "typical" day so as to observe what differences, if any, may occur in body composition determinations obtained at different times during the day. The initial test of the day paralleled the classic approach to body composition estimates in which measurements are made early in the morning and in the post-absorptive state. The same subjects then were tested under several different conditions -- before and after meals and before and after moderate exercise. All possible combinations of meals and exercise were not exhausted; only the most typical situations were studied.

Definitions

<u>Body Composition</u> - The division of the body into two components of body fat and lean body mass.

<u>Body Density</u> - A measure of weight per cubic centimeter of the body which varies with the relative contributions of body fat and lean body mass.

<u>Residual Lung Volume</u> - The amount of air remaining in the lungs after a maximal exhalation.

<u>End Tidal Lung Volume</u> - The amount of air remaining in the lungs after a normal exhalation.

<u>Underwater Lung Volume</u> - The amount of air remaining in the lungs after a perceived maximal exhalation while the subject is completely submerged. Underwater lung volume may or may not be equal to the residual lung volume as determined in air.

CHAPTER II

REVIEW OF THE LITERATURE

The literature directly related to this study has been divided into three sections: (a) studies of the effects of food ingestion on hydrostatic weighing measures, (b) studies of the effects of exercise on hydrostatic weighing measures, and (c) the literature related to the specific hydrostatic weighing system that was used in the current study.

The Effects of Food Ingestion on Hydrostatic Weighing Measures

A major source of error in body composition estimations using hydrostatic weighing arises from the presence of gas in the viscera (6). The volume of gas in the abdominal cavity has been estimated to range between 28 ml and 1330 ml by Buskirk (5) who cited studies by von Doblen (1955), Blair (1947), Marshall (1955), and Keys and Brozek (1953). Buskirk recommended that a constant of 100 ml of abdominal gas be included in all body density calculations (5). The original work of Behnke, Fenn and Wilham (2) showed that the effects of gas in the abdominal viscera could be minimized by taking hydrostatic measurements in the morning in the post-absorptive state.

Consolazio, Johnson and Pecora (7) recommended that subjects being weighed during the forenoon should have fasted from 9:00 P.M. the night before and those being weighed in the afternoon should have fasted from 6:30 A.M. on the day of the examination. These recommendations generally have been followed by investigators concerned with accurate measurements of underwater weight.

Few studies have been conducted to examine the direct effect of food ingestion on hydrostatic weighing measures. Durnin and Satwanti (10) found that light (500 calories) and heavy (1200 -2200 calories) meals had very small effects on body density and resulted in little more than a 0.05% difference in the final percentage of body fat calculations. They concluded that fasting and non-fasting states, and the resulting decrease or increase in intestinal gas, had minimal effects on estimations of the percentage of body fat when hydrostatic weighing is the method of measurement. The minimum time from food ingestion to the actual weighing underwater was one and one-half hours, one hour longer then in the current study. However, the present study was designed also to examine the effects of food ingestion four hours after eating. This may be a more reasonable time in which to expect gas build up in the viscera.

Girondola, Wiswell and Romero (14) examined changes in body composition estimations resulting from hyperhydration and dehydration. These authors concluded that day-to-day fluctuation in hydration is one of the primary factors that contributes to variablilty in densitometric analysis. While significant differences

in body density and percentage of body fat were found, only one residual lung volume was estimated in air before the testing conditions were imposed.

The Effects of Exercise on Hydrostatic Weighing Measures

Several studies have been conducted to determine changes in various lung volumes after a bout of moderate to strenuous exercise. Stubbing, Pengally, Morse and Jones (32) found an increase in residual volume of 119% over the residual volume at rest. Buono, Constable, Rotkis, Stanforth and Wilmore (4) examined the effects of an acute bout of exercise on selected pulmonary functions and the effects on subsequent body composition calculations. They reported significant differences in residual lung volume through 30 minutes post-exercise and significant differences in total volume through 15 minutes post exercise. These results translated to differences in body composition estimations with absolute errors as large as 4.2% in individual observations. The relative errors were as large as 36.4%. It should be noted that the lung volume measurements were taken pre-exercise and 5, 15, 30, 60 and 120 minutes post-exercise, while a single underwater weight was measured once at 120 minutes post-exercise.

Girondola, Wiswell, Mohler, Romero and Barnes (13) also found an increase in residual lung volume following a 7 mph, 3% grade, 14-

minute run. The residual lung volume estimates increased by 15%, which suggested that body density measures involving residual lung volume estimates should not be made following exercise. The time of estimating residual lung volume in relation to the underwater weighing were not published with the study.

The Hydrostatic Weighing System

There are two important factors that must be considered when designing a hydrostatic weighing system. These factors relate to the major sources of error in the hydrostatic weighing procedure. The system must include: first, an accurate method of measuring the underwater weight; and second, an accurate method of determining the underwater lung volume at the time the underwater weight is recorded.

The method for weighing a person underwater has varied little since the initial work of Behnke, Feen and Wilham (2). Typically, an autopsy scale is attached to a support system and the subject is weighed while sitting or lying down underwater. However, this method of measuring underwater weight presents a problem due to the fluctuatuing pointer of the autopsy scale. The scale fluctuations must be averaged by sight to estimate the underwater weight. Akers and Buskirk (1) developed a weighing system that utilizes force transducers. The advantage is a graphic recording of the underwater weight which gives the test administrator time to interpret the recording after the subject has been removed from the water. A

modification of this underwater weighing system was used in the current study.

Residual lung volume may be determined by either of two basic methods: the open circuit method developed by Darling, Cournand and Richards (9) and the closed circuit method reported by Lundsgaard and Van Slyke (22).

The open circuit method requires that the subject inspire pure oxygen for seven minutes with all of the expired air being collected. When all of the nitrogen has been washed out of the lungs, the volume of expired air is determined and a sample is drawn for analysis. Residual lung volume then is calculated by standard dilution equations. Two difficulties with the open circuit method are the amount of time involved and, more importantly, the fact that the subject is usually immersed only to the neck during the breathing. Vossekuil (34) found body composition estimates to be inaccurate when residual lung volume was estimated with the subject immersed only to the neck.

In the closed circuit method developed by Lundsgaard and Van Slyke (22) the subject exhales maximally and then takes four or five deep respirations from a surgical respiration bag filled with 3 to 4 liters of pure oxygen. A sample from the bag is drawn and analyzed for nitrogen content, and the residual lung volume then is calculated. Rahn, Fenn and Otis (26) modified the original method by showing that equilibrium between the gas in the lungs and the gas in a 2-liter respiration bag occurs after only three breaths. They

further demonstrated that the value for nitrogen content in dry alveolar air is 80% rather than the 79.1% used by Lundsgaard and Van Slyke.

The method used for determining underwater lung volume in this study is a further modification of the closed circuit method. A four-breath protocol was adopted to ensure sufficient mixing between the alveolar gas and the oxygen in the respiration bag. Lack of sufficient mixing results in over estimates of the percentage of body fat. The alveolar nitrogen level was calculated to be 78%. The value of 78% nitrogen in alveolar air was used because the samples drawn for analysis were saturated with water vapor (36).

CHAPTER III

RESEARCH METHODS

The present study was undertaken to examine differences in body composition estimations as quantified by hydrostatic weighing under the following conditions: (a) before and after morning and noon meals and (b) before and after a moderate bout of exercise.

Subjects

Twenty-four normal, healthy men and women ranging in age from 20-30 years of age were recruited as volunteers from the staff and students at Michigan State University. None were emaciated or grossly obese. An informed consent form was signed by each subject prior to any testing. Permission for the use of human subjects in the study was obtained from the University Committee on Research Involving Human Subjects.

Hydrostatic Weighing System

The water container that was used is a 1000-gallon capacity polyurethane tank that measures five and one-half feet in diameter and is six feet deep. The water is circulated through a small

swimming pool filter to prevent accumulation of dust and debris in the tank. A swimming pool heater is used to maintain the water temperature in the 95 to 98 degree Fahrenheit range desired for hydrostatic weighing. Chlorine and pH levels of the water are maintained by the manual administration granular chlorine and soda ash and are monitered daily.

The tank is surrounded by a wooden floor three and one-half feet above the tank bottom. The floor is covered with a rubberized carpet to prevent decay. The entire weighing area is enclosed to provide privacy for the subjects.

Two ladders made of two-inch plastic piping provide access to a small platform at the top edge of the tank -- one ladder leads from the exterior of the tank to the platform, the other ladder leads from the platform into the tank. All ladder and platform surfaces are covered with a nonslip material. The platform at the top edge of the tank allows for a smooth transition of the subject into and out of the tank.

The weighing system consists of three parts: (a) a wall assembly, (b) a weighing assembly and (c) a chair assembly. A complete diagram is provided in Appendix C.

The function of the wall assembly is to provide a strong, rigid base for the weighing assembly. The wall assembly also includes the anchored strain gauge (Model SR-4 Load Cell Type U1-B, Balwin-Lima Hamilton Corporation).

The weighing assembly consists of reinforced angle irons which

are formed to allow for the attachment of the chair assembly. The weighing assembly is hung from the strain gauge and is stabilized by attachments to the wall assembly. The weighing assembly has a series of rungs that allow the chair assembly to be suspended at varying depths depending on the height of the subject.

The chair assembly is made of two-inch plastic pipe and a plastic seat that measures 18 x 42 inches. The chair assembly also includes an 18 x 42 inch shelf for standing. Underwater weight can be measured within ± 0.1 lb while the subject is sitting anywhere on the chair seat.

A continuous signal from the strain gauge is sent to a Wheatstone bridge where it is converted to pounds and sent to a pen recorder (Model 2115M - Allen Datagraph Corporation). The range of the recorder is 0 to 12.5 pounds. The system is calibrated with a 9.95-pound iron weight.

Underwater Lung Volume

The underwater lung volume is determined using the closed-circuit nitrogen dilution method of Lundsgaard and Van Slyke (22), modified by Rahn, Fenn and Otis (26), and adapted for use with the underwater weighing system used in the Center for the Study of Human Performance at Michigan State University. The rebreathing apparatus consists of a plastic pnuematic Geesman Valve with a rubber mouthpiece attached. The Geesman Valve has two chambers -- one that

leads to room air while the other leads to a respiration bag. The pnuematic valve, which is driven by air pressure, is operated outside of the tank with solenoids activated by a toggle switch on a control panel.

Oxygen is bubbled through water and is stored temporarily in a spirometer. The surgical respiration bag is filled with water-saturated oxygen from the spirometer by a one-liter hand operated syringe. (The spirometer is used so that the water-saturated oxygen does not enter the syringe under pressure.) The syringe is connected to the respiration bag by one-half inch plastic tubing. The respiration bag is attached to an evacuation pump which empties the gas in the bag between trials.

The respiration bag also contains a small tube for extraction of a gas sample. The extraction pump takes a constant sample at the rate of 3 milliliters per minute. The sample is analyzed for nitrogen content by a Med-Science 505 Nitralyzer which provides the nitrogen percentage in a digital readout.

Underwater lung volume is calculated as previously described. Body density is calculated by the Buskirk formula (5) with the exception that the estimate of intestinal gas in ml is mathematically related to body size by multiplying the body weight in kilograms by 1.4 . (This procedure yields a value of 100 ml for the standard 70-kg man.) Per-cent body fat is calculated using the Siri (30) formula. These formulas are provided in Appendix B.

Test Personnel

The test procedure requires two persons, a test administrator and a test recorder, both of whom are fully trained in the hydrostatic weighing method as described in the guidelines of the Center for the Study of Human Performance. In the current investigation, the test administrator was the same throughout all of the testing. The responsibilities of the test administrator include giving instructions to subjects, weighing all subjects on land, recording and reporting the underwater weight, operating the solenoid toggle switch, and calibrating both the weighing system and the nitrogen analyzer. The responsibilities of the test recorder include recording the temperature of the ambient air, the temperture of the tank water, the temperture of the syringe gas, the depth of the mouthpiece, and the nitrogen percentage of the rebreathed gas. The test recorder also calculates the relative humidity, the nitrogen calibration point, and the body composition values and then records this information on data collection sheets.

Testing Procedures

Each subject was trained in the hydrostatic weighing procedure used in the Center for the Study of Human Performance one to three days before his or her test date. The training included simulations and actual underwater trials of the test procedure.

Each subject reported to the laboratory on the day of testing and was asked to change into a swim suit and, if necessary, to void the bladder and the large bowel before any weighing took place. The weight in air was measured on a balance scale to the nearest gram and recorded. The subject then was weighed underwater in an upright, seated position. The underwater lung volume was determined at the same time as the underwater weight. Body composition estimations were calculated using a Hewlett-Packard 67 programmable calculator. The body composition calculations for trial one were completed by the time trial two was completed. The elapsed time for each trial was 30 seconds with 30 to 45 seconds between trials. Each subject was weighed underwater a minimum of two times. If the first two body density determinations differed by more than .001 grams/ml, a third trial was taken. The mean of two or three trials was recorded as the body density for the subject. It was possible to complete three trials within a 5 minute interval which was allowed by the research design.

Research Design

The effects of food ingestion and exercise on body composition determinations as quantified by hydrostatic weighing, were examined. This was accomplished by weighing the same subjects under different experimental conditions. Breakfast and lunch were provided for all subjects with no attempt to limit the amount of food consumed. The

subjects each recorded the type and quantity of food ingested at each meal. The subjects were allowed to drink non-carbonated beverages between testing sessions but were asked to refrain from eating solid foods of any type. The bout of exercise took place in the laboratory on a treadmill or on a cycle ergometer under the supervision of the test administrator. The moderate bout of exercise was defined as 20 min of walking, jogging or running on the treadmill or of riding the ergometer while maintaining a heart rate of at least 120 beats a minute. The subjects were weighed on land before and thirty minutes after the morning and noon meals and before and then fifteen minutes after the bout of exercise in the afternoon. The subjects were weighed underwater before and after the morning and noon meals and before and then fifteen and thirty minutes after the bout of exercise.

The following time schedule was followed during each test day:

6:45 A.M.	Meet in the laboratory. Subjects were instructed not to eat after 7:00 P.M. the previous day and not to smoke before they arrive at the laboratory. Subjects prepared for initial weighing.
7:00 A.M.	Pre-breakfast body composition estimates.
7:30 A.M.	Subjects eat breakfast.
8:15 A.M.	Subjects measured one-half hour post prandial (breakfast).
11:15 A.M.	Subjects report to the laboratory for noon weighings.
11:30 A.M.	Subjects measured four hours post-prandial (breakfast) and prior to lunch.

12:00 P.M.	Subjects eat lunch.
12:30 P.M.	Subjects are measured one-half hour post-prandial (lunch).
3:45 P.M.	Subjects report to laboratory for afternoon weighings.
4:00 P.M.	Subjects are measured four hours post-prandial (lunch) and prior to exercise.
4:45 P.M.	Subjects are measured 15 minutes after exercise.
5:00 P.M.	Subjects are measured 15 minutes after exercise.

The subjects were randomly assigned to test days and to test order on the morning of the test day. The schedule permitted the weighing of three or four subjects per test day. The first subject was weighed and then began to eat (or exercise) while the second subject was being weighed. The established test order was maintained throughout a given day to allow the time from the end of food ingestion or exercise to remain constant for each subject.

Statistical Analysis

The data were analyzed using a two-way, mixed-effects anova with fixed factor A being the test condition and random factor B being subject. Body density and land weight each served as dependent variables for separate anova calculations. Data were collected on 20 subjects and then analyzed. The initial analysis suggested that more data should be collected to increase the statistical power. Data

were collected on four additional subjects, pooled and then analyzed again. The decision was made to terminate data collection as significance was achieved.

Planned comparisons were used to test the following research hypotheses which were determined to be most useful after consideration of the possible effects that food ingestion and a moderate bout of exercise might have on body composition estimations:

1. The pre-breakfast body composition estimates would be significantly different from the post-breakfast body composition estimates.

2. The pre-breakfast, pre-lunch and the pre-exercise body composition estimates would not be significantly different.

3. The pre-breakfast body composition estimates would be significantly different from the post-lunch body composition estimates.

4. The pre-exercise body composition estimates would be significantly different from the post-exercise body composition estimates.

The .01 level of significance was set before testing began and was maintained for all anova and planned comparison tests. The .05 level was used for Tukey post-hoc tests.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to examine the effects of food ingestion and moderate exercise on body composition estimates as quantified by hydrostatic weighing. The data and statistical analyses related to land body weight are presented first. Discussion of the data and statistical analyses related to body density and body fat follow.

Land Body Weight

The results for land body weight are presented in tables 4.1, 4.2, and 4.3. The analysis of variance (Table 4.1) for land body weight was highly significant ($P < .01$). The planned comparisons (Table 4.2) also were statistically significant ($P < .01$) with the exception of the pre-breakfast versus pre-lunch versus pre-exercise comparison. Table 4.3 lists the land body weight (kilograms) for each subject at each test interval during the day.

Table 4.1 Analysis of Variance Land Body Weight

	Sums of Squares	df	Mean Square	F
Session	11.5600	5	2.3720	22.62*
Subject	18006.6167	23	782.8964	
Session by Subject	11.7533	115	.1022	
Total	18029.9300	143		

* P .01

Table 4.2 Planned Comparisons for Land Body Weight

Comparison	Significance Level
Pre-breakfast vs. Post-Breakfast	.01
Pre-breakfast vs. Pre-lunch vs. Pre-exercise	NS
Pre-exercise vs. Post-exercise	.01
Pre-breakfast vs. Post-lunch	.01

Table 4.3 Land Body Weight (kgs), by Subject, by Test Session

Subject	Pre-Break	Post-Break	Pre-Lunch	Post-Lunch	Pre-Exer	Post-Exer
1	82.53	83.07	82.25	82.71	82.13	82.25
2	79.41	80.05	79.17	80.29	79.79	78.05
3	56.11	56.43	55.57	56.03	55.81	55.73
4	74.05	74.92	74.62	75.69	75.13	74.95
5	69.08	69.16	68.84	69.18	68.99	68.75
6	77.09	78.07	77.49	78.11	77.53	77.43
7	67.54	68.00	67.12	67.68	67.30	66.96
8	53.10	53.59	52.92	53.51	52.94	52.48
9	55.57	55.43	55.43	55.89	55.69	55.07
10	47.11	46.40	46.32	46.72	46.58	46.60
11	78.67	79.07	78.67	79.31	78.83	78.65
12	69.02	69.74	69.04	69.44	69.52	68.78
13	85.13	86.12	85.50	86.54	86.02	85.05
14	72.00	72.16	71.80	72.32	70.98	69.38
15	70.30	71.12	70.98	71.18	70.72	70.48
16	71.00	71.40	70.96	71.64	71.14	70.39
17	96.43	97.11	96.27	97.35	96.91	96.45
18	63.37	62.97	62.67	62.99	62.83	62.77
19	63.63	64.05	63.49	64.17	63.53	63.47
20	68.60	69.00	68.28	68.64	68.22	68.04
21	54.67	54.89	54.41	54.97	54.47	54.46
22	68.74	69.00	68.62	69.04	68.32	68.24
23	64.62	65.20	64.66	65.60	65.26	64.98
24	75.97	76.15	75.67	76.13	75.77	75.39
Mean	69.32	69.72	69.20	69.78	69.34	68.97

The significant changes in land body weight over the experimental conditions imposed (i.e., before and after food ingestion and before and after exercise) were expected (Table 4.1). It is reasonable to assume that after eating a meal land body weight will increase and that after exercise land body weight will decrease. It is further reasonable to assume that as time passes following the eating of a meal (four hours in this study) the land body weight will return to a value which is close to the pre-meal land body weight. The planned comparisons (Table 4.2) confirm all of these assumptions.

Body Density and Body Fat

The results for body density are presented in tables 4.4 through 4.6. The overall analysis of variance for body density (Table 4.4) was statistically significant ($P < .01$). The planned comparisons tests, which were selected before the study began, (Table 4.5) were all nonsignficant at the .01 level. Additional Tukey post-hoc comparisons are presented in table 4.6. The mean values pre-breakfast versus post-exercise (15 and 30 minutes) were significantly different ($P < .05$).

Body densities were converted to percentages of body fat for ease of interpretation. Table 4.7 contains the group means and standard deviations for each test session. Table 4.8 presents: (a) the percentages of body fat for each subject at each of the first five test sessions (exercise effects eliminated); (b) the mean,

standard error of the mean, and the absolute value of the maximum deviation from the mean for each subject; and (c) the overall mean for each column. The standard errors ranged from a low of 0.1% body fat to a high of only 0.6% body fat with an average of 0.3% body fat. These results translate to a 90% confidence interval with a maximum width of only ± 1.3% body fat and an average width of only ± 0.6% body fat when the Michigan State University protocol is used. Because there were no significant differences in percentage of body fat during the first five test sessions, each subject's mean value can be assumed to be an unbiased estimate of that subject's true value and, therefore, the final column in Table 4.8 represents the maximum measurement errors that were encountered in this investigation. It can be seen that these maximum errors, over five trials per subject, ranged from 0.2% body fat to 1.8% body fat with an average of only 0.8% body fat.

This would be an appropriate time to review the planned comparisons which were selected before the study began, to determine if the following hypotheses suggested by these comparisons were, in fact supported by the obtained data.

1. The pre-breakfast body composition estimates would be significantly different from the post-breakfast body composition estimates.

2. The pre-breakfast, pre-lunch and the pre-exercise body composition estimates would not be significantly different.

Table 4.4 Analysis of Variance - Body Density

	Sums of Squares	df	Mean Square	F
Session	.5506	6	.0918	3.375*
Subject	761.7229	23	33.1184	
Session by Subject	3.7523	138	.0272	
Total	766.0258	167		

* P .01

Table 4.5 Planned Comparisons for Body Density

Comparisons	Significance Levels
Pre-breakfast vs. Post-Breakfast	NS
Pre-breakfast vs. Pre-lunch vs. Pre-exercise	NS
Pre-exercise vs. Post-exercise	NS
Pre-breakfast vs. Post-lunch	NS

Table 4.6 Tukey Post-hoc Comparisons for Body Density

Comparisons	Significance Level
Pre-breakfast vs. Pre-Exercise	NS
Pre-breakfast vs. Post-exercise (15 Minutes)	.05
Pre-breakfast vs. Post-exercise (30 Minutes)	.05

Table 4.7 Summary Values, by Test Sessions, for Percentages of Body Fat

	Pre-Break	Post-Break	Pre-Lunch	Post-Lunch	Pre-Exer	Post-Exer 15 min	Post-Exer 30 min
Mean	20.6	20.2	20.2	20.5	20.2	19.9	19.9
S.D.	9.7	9.6	9.7	9.8	9.6	10.0	10.0

Table 4.8 Percentages of Body Fat, by Subject, for Sessions 1 to 5

Subj.	Sex	Pre-Break	Post-Break	Pre-Lunch	Post-Lunch	Pre-Exer	Subject Mean	Subject Standard Error	Subject Maximum Dev.
1	F	32.6	32.6	32.9	32.2	31.7	32.4	0.2	0.7
2	M	7.7	7.0	7.8	8.0	8.0	7.7	0.2	0.7
3	F	20.7	20.0	21.1	22.3	21.1	21.0	0.4	1.3
4	M	16.9	17.3	15.9	17.3	18.3	17.1	0.4	1.2
5	F	37.5	38.1	38.2	39.0	38.5	38.3	0.2	0.8
6	M	19.4	18.5	18.2	19.1	19.1	18.9	0.2	0.8
7	F	32.1	31.7	31.3	31.7	30.4	31.4	0.3	1.0
8	F	11.9	13.0	11.8	12.4	11.6	12.1	0.3	0.8
9	F	21.5	21.7	21.4	23.0	20.9	21.7	0.4	1.3
10	F	28.0	25.6	27.1	26.2	24.5	26.3	0.6	1.8
11	M	19.3	20.2	19.0	18.5	20.1	19.4	0.3	1.0
12	M	7.4	7.7	7.4	7.6	7.6	7.5	0.1	0.4
13	M	10.9	10.4	10.4	10.3	10.6	10.5	0.1	0.4
14	M	7.6	6.2	6.8	6.9	5.6	6.6	0.3	1.0
15	M	10.3	10.5	9.9	9.4	9.6	9.9	0.2	0.6
16	M	12.5	12.1	13.4	13.6	14.4	13.2	0.4	1.2
17	M	31.1	29.7	30.6	30.7	31.0	30.6	0.2	0.9
18	F	25.1	24.2	24.2	24.7	24.7	24.6	0.2	0.5
19	F	30.2	29.9	28.6	29.6	29.3	29.5	0.3	0.7
20	F	33.2	32.0	32.2	32.5	32.1	32.4	0.2	0.8
21	F	20.2	19.0	19.0	19.2	19.6	19.4	0.2	0.8
22	M	10.7	11.1	10.0	9.5	10.0	10.3	0.3	0.8
23	M	13.9	13.8	13.5	13.8	13.5	13.7	0.1	0.2
24	F	33.4	33.5	33.2	33.2	33.4	33.3	0.1	0.8
Mean		20.6	20.2	20.2	20.5	20.2	20.3	0.3	0.8

3. The pre-breakfast body composition estimates would be significantly different from the post-lunch body composition estimates.

4. The pre-exercise body composition estimates would be significantly different from the post-exercise body composition estimates.

The only hypothesis that is supported is the second (Table 4.5). The results indicate that there is no difference whether a subject has hydrostatic body composition determinations made early in the morning, after eating breakfast, before noon, or in the afternoon after eating both breakfast and lunch.

However, the Tukey Post-Hoc comparisons (Table 4.6) show that there were significant differences ($P < .05$) between the pre-breakfast weighings and the 15-minute and 30-minute post-exercise weighings. The data indicate that there will be differences from the usual criterion measurement, the pre-breakfast weighing, if the subject is weighed after a moderate bout of exercise. Most subjects in this study had an exercise-related increase in body density which resulted in a corresponding decrease in the calculated percentage of body fat. This difference amounted to a mean decrease of 0.3% body fat 15 minutes post-exercise and 0.4% 30 minutes post-exercise. These results agree with the work of Buono et al (4) who also found an increase in body density after an acute bout of exercise. The mean difference in the percentage of body fat in that study was 1.7% 15 minutes post-exercise and 1.2% 30 minutes post-exercise. There was, however, a difference in protocol with that study using only one land body weight and only one underwater weight with residual lung volumes measured on land at selected intervals before and after the exercise bout.

The current results after exercise also agree with the work of Girondola et al (14) who examined changes in body density before and after dehydration. The mean decrease in the percentage of body fat reported was 0.7%. Again, there were differences in the methods used with that study measuring residual lung volumes out of the water. The differences observed post-exercise in the current study may be the result of dehydration.

Because exercise or exercise-related dehydration was found to affect body composition, Table 4.8 lists the percentage of body fat of each subject during the course of only the first five weighing sessions. The range of mean values over the first five test sessions was only 0.4 per-cent body fat (Table 4.7). The importance of comparing the means notwithstanding, it is equally important to examine intraindividual variability. There appeared to be no real pattern for increases or decreases in the percentage of body fat among subjects. The percentage of body fat tended to decrease after breakfast but tended to increase after lunch. Perhaps there was an unknown slight difference in the densities of the foods eaten, but there were no patterns that indicated intraindividual variability was dependent on the sex of the subject or on the amount of food consumed during either meal. In general, the results of Table 4.8 support the conclusion that there is little difference when body composition estimates are made in relation to time of food ingestion.

The obtained standard errors and confidence intervals suggest a favorable comparison with the work of Durnin, who reported a 90% confidence interval of $\pm$ 1.5% body fat under standardized

experimental conditions. The confidence interval suggested by Durnin agrees with the measurement errors reported by several other authors (3,30).

The original research hypotheses can now be reviewed to determine whether they should by accepted or rejected.

1. There will be a significant difference in body composition estimates as quantified by hydrostatic weighing before and after the ingestion of food.

This hypothesis cannot be accepted. The planned comparison and post-hoc tests were not statistically significant.

2. There will be a significant difference in body composition estimates as quantified by hydrostatic weighing before and after a moderate bout of exercise.

This hypothesis can be accepted as significant differences (P .05) were found in body composition estimates when the first morning results were contrasted with the two post-exercise results. The data agree with the findings of both Buono et al (4) and Girondola et al (14).

3. Hydrostatic weighing procedures will require a precise protocol to limit intraindividual variability.

This hypothesis can be accepted in part. Specifically, body composition estimates as quantified by hydrostatic weighing should be scheduled before exercise or exercise testing to limit intraindividual variability. When the effects of exercise are eliminated, the carefully standardized Michigan State University

protocol yields highly reliable data.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of the current investigation was to determine the effects of food ingestion and a moderate bout of exercise on body composition estimations as quantified by hydrostatic weighing. Twenty-four normal, healthy males and females 20 to 30 years of age, served as subjects. Body composition estimates were made before and after food ingestion in the morning and at noon as well as before and after a moderate bout of exercise in the afternoon. Body density and land body weight served as dependent variables. Data were analyzed by a two-way, mixed-model analysis of variance with testing session serving as the fixed factor and subject serving as the random factor.

There were statistically significant differences in land body weight before and after food ingestion as well as before and after exercise. There were no significant differences between the pre-breakfast, pre-lunch and pre-exercise land body weights. Significant differences were found in body density only when the pre-breakfast data were compared with the post-exercise data. No significant differences in body density were found before and after breakfast or before and after lunch.

Conclusions

1. There is a significant difference in land body weight before and after the ingestion of food.
2. There is a significant difference in land body weight before and after a moderate bout of exercise.
3. Meal-related differences in land body weight tend to disappear four hours after food ingestion.
4. There are no statistically significant differences in body density before and after the ingestion of food.
5. There is a significant difference in body density estimated in the morning before breakfast and estimated in the afternoon after a moderate bout of exercise.

Recommendations

1. Further studies should be made with other age groups to determine if the intraindividual variability under the test conditions studied is age-group dependent.
2. When hydrostatic weighing is used to estimate body composition, the measurement should take place before any exercise or exercise tests.

APPENDICES

APPENDIX A
BASIC DATA

APPENDIX A

BASIC DATA

Body Density (g/ml) by Subject, by Testing Sessions

Subject	Pre-Breakfast	Post-Breakfast	Pre-Lunch	Post-Lunch	15 min Pre-Exercise	30 min Post-Exercise	Post-Exercise
NA	1.0258	1.0258	1.0251	1.0265	1.0279	1.0282	1.0289
MM	1.0814	1.0832	1.0813	1.0809	1.0809	1.0828	1.0828
SE	1.0517	1.0531	1.0509	1.0480	1.0508	1.0487	1.0482
ML	1.0602	1.0593	1.0625	1.0594	1.0571	1.0565	1.0569
KP	1.0154	1.0141	1.0140	1.0122	1.0134	1.0134	1.0127
BS	1.0546	1.0565	1.0573	1.0553	1.0553	1.0537	1.0530
TB	1.0268	1.0277	1.0285	1.0277	1.0304	1.0289	1.0302
KM	1.0717	1.0692	1.0720	1.0705	1.0724	1.0764	1.0772
CF	1.0499	1.0494	1.0502	1.0466	1.0511	1.0537	1.0542
SW	1.0355	1.0408	1.0375	1.0395	1.0412	1.0435	1.0449
TK	1.0549	1.0528	1.0556	1.0567	1.0529	1.0544	1.0544
DZ	1.0822	1.0816	1.0823	1.0817	1.0817	1.0838	1.0838
TM	1.0739	1.0752	1.0751	1.0754	1.0748	1.0780	1.0771
DD	1.0817	1.0850	1.0837	1.0833	1.0864	1.0891	1.0895
SP	1.0755	1.0749	1.0763	1.0776	1.0772	1.0770	1.0778
PH	1.0703	1.0711	1.0683	1.0678	1.0659	1.0689	1.0688
SH	1.0289	1.0320	1.0301	1.0297	1.0291	1.0304	1.0310
SL	1.0419	1.0438	1.0438	1.0428	1.0428	1.0456	1.0474
PS	1.0309	1.0316	1.0343	1.0321	1.0328	1.0326	1.0326
SH	1.0245	1.0270	1.0265	1.0260	1.0267	1.0259	1.0248
PA	1.0528	1.0555	1.0554	1.0549	1.0542	1.0547	1.0538
JW	1.0745	1.0736	1.0761	1.0773	1.0762	1.0764	1.0767
JG	1.0670	1.0672	1.0679	1.0672	1.0679	1.0690	1.0683
NP	1.0240	1.0238	1.0244	1.0244	1.0241	1.0219	1.0220

APPENDIX B

FORMULAS

APPENDIX B

FORMULAS

1. $$VRL_{BTSP} = VO_2 \frac{(Nb - Nc)}{(Na - Nb)} \times \frac{(B - PH_2O)}{(B - 47)} \times \frac{(310)}{(273 - Tg)} - DS$$

VRL_{BTSP} = Volume of gas remaining in lungs after exhalation (ml)

VO_2 = Original value of oxygen in bag and tubing (ml) (expressed at ambient temperature and pressure and with oxygen saturated with water)

Nb = Nitrogen in bag after rebreathing (%)

Nc = Nirogen in bag before rebreathing (%)

Na = Nitrogen in alveoli prior to rebreathing (use constant of 78%)

B = Barometric Pressure (mmHg)

PH_2O = Partial pressure of H_2O at spirometer temperature

Tg = Temperature of gas in syringe (centigrade)

DS = Dead space in valve (ml)

2. $$Db \qquad \frac{Wa}{\frac{(Wa - Ww^*)}{Dw} - (VRL + VGI)}$$

Db = Body density (g/ml)

Wa = Body weight in air (g)

Ww* = Body weight in water corrected for mouthpiece buoyancy

Dw = Density of tank water at water temperature of tank

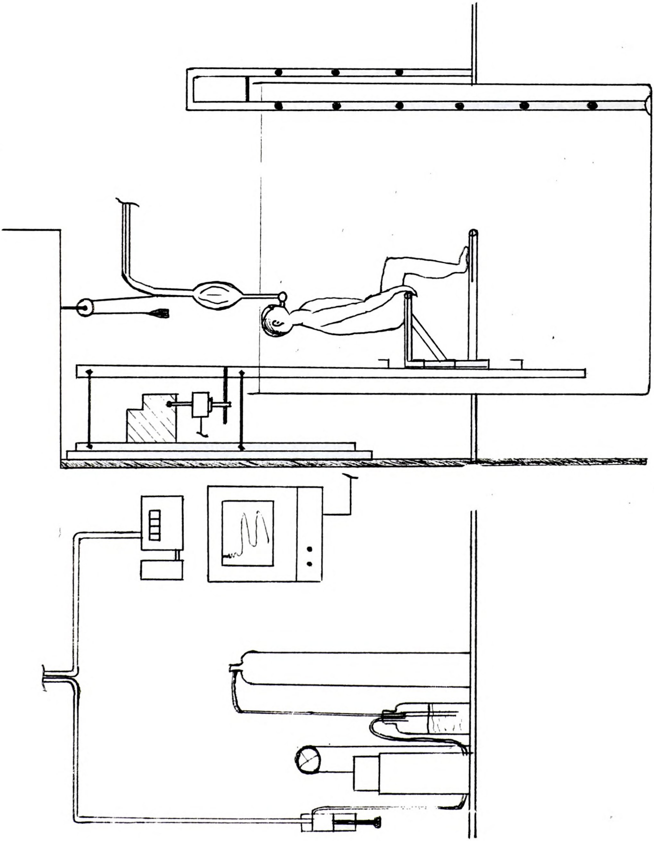
VRL = Volume of gas remaining in lungs after exhalation (ml)

VGI = Volume of gas in intestinal tract (VGI = 1.4 x Wa)

3. Body Fat (%) = ((4.95/Db) - 4.5) x 100

APPENDIX C

DIAGRAM OF TEST INSTRUMENT



BIBLIOGRAPHY

BIBLIOGRAPHY

1. Akers, R; E.R. Buskirk. "An underwater weighing system utilizing 'force cube transducers." J. Appl. Physiol. 26: 649-652, 1969

2. Behnke, A.R.; B.G. Feen and W.C. Wilham. "The specific gravity of healthy men." J. Amer. Med. Assoc. 118 (7) 495-497, 1942

3. Brozek, J. ; F.Grande ; J.T. Anderson ; A. Keys. "Densitometric analysis of body composition: revision of quantitative assumptions." Ann. N.Y. Acad. 110:113-140, 1963

4. Buono, M.J. ; S.H. Constable ; A.R. Morton ; T.C. Rotkis ; P.R. Stanforth and J.H. Wilmore. "The effect of an acute bout of exercise on selected pulmonary functions measurements." Med. Sci. Sport Exercise 13 (5): 290-293, 1980

5. Buskirk, E.R. "Underwater weighing and body density: a review of procedures." Nat. Acad. Sci. 90-105, 1961

6. Buskirk, E.R. ; B. Franklin ; J. Hodgson ; H. Gahagan ; J. Kollias and J. Mendez. "Effects of physical conditioning on cardiorespiratory function, body composition, and serum lipids in relatively normal weight and obese middle aged women." Int. J. Obes. 3.97-109, 1979

7. Consolazo, C.F. ; R.E. Johnson and L.J. Pecora. "Physiological measurements of metabolic functions in man." New York, New York McGraw-Hill pps. 265-312

8. Cureton, K.J. ; D.B. Sparling. "Distance running performance and metabolic responses to running in men and women with excess weight experimentally equated." Med. Sci. Sport Exercise 12 (4) 288-294, 1980

9. Darling, R.C. ; J. Cournand and D.W. Richards. "Studies on the intrapulmonary mixture of gases : open-circuit method for measuring residual air." J. Clin. Invest. 19: 609-618, 1940

10. Durnin, J.V.G.A. and Satwanti. "Variations in the assessment of the fat content of the human body due to experimental technique in measuring body density." Ann. H. Biol. 9(3): 221-225, 1982

11. Fahey, T.D. ; R. Rolph ; P. Moungee ; J. Nagel and S. Mortara. "Serum testosterone, body composition and strength of young adults." Med. Sci. Sport Exercise 8(1): 31-34, 1976

12. Forbes, R.M. ; A.R. Cooper ; H.H. Mitchell. "The composition of the adult human body as determined by chemical analysis." J. Biol. Chem. 203: 359-366, 1953

13. Girondola, R.N. ; R.A. Wiswell ; J.G. Mohler ; G.T. Romero and W.S. Barnes. "Effects of water immersion on lung volumes : implications for body composition analysis." J. Appl. Physiol. 43(2): 276-279, 1977

14. Girondola, R.N. ; R.A. Wiswell and G.T. Romero. "Body composition changes resulting from fluid ingestion and dehydration." Res. Quar. 48(2) : 299-303, 1977

15. Goldman, R.F. and E.R. Buskirk. "Body volume measurement by underwater weighing: description of a method." Nat. Acad. Sci. 78-79, 1961

16. Hampton, M.C. ; R.L. Hueneman ; L.R. Shapiro ; B.W.Mitchell and A.R. Behnke. "A longitudinal study of gross body composition and body conformation and their association with food and activity in a teen age population." Am. J. Clin. Nut. 19: 422-435, 1966

17. Jackson, A.S. amd M.L. Pollack. "Generalized equations for predicting body density in man." Brit J. Nutr. 40(3): 497-504, 1975

18. Keys, A. and J. Brozek. "Body fat in adult man." Physiol. Rev. 33: 245-320, 1953

19. Kitagawa, K. ; M. Suzuki and M. Miyashita. "Anaerobic power output of young obese men." Eur. J. A. Physiol. 43: 229-234, 1953

20. Leighton, C.K. ; L.R. Shapiro ; M.H. Crawford and R.L. Huenemona. " body composition and physical activity in 8-year old children." Am. J. Clin. Nut. 34: 2770-2775, 1981

21. Leon, A.S. ; J. Conrad ; D.B. Hunninghake and R. Serfass. "Effects of a vigorous walking program on body composition and lipid metabolism of obese young men." Am. J. Clin. Nut. 32: 1776-1787, 1979

22. Lundsgaard, C. and D.D. Van Slyke. "Studies of lung volume: relation between thorax size and lung volume in normal adults." J. Exptl. Med. 27: 65-85, 1918

23. Mendez, J. and H.C. Lukaski. "Variability of body composition in ambulatory subjects measured at different days." Am. J. Clin. Nut. 34: 78-81, 1981

24. Moody, D.L. ; J.H. Wilmore ; R.N. Girondola and J.P. Royce. "The effects of a jogging program on the body composition of normaland obese high school girls." Med. Sci. Sport Exercise 4: 210-213, 1972

25. Pollack, M.L. ; E. Eddins ; B. Coleman ; A.C. Linnewalda and A. Jackson. "Prediction of body density on young and middle aged women." J. Appl. Physiol. 38: 745-749, 1974

26. Rahn, H. ; W.O. Fenn and A.B. Otis. "Daily variations of vital capacity, residual air and expiratory reserve including a study of the residual air method." J. Appl. Physiol. 1: 725-736, 1949

27. Satwanti ; H. Bharadwaj and I.D. Singh. "Relationship of body density measurements in young punjabi women." Hum. Bio. 49: 203-213, 1977

28. Satwanti ; H. Bharadwaj and I.D. Singh. "Determinations of body density using normal procedure." Hum. Bio. 50: 515-527, 1978

29. Shephard, R.j. ; G. Jones ; K. Ishil ; M. Kaneko and A.J. Olbrecht. "Factors affecting body density and thickness of subcutaneous fat." Am. J. Clin. Nut. 22: 1175-1188, 1969

30. Siri, W.E.. "Body composition from fluid spaces and density: analysis of methods." Nat. Acad. Sci. 223-244, 1961

31. Slaughter, M.H. ; and T.G. Lohman. "Relationship of body composition to somatotype." Am. J. Phys. Anth. 44: 237-244, 1976

32. Stubbing, D.G. ; L.D. Pengaly ; J.C. Morse and N. Jones. "Pulmonary Mechanics during exercise in normal males." J. Appl. Physiol. 49: 506-510, 1980

33. Vossekuil, C.S. . "The effects of water immersion and level of exhalation upon body density analysis." Master's Thesis, 1981

34. Vossekuil, C.S. ; W.D. Van Huss ; R. Wells ; H. Sprague and W.W. Heusner. "The effects of immersion upon residual volume and estimated body composition." Submitted for publication

35. Webb, P.. "Energy expenditure and fat free mass in men and women." Am. J. Clin. Nut. 34: 1816-1826, 1981

36. Wells, R. "Underwater weighing: Errors and corrections." Unpublished 1983

37. Wilmore, J.H. and A.R. Behnke. "Predictability of lean body weight through anthropometric assessment in college men." J. Appl. Physiol. 25: 349-355, 1968

38. Wilmore, J.H. and A.R. Behnke. "An anthropometric estimation of body density in young men." J. Appl. Physiol. 27: 25-31, 1969

39. Wilmore, J.H. ; R.N. Girondola and D.L. Moody. "Validity of skinfold and girth assessment for predicting alterations in body composition." J. Appl. Physiol. 29: 313-317, 1970