A Comparison of Percent Body Fat Calculated by Three Methods: Hydrostatic Weighing, Skinfolds, and Near Infrared Technique

James W. Hill
Western Michigan University

Follow this and additional works at: https://scholarworks.wmich.edu/masters_theses

Part of the Health and Physical Education Commons

Recommended Citation
https://scholarworks.wmich.edu/masters_theses/877

This Masters Thesis-Open Access is brought to you for free and open access by the Graduate College at ScholarWorks at WMU. It has been accepted for inclusion in Master's Theses by an authorized administrator of ScholarWorks at WMU. For more information, please contact maira.bundza@wmich.edu.
A COMPARISON OF PERCENT BODY FAT CALCULATED BY THREE METHODS: HYDROSTATIC WEIGHING, SKINFOLDS, AND NEAR INFRARED TECHNIQUE

by

James W. Hill

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Arts
Department of Health, Physical Education and Recreation

Western Michigan University
Kalamazoo, Michigan
April 1992
A COMPARISON OF PERCENT BODY FAT CALCULATED BY THREE METHODS: HYDROSTATIC WEIGHING, SKINFOLDS, AND NEAR INFRARED TECHNIQUE

James W. Hill, M.A.

Western Michigan University, 1992

The purpose of this study was to determine the validity of the near infrared technique for assessing body composition. Hydrostatic weighing was used as the criterion measure to which skinfold technique and near infrared technique (as measured by the Futrex-5000) were compared. Two hundred subjects (115 females, 85 males) had their body composition assessed by the three techniques. The intra-class reliability of the Futrex-5000 was measured at $r = .997$. The Pearson product-moment correlation between hydrostatic weighing and the Futrex-5000 was $r = .71$, $p < .01$. The mean percent body fat derived from hydrostatic weighing was 19.3% compared to 21.6% for the Futrex-5000. A $t$ test indicated a significant difference between the mean percent body fats calculated by hydrostatic weighing and the Futrex-5000, $t(160) = -5.21$, $p < .01$. This study indicated that the Futrex-5000 was not as valid as either skinfold technique or hydrostatic weighing.
ACKNOWLEDGMENTS

I would like to acknowledge my advisor and committee chairperson, Dr. Mary Dawson, for her assistance and direction in completing this thesis. I would like to also thank the other members of the committee, Dr. Roger Zabik and Dr. Hal Ray, for their help.

Appreciation is given to Western Michigan University, Kalamazoo, for the use of their facilities. Appreciation should also be expressed to Joe Estkowski for his computing expertise, and to Sharon Jones for her format assistance. My thanks are also extended to Karen Snyder for the information she provided for this study and to Jeff Gailhouse and Gavin Testa for their help in collecting data.

James W. Hill
INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.
A comparison of percent body fat calculated by three methods:
Hydrostatic weighing, skinfolds, and near infrared technique

Hill, James William, M.A.
Western Michigan University, 1992
# TABLE OF CONTENTS

ACKNOWLEDGMENTS ............................................... ii

LIST OF TABLES ................................................... v

CHAPTER

I. INTRODUCTION ............................................... 1

- Statement of the Problem ................................ 2
- Purpose of the Study ...................................... 2
- Delimitations .............................................. 3
- Limitations of the Study ................................. 3
- Basic Assumptions ........................................ 3
- Hypotheses .................................................. 4
- Definition of Terms ...................................... 4

II. REVIEW OF LITERATURE .................................... 5

- Hydrostatic Weighing .................................... 5
- Skinfolds .................................................... 7
- Near Infrared Technique ................................. 12

III. METHODS AND PROCEDURES ............................. 18

- Subjects .................................................... 18
- Instrumentation .......................................... 18

- Hydrostatic Weighing .................................... 18
- Health-O-Meter Scale .................................... 18
- Spirometer ............................................... 19
- Futrex-5000 .............................................. 19
- Skinfolds ............................................... 19
Table of Contents—Continued

CHAPTER

Data Collection ........................................... 20
Near Infrared Technique .................................. 20
Skinfolds .................................................. 21
Hydrostatic Weighing .................................... 21
BMI .......................................................... 23
Statistical Design ....................................... 23

IV. RESULTS AND DISCUSSION .......................... 24

Results .................................................... 24
Reliability ............................................... 24
Descriptive Statistics .................................... 25
Validity .................................................... 27
Discussion ............................................... 29

V. SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS .......... 33

Summary ................................................... 33
Findings ................................................... 34
Conclusions ............................................... 35
Recommendations ......................................... 35

APPENDICES

A. Informed Consent Form .................................. 36
B. WMU Human Subjects Institutional Review Board Approval .................. 39

BIBLIOGRAPHY ................................................. 41
LIST OF TABLES

1. Means and Standard Deviations for Percent Fat Techniques: Skinfolds, Futrex-5000, Hydrostatic Weighing, and BMI ....................................................... 26

2. Pearson Correlation Coefficients of Skinfolds, Futrex, HW, and BMI ................................................................. 27
CHAPTER I

INTRODUCTION

Appearance is a big concern for many people. Every year people spend millions of dollars on beauty aids, exercise equipment, nutritional supplements, and jewelry. Oftentimes, these items are used simply to improve one's appearance. One of the biggest obsessions for people is their body weight. Everyone wants to be at the "proper" weight either for health reasons or, more often than not, so he/she will look appealing. Weight, however, does not tell the whole story as it does not separate lean tissue weight (muscle, bone, connective tissue) from fat weight.

Body composition measurements are more popular now than previously because people realize that weight on the scale does not indicate degrees of fat. Hydrostatic weighing is the most reliable measure of body composition. A problem with hydrostatic weighing is the inconvenience of submerging people in water. Skinfold measurements have also been widely used in body composition testing. Skinfolds are simple and much more convenient to use. The accuracy of the skinfold method, however, depends a lot on the skill of the person using the calipers.

A new procedure, the near infrared technique, measures body composition quickly and easily without the inconvenience of underwater weighing by use of the Futrex-5000 (Futrex, Inc., Gaithersburg,
Maryland). The Futrex-5000 has a built-in computer program which prints out the subjects' percent body fat and exercise recommendations. Subject apprehension would be greatly alleviated with such a technique.

Statement of the Problem

The problem of the study was to determine the validity of the near infrared technique in the measurement of body composition. Concurrent validity was measured using Pearson product-moment correlations.

Purpose of the Study

Hydrostatic weighing is the accepted standard measure for body composition analysis. Although this method is the most reliable, problems do exist. Many subjects feel uncomfortable or are simply afraid of water and, therefore, an accurate measurement is difficult, if not impossible, to attain. Also, the possible inconvenience of finding a suitable water tank to complete the measurements could be a problem. The skin caliper method can be very accurate; however, it is based on two assumptions. Subcutaneous fat represents a constant proportion of total fat, and the skinfold sites measured represent the average overall fat thickness (Lukaski, 1987). The near infrared technique, if accurate, would provide a non-invasive, simple way of measuring a subject's fat composition. The purpose of this study was to compare the reliability and validity of this technique as measured
by the Futrex-5000 using both skinfolds and hydrostatic techniques as criterion measures.

This research study was completed to expand the body of knowledge of body composition measurement. Ideally, this research will help practitioners choose the correct measurement technique for their purpose.

Delimitations

The study was delimited to the following:

1. Subjects were students at Western Michigan University, Kalamazoo, Michigan.

2. All measurements for each subject were taken within two hours.

Limitations of the Study

The limitations of the study were as follows:

1. The degree of reliability and validity of the Cosmed Pony Spirometer (Vacumed, Inc., Ventura, California) was not known.

2. The subjects' ability to expel air while underwater was not known.

Basic Assumptions

The assumptions of the study were as follows:

1. Subjects performed to the best of their ability.

2. Individuals trained in the various measurement procedures
followed identical procedures for each subject.

Hypotheses

This study tested the following hypotheses:

1. The near infrared technique is not as reliable a technique for the measurement of body fat as underwater weighing.

2. The near infrared technique is not as reliable a technique for the measurement of body fat as skinfolds.

3. Validity of the near infrared technique is not as high as hydrostatic weighing or skinfolds.

Definition of Terms

The following terms were used in this study.

1. Body Composition: The percentage of a body's total weight which is fat tissue, as compared to the amount of total body weight from lean body mass.


3. Hydrostatic Weighing (HW): A way of assessing body composition by measuring body density while underwater.

4. Skinfold Technique: A way of assessing body composition utilizing the measurement of various fat folds on the body.

5. Body Mass Index (BMI): A way of assessing one's body composition utilizing the formula weight in kilograms divided by height in meters squared.
CHAPTER II

REVIEW OF LITERATURE

Eighty years ago German pediatricians performed the first quantitative studies of body composition on children who had died of malnutrition (Garrow, 1982). Cadavers were used for measurements of body composition in adults as early as 1945 (Garrow, 1982). The use of body density to estimate body composition goes back to the 1930s when the U.S. Navy was interested in the body composition of test divers (Wilmore, 1983). The ability to measure body composition has improved substantially since using cadavers. There are several ways to determine body composition (e.g., bioelectrical impedance, skinfolds, etc.). This paper will address a review of the research related to hydrostatic weighing, skinfolds, and the near infrared technique.

Hydrostatic Weighing

A paper by Fletcher and McNaughton (1987) stated that the three most popular methods of determining body fat are underwater weighing, skinfolds, and x-ray. The researchers noted that underwater weighing has long been regarded as an extremely accurate way to determine percentage of body fat. Underwater weighing is commonly used as the criterion measure for studies testing various field methods (Oppliger, Looney, & Tipton, 1987).
Fletcher and McNaughton (1987) studied 11 elite cyclists. Hydrostatic weighing, skinfolds, and x-ray technique were used to determine the cyclists' body composition. A strong similarity was demonstrated in the results of all three methods; the mean percent fat for the 11 cyclists was 10.7% for hydrostatic weighing, 11% for skinfolds, and 8.9% for x-ray. Since the results correlated very closely, the debate concerning which technique was best considered the amount of time, simplicity, and potential error in each technique. The approximate time involved in the measurement of body composition per subject was 27 minutes for underwater weighing, 7 minutes for skinfolds (7 sites), and 4 minutes for x-ray. Time, along with skill level of practitioners and types of subjects, all were key factors in selecting the preferred method.

There are many ways to measure body composition. Most methods have at least some merit but many methods are either too difficult to administer or too expensive to use.

Davis, Dotson, and Curtis (1985) designed a study to develop a simple, but accurate technique that involved minimal equipment, training, and time. Subjects for the study were 436 males. Percentage of body fat was determined using hydrostatic weighing, anthropometric measurements, and skinfold technique. The subjects performed at least six hydrostatic weighing trials. The anthropometric measures utilized were height, weight, waist girth, and neck girth. The pectoral, subscapular, tricep, and iliac skinfold sites were measured for the skinfold technique. An anthropometric equation using age,
waist circumference, and height had a correlation coefficient of $r = .86$ to .94, with hydrostatic weighing. The authors concluded that valid prediction equations for the estimation of percent body fat in adult males could be derived using only a tape measure.

Wilmore (1983) pointed out that although the measure of body density is considered the best prediction of percent body fat, some discrepancies exist. A certain amount of body fat is necessary to sustain life and generally percent body fat estimates of 3% or less are considered underestimates, or measurement error (Wilmore, 1983). A few studies using body density to compute body composition have resulted in measures of percent body fat well below 3%. Body volume is the most commonly used method of body composition assessment. Fat has a lower density than lean tissue, causing relatively fat subjects to have a lower overall density. The most commonly used method for measuring body volume is hydrostatic weighing (Brodie, 1988a).

One method of hydrostatic weighing commonly used takes the mean of the final three underwater trials as the subjects' true underwater weight. Another method utilizes the maximal underwater weight recorded in all trials in the conversion equation (Brodie, 1988a). Hydrostatic weighing is often the criterion for evaluating the validity of other body composition techniques.

**Skinfolds**

For many people, a reasonable estimate of body fat can be obtained from height and weight. But in today's weight conscious
society many people want a more precise measure. People of uncommon body builds and athletes need to be very conscious of their body composition (Durnin & Womersley, 1974). A frequently used field technique for determining body composition is skinfolds (Oppliger et al., 1987). A large portion of body fat lies in the subcutaneous area. Skinfold measurements at various sites on the body yield an estimate of total body fat (Garrow, 1982). A great deal of research suggests that skinfold measurements are a valid and reliable means of assessing body composition as long as at least two measurements are taken at each site and the measurements are taken by someone who has experience in proper skinfold measurement technique (Oppliger et al., 1987). Skinfold measurement is a cheap method for determining body composition. However, interobserver differences and the difficulty of accurately measuring skinfolds on very obese subjects are major drawbacks (Garrow, 1982). Interobserver differences usually occur when one or both of the people operating the skin calipers are inexperienced. Skinfold measurements on very obese people are difficult to measure and can also lead to interobserver differences even with very experienced practitioners.

A study by Oppliger et al. (1987) indicated that four sources of error observed in skinfold analyses were interinvestigator differences, measurement consistancy over time, measurements using different skin calipers, and too few repetitions with the calipers. Skinfold measurements were taken at 6 sites on 50 male subjects. The conclusions of the study were that skinfolds can be highly reliable
if high quality skin calipers are used by experienced practitioners. The practitioner should utilize multiple trials with the calipers when measuring skinfolds. The scores from the trials should then be averaged for a final skinfold score. In Oppliger's et al. (1987) study, however, only small amounts of error were caused by inter-investigator error, calipers, consistency over time, repetitions, or interactions between these variables. Durnin and Rahaman (1967) indicated that a simple method of assessing body fat, quantitatively, that could be used in the field, and not just in hospitals and labs, would be very valuable.

Durnin and Rahaman (1967) conducted a study comparing skinfolds with the criterion measure, hydrostatic weighing, to see just how accurate skinfold measurements were in predicting body composition. The study was conducted on 105 young adults and 86 adolescents. Four skinfold sites were used, namely: the biceps, triceps, subscapular, and suprailiac. Hydrostatic weighing was used as the criterion measure. Several practice trials were given to each subject before three actual trials took place and the mean of the three trials was the final value. The results were analyzed separately for men, women, boys and girls. It is known that men and women differ in the amount of subcutaneous fat and the authors believed the possibility of this existing in boys and girls was high. The correlation coefficients for total skinfold thickness and body density in young adult men and women were $r = -0.835$ and $r = -0.778$, respectively. The values for boys and girls were $r = -0.760$ and $r = -0.778$, respectively. All
of the correlation coefficients were significant at the $p < .001$ level.

In a study by Durnin and Womersley (1974), skinfold analysis was compared to hydrostatic weighing for both men and women aged 16-72 years. The subjects were 209 men and 272 women who were deliberately selected to represent a variety of body types. The four skinfold sites used were biceps, triceps, subscapular, and suprailiac. Underwater weighing was performed by first giving the subjects several practice trials and then measuring the three actual trials. More trials were performed if poor agreement existed among the first three trials. The coefficients for the sums of two or more skinfolds and hydrostatic weighing varied from $r = -.70$ to $r = -.90$ for the different age groups. As the age of the subjects increased, there was less agreement between skinfolds and hydrostatic weighing. It was evident that the relationship between body density and skinfold measurements was not linear over time. The fact that the relationship between body density and skinfolds was not linear could be because a greater proportion of total body fat is situated internally rather than subcutaneously. As people grow older, skinfold compressibility may be greater which would prevent accurate comparisons with younger subjects (Durnin & Womersley, 1974).

Skinfold measure as a tool for estimating body composition is based on two assumptions: (1) thickness of subcutaneous fat represents a constant proportion of total fat, and (2) the sites selected for skinfold measurements represent the average thickness of the
subcutaneous fat (Lukaski, 1987). Lukaski stated that the general precision of skin calipers can easily give an estimate of percent body fat within 5%. Error increases slightly when skinfolds get very large, greater than 15mm, or very small, less than 5mm.

A study by Thomas, Sterner, and Burke (1986) compared skinfold measurement with a visual technique for estimating percent fat. Five subjects were used for reference photographs representing different levels of percent body fat. Each subject was photographed from the front, back, and right side while standing in an anatomical position. The experts looked at the reference pictures and compared them to the pictures of each subject and then estimated the subjects' percent body fat. The subjects for the study were 76 male volunteers which were tested over a five-week period. Skinfold thickness was measured at four sites: the biceps, triceps, subscapular, and suprailiac. Three measures were taken at each site and then averaged for the subjects' final score. Underwater weighing was used as the criterion measure to which skinfolds and visual technique would be compared. Underwater weight consisted of five to ten trials with the mean of the last three trials used as the final value. Visual technique was performed by two experts in body composition measures. The correlation coefficient between percent fat measured by skinfolds and percent fat measured by hydrostatic weighing was $r = .85$. The mean percent fat based on hydrostatic weighing was 19.3% compared to a mean of 17.4% based on skinfolds. Visual technique had an inter-rater reliability coefficient of $r = .80$ for rater one and $r = .79$ for
rater two, \( p < .01 \). The mean percent fat based on visual technique was 19.2% for rater one and 16.6% for rater two, compared to the mean of 15.3% found using hydrostatic weighing (Thomas et al., 1986).

Near Infrared Technique

In 1986, Rosenthal wrote an article explaining the near infrared technique (NIR) technology. A history of two different NIR approaches was reviewed and explained in detail. For nearly fifteen years, NIR has been used in long wavelengths. At these wavelengths, proteins, oil, starch, etc., have strong absorptions. Accurate measurements can be obtained providing particle size remains relatively constant. This method requires the sample to be in a fine powder form. Transmission technology uses NIR energy at shorter wavelengths. A portion of this energy is transmitted through the sample and is measured by a silicon detector as it exits through the back of the sample. NIR technology has changed over the years. Infrared emitting diodes (IREDS) have allowed NIR technology to be used in such items as television remote controls, and burglar alarms. Transmission technology has made it possible to test solid samples and the technology does not involve moving parts. Transmission measurements are the preferred method for most wheat analysis today, since it is more practical for samples of high moisture or high oil, and for samples taken in extreme temperatures.

In a study by Conway, Norris, and Bodwell (1984) a new form of human body composition was tested called infrared interactance.
Infrared interactance was derived from earlier research conducted by the USDA Beltsville Agricultural Center, Beltsville, Maryland, in the area of near infrared reflectance. The subjects consisted of 20 males and 33 females. Interactance spectra were measured at five sites: triceps, biceps, subscapular, suprailiac, and thigh. Twenty scans were made at each site and averaged by the instrument. The body composition of the subjects was determined using NIR and was compared to results from skinfold, ultrasound, and a method called deuterium oxide dilution (D\textsuperscript{2}O). The correlation coefficients between percent body fat as predicted by D\textsuperscript{2}O and as predicted by infrared interactance were \( r = .84 \) for males, \( r = .95 \) for females and \( r = .94 \) for both males and females. The correlation coefficients between percent fat predicted by skinfolds and by infrared interactance were \( r = .74 \) for males, \( r = .83 \) for females, and \( r = .86 \) for both males and females. The ultrasound technique's body fat estimates correlated with those of the infrared interactance as \( r = .64 \) for males, \( r = .84 \) for females, and \( r = .84 \) for both males and females (\( p < .01 \) for all values). The mean percent body fat estimates for males were 24.9% with infrared interactance, 24.0% with D\textsuperscript{2}O, 23.0% with skinfolds and 17.5% for the ultrasound technique. The mean percent fat estimates for females were 32.2% with infrared interactance, 32.2% with D\textsuperscript{2}O, 30.7% with skinfolds, and 24.5% for the ultrasound technique. The total mean percent fat values for both males and females were 29.1% with infrared interactance, 29.1% with D\textsuperscript{2}O, 27.8% with skinfolds, and 21.9% for the ultrasound technique.
The article suggested that infrared interactance successfully predicted body composition in the subjects tested. This study, however, did not use the most commonly used criterion measure, hydrostatic weighing, or the commercially available Futrex-5000 (Futrex, Inc., Gaithersburg, Maryland).

A preliminary report by Gullstrand (1988) tested a new method for body composition measurement using the Futrex-5000. The Futrex-5000 measures fat under the skin and in the muscle. The manufacturers of the Futrex-5000 stated that the instrument was calibrated to give results within 2% of hydrostatic weighing. Boson Sportcenter in Liding, Sweden was the setting for Gullstrand's study comparing skinfold technique with the Futrex-5000. The subjects were 23 women and 59 men, most of whom were elite athletes. The results showed that the Futrex-5000 was in close agreement with the skinfold technique as the correlation coefficient between the two was $r = .89$, $p < .001$. In conclusion, Gullstrand found the Futrex-5000 reliable, efficient and easy to use.

Davis and Paynter (1987) summarized the initial evaluation of the Futrex-5000. The Futrex-5000 uses infrared interactance technology similar to that used by Conway et al. (1984). The initial evaluation included more than eighty subjects of different gender, race, and fitness levels. Body composition was determined at a Human Performance Center in Alexandria, Virginia by hydrostatic weighing, skinfolds, anthropometric measurements, and by the Futrex-5000. Measurements are taken with the Futrex-5000 by placing the optical
light wand through a light protective shield and placing the wand on the bicep half-way between the shoulder and the elbow of the dominant arm. Results showed that the test-retest reliability assessed over three days on ten subjects was .94 based on an interclass correlation. The concurrent validity was .83 based on comparisons with hydrostatic weighing. The data suggested that the Futrex-5000 was reliable and valid.

A study done by Dotson, Davis, and Whitcomb (1988) compared body composition values by the Futrex-5000 to skinfolds and anthropometric measurements. The study's subjects were children 5-13 years old. The purpose of this study was to determine body composition values using skinfold and anthropometric measures from the Physical Best Assessment Program provided by the American Alliance for Health, Physical Education, Recreation, and Dance, and to compare these values with the values collected by using the Futrex-5000 (Dotson et al., 1988). Data analysis was performed on randomly generated groups labeled the calibration group and the validation group. It was concluded that the Futrex-5000 could be used effectively for measuring body composition in pre-adolescent children.

Sawai, Mutoh, and Miyashita's (1989) study determined the effectiveness of the Futrex-5000 in measuring body fat in native Japanese. The subjects were volunteers, 67 males and 52 females, ranging in age from 18-58 years. Height and weight were measured for each subject and percent body fat was estimated by hydrostatic weighing, skinfolds, and the BFT-2000, which is the Japanese language model of the
Futrex-5000 (Futrex, Inc., Gaithersburg, Maryland). The study population was believed to be representative of the Japanese population as a whole. The Futrex-5000 Japanese equivalent had correlation coefficients of $r = .88$ with hydrostatic weighing and $r = .83$ with skinfolds at the $p < .001$ level of significance. The percent body fat mean showed NIR at 18.58, hydrostatic weighing 18.58, and skinfolds at 18.62. This study supported the manufacturer's claim that the Futrex-5000 is a valid means of assessing body fat.

A study performed by Israel et al. (1989) resulted in unfavorable results for the consumer version of NIR technology known as the Futrex-5000. The purpose of this study was to determine the validity of the NIR device. The study compared NIR with hydrostatic weighing and three- and seven-site skinfold estimates in their ability to assess body composition. The subjects consisted of 80 Caucasian males, many of whom were athletes and exercised frequently. Skinfolds were taken at seven sites: chest, axilla, triceps, subscapula, abdomen, suprailium, and thigh. The skinfold sites used for the three-site analyses were the chest, abdomen, and thigh. The Futrex-5000 was the NIR instrument being tested. Analysis of variance indicated a significant difference among the methods used. Post-hoc analysis revealed that NIR significantly $p < .01$ overestimated body density and underestimated percent fat when compared to hydrostatic weighing and three- and seven-site skinfold analysis. The absolute differences were small between the Futrex-5000 and hydrostatic weighing, 3.1% body fat. This, however, represented a large relative
error of 24%. Correlation coefficients compared to hydrostatic weighing were as follows: body mass index \( r = .68 \), Futrex-5000 \( r = .79 \), three skinfold sites \( r = .87 \), and seven skinfold sites \( r = .90 \) (\( p < .0001 \)). The data showed a large deviation between NIR and hydrostatic weighing as 56% of the subjects were within plus or minus 4% of the hydrostatic weighing estimates.

Of the variables input into the Futrex-5000, the primary contributors in the prediction equation for NIR were, in order: optical density measure from the Futrex-5000 light wand, activity level, weight, age, and height. The results showed the commercially available NIR device, the Futrex-5000, was not accurate in estimating body composition with this population.

A study by Bardo and Snyder (1990) compared percent body fat calculated by hydrostatic weighing and by the Futrex-5000. The subjects were a homogeneous group ranging from 17-30 years of age. Results of the study indicate that the Futrex-5000 over estimated percent body fat. A low correlation representing concurrent validity of .63 was found between hydrostatic weighing and the Futrex-5000. The exercise level of the subject was found to have the greatest effect on the correlation coefficient in comparison to other subject variables (Bardo & Snyder, 1990). The research concluded that the near infrared technique was an invalid tool in measuring body composition.
CHAPTER III

METHODS AND PROCEDURES

The purpose of the study was to determine the validity of the Futrex-5000, a near infrared technique, for assessing body composition. The procedures used in this study were grouped under the following headings: (a) subjects, (b) instrumentation, (c) data collection procedures, and (d) statistical design.

Subjects

The 200 subjects for this study were Western Michigan University students enrolled in Health for Better Living (PEPR 100). Subjects participated in hydrostatic weighing, skinfolds, and near infrared technique as part of their requirements for class. The purpose of the study was explained to the students.

Instrumentation

Hydrostatic Weighing

A stainless steel hydrostatic weighing tank 4 x 4 x 4 feet was used. A T-bar was attached to a Chatillon scale (Chatillon, Inc., New York, New York) with a capacity of 9 kilograms. A velcro weight belt was worn by the subjects.
Health-O-Meter Scale

A continental Health-O-Meter scale (Continental Scale Corp., Chicago, Illinois) was used to weigh people on dry land to the nearest half pound.

Spirometer

Forced vital capacity was measured by the Cosmed Pony Spirometer, model number 16503 (Vacumed, Inc., Ventura, California). A turbine flow meter within the device measured the flow rate and volume of the expired air. One inch, disposable mouthpieces were attached to the apparatus. No reliability statistics could be obtained from the technical assistance center listed in the back of the user's manual.

Futrex-5000

The Futrex-5000 is a computerized instrument which measures interactive lightwaves to predict percent body fat. A light wand was used to emit a light beam at the site of the bicep. The presence of fat at the site altered the spectrum of the light beam. The change in spectrum was then measured and used to estimate percent body fat. Davis and Paynter (1987) concluded through a preliminary investigation that NIR can assess body composition with excellent reliability and validity. Built-in software programs allowed for storage of statistics as well as print-outs.
Skinfolds

Skinfolds were measured with Lange (Cambridge Scientific Industries, Inc., Cambridge, Maryland) skin calipers at the appropriate body sites. Jackson and Pollock's three-site formula for skinfolds was used for determining body composition (Baumgartner & Jackson, 1991).

Data Collection

The subjects were Western Michigan University undergraduate students enrolled in Health for Better Living (PEPR 100). The subjects began by signing an informed consent form and having their height and weight measured. Appendix A contains a copy of the consent form.

Near Infrared Technique

The subjects answered a series of questions in regard to physical characteristics: gender, height, weight, body frame, age, and exercise level. Exercise level was determined according to the following parameters: (a) less than 15 minutes a day was no exercise, (b) 15-30 minutes of walking or other non-monitored light exercise was low exercise, (c) at least 20 minutes of exercise three times per week where the subject was conscious of his/her workload defined moderate exercise, (d) exercise of longer than 60 minutes at least 5 days a week was heavy exercise. The subject's body frame was determined using the elbow breadth measurement technique (Lohman,
Roche, & Martorell, 1988).

After answering the questions, a light wand was lightly placed over the bicep of the right arm halfway between the elbow and shoulder of the right arm. Within 10 seconds, an estimation of the individual's percent body fat was printed out.

Skinfolds

Subjects' skinfolds were measured using Lange (Cambridge Scientific Industries, Inc. Cambridge, Maryland) skin calipers. The calipers were used to measure the size of the skinfold at the chest, abdomen, and thigh areas for men, and the triceps, suprailium, and thigh sites for women. These sites were from Jackson and Pollock's three-site formula (Baumgartner & Jackson, 1991). The subject was taken behind a curtain and had two skinfold measures taken at each site. The final skinfold score for that site was derived by averaging the two skinfold measures taken. All skinfold measures were taken by the same person for consistency.

Hydrostatic Weighing

The first step in the hydrostatic weighing process was to have the subjects' vital capacity measured. Each subject was given a demonstration of how to use the pony spirometer (Vacumed, Inc., Ventura, California) after which their vital capacity was measured. For each subject, age, height (centimeters), weight (pounds), ethnic correction, and gender were entered into the pony spirometer. Each
subject was given a mouthpiece and was instructed to make a tight seal around it with their lips and to exhale as much air as they could. A nose clip was used to prevent air from escaping through the nose. The mouthpiece was connected to the turbine flow meter, which measured the flow rate and volume of the expired air. Three trials were performed by each subject and the highest score was used in the prediction equation.

Subjects then proceeded with the underwater weighing technique by attaching a weight belt around their waist. The method of weighing was then explained to each subject and any questions were answered at that time. Subjects were allowed time to feel comfortable in the water before the actual underwater weight was taken. Once the subject felt comfortable, they straddled the T-bar, placed it behind the knees, and held onto the bar below the water's surface. When ready, the subject submerged, exhaled as much air as possible, assumed a fetal position and stayed underwater as long as possible. The subjects were told to stay as still as possible underwater and not to touch the bottom or sides of the tank. At least six trials were completed on each subject. Ten trials were measured if a consistent weight was not obtained by the sixth trial. The highest weight attained was then recorded as the underwater weight. The underwater weight was used with the highest vital capacity score in the computer. The computer utilized the Siri equation to convert body density to percent body fat.
BMI was calculated on all subjects as weight in kilograms divided by height in meters squared. BMI was included for comparative purposes as many studies have shown close correlations between BMI and hydrostatic weighing (Brodie, 1988a).

Statistical Design

Hydrostatic weighing was used as the criterion measure for determining the concurrent validity of NIR. The independent variables of the study were HW, skinfold technique, NIR, and BMI. The dependent variable was the actual percent fatness of the subjects. Means and standard deviations were calculated on the dependent variables. The Pearson product-moment correlation calculated the correlations between different variables in the study. A t test was used to test for differences between the mean percent body fats calculated by HW, NIR, BMI, and skinfold technique.
CHAPTER IV

RESULTS AND DISCUSSION

This study investigated the reliability and validity of the Futrex-5000, a near infrared technique, for measuring body composition. The Futrex-5000 produced a score for each subject that represented the subject's percent body fat. This score was compared to the criterion measure, hydrostatic weighing, and to the measures obtained by the skinfold technique and BMI.

The total number of subjects was 200, 115 females and 85 males. All 200 subjects were tested using the skinfold technique. All but two of the 115 females, and all 85 males were measured on the Futrex. The breakdown for the group measured by hydrostatic weighing was 77 males and 86 females. Pearson product-moment correlations were used to determine the relationship between the four measuring techniques.

Results

Reliability

Intraclass reliability coefficients were calculated on the values produced by the Futrex-5000. Five subjects were measured by the Futrex-5000. Measures were repeated five different times for each subject and the results were recorded. The reliability was tested using an intraclass reliability coefficient. A one-way ANOVA model was used to calculate the intraclass reliability (Baumgartner,
The same procedure was used to determine the intraclass reliability of skinfold measures at the three sites used for males (chest, abdomen, thigh). The results showed the intraclass coefficients to be very high. The intraclass reliability of the Futrex-5000 was $r = .997$. The intraclass reliability coefficients for the three skinfold sites were thigh, $r = .999$; abdominal, $r = .997$; and chest, $r = .999$. There was no significant difference between the reliability of the Futrex-5000 and skinfolds.

**Descriptive Statistics**

There were 200 subjects in the study, 85 males and 115 females. The mean age for the subjects was 20.3 years with a standard deviation of 3.1. The oldest subject was 50 and the youngest was 18 years of age. The mean weight for the subjects in kilograms was 67.2; the standard deviation was 14.9. The weight range was 134 kg to 44.1 kg. The mean height for the subjects in meters was 1.7; the standard deviation was .08. The height range was 1.9 meters to 1.5 meters.

Percent body fat was found on 200 subjects using skinfolds. The mean percent fat was 17.4%, and the standard deviation was 7.7%. The maximum and minimum percent fat values measured were 33% and 2.4%, respectively.

Percent body fat was measured on 198 subjects using the Futrex-5000. The mean percent body fat was 22.1% with a standard deviation of 6.8%. The maximum measured percent fat was 38% and the minimum
value was 5%.

Hydrostatic weighing was utilized in predicting the percent body fat of 163 subjects. The mean percent body fat measure was 19.3%, and the standard deviation was 7.5%. The maximum measured percent fat was 38% and the minimum value was 4%.

The body mass index (BMI) was calculated on 200 subjects. BMI was calculated as weight in kilograms divided by height in meters squared. An acceptable level of body fat is represented by a BMI score of no more than 25 for men and no more than 27 for women (DiGirolamo, 1986). The mean BMI score was 22.8 for all subjects with a standard deviation of 3.5. Descriptive statistics for male, female and all subjects are listed in Table 1.

Table 1

Means and Standard Deviations for Percent Fat Techniques:
Skinsfolds, Futrex-5000, Hydrostatic Weighing, and BMI

<table>
<thead>
<tr>
<th></th>
<th>Skinfolds % mean (SD)</th>
<th>Futrex-5000% mean (SD)</th>
<th>Hydrostatic% mean (SD)</th>
<th>BMI mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>10.9 (6.0)</td>
<td>17.5 (6.6)</td>
<td>13.4 (5.3)</td>
<td>24.8 (3.7)</td>
</tr>
<tr>
<td>Female</td>
<td>22.2 (4.7)</td>
<td>25.6 (4.5)</td>
<td>24.5 (4.8)</td>
<td>21.4 (2.4)</td>
</tr>
<tr>
<td>Total</td>
<td>17.4 (7.7)</td>
<td>22.1 (6.8)</td>
<td>19.3 (7.5)</td>
<td>22.9 (3.5)</td>
</tr>
</tbody>
</table>

Table 1 illustrates that the mean percent body fat for males measured by the Futrex-5000 is 17.5%. This mean is higher than the 13.4% body fat mean for males measured by the criterion measure, hydrostatic weighing. The mean percent fat for females measured by
the Futrex-5000 is 25.6% compared to 24.5% measured by hydrostatic weighing. Combining both the male and female samples produces the total row in Table 1. The totals indicate the mean percent fat measures as 17.4% for skinfolds, 22.1% for the Futrex-5000, and 19.3% for hydrostatic weighing. The BMI scores listed in Table 1 are 24.8 for males, 21.4 for females, and 22.9 for all subjects.

Validity

The Pearson product-moment correlation results are illustrated in Table 2. The Pearson product-moment correlations illustrate the concurrent validity of the Futrex-5000.

Table 2

Pearson Correlation Coefficients of Skinfolds, Futrex, HW, and BMI

<table>
<thead>
<tr>
<th></th>
<th>Skinfolds</th>
<th>Futrex</th>
<th>HW</th>
<th>BMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skinfolds</td>
<td>1.00</td>
<td>.68</td>
<td>.83</td>
<td>.64</td>
</tr>
<tr>
<td>Futrex</td>
<td>.68</td>
<td>1.00</td>
<td>.61</td>
<td>.54</td>
</tr>
<tr>
<td>HW</td>
<td>.83</td>
<td>.61</td>
<td>1.00</td>
<td>.52</td>
</tr>
<tr>
<td>Females</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skinfolds</td>
<td>1.00</td>
<td>.30</td>
<td>.48</td>
<td>.60</td>
</tr>
<tr>
<td>Futrex</td>
<td>.30</td>
<td>1.00</td>
<td>.32</td>
<td>.22</td>
</tr>
<tr>
<td>HW</td>
<td>.48</td>
<td>.32</td>
<td>1.00</td>
<td>.38</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skinfolds</td>
<td>1.00</td>
<td>.72</td>
<td>.85</td>
<td>.03</td>
</tr>
<tr>
<td>Futrex</td>
<td>.72</td>
<td>1.00</td>
<td>.71</td>
<td>.01</td>
</tr>
<tr>
<td>HW</td>
<td>.85</td>
<td>.71</td>
<td>1.00</td>
<td>-.12</td>
</tr>
</tbody>
</table>
abbreviations were used: HW was hydrostatic weighing, Futrex was the Futrex-5000 NIR technique and BMI was Body Mass Index.

The following correlation coefficients were produced for the 85 males: (a) HW and Futrex, $r = .61$; (b) HW and Skinfolds, $r = .83$; (c) HW and BMI, $r = .52$; (d) Futrex and Skinfolds, $r = .68$; (e) Futrex and BMI, $r = .54$; and (f) Skinfolds and BMI, $r = .64$. All of these measures are significant at the $p < .01$ level of significance.

The Pearson product-moment correlations calculated for the 115 females were as follows: (a) HW and Skinfolds, $r = .48$; (b) HW and Futrex, $r = .32$; (c) HW and BMI, $r = .38$; (d) Skinfolds and Futrex, $r = .30$; (e) Skinfolds and BMI, $r = .60$; and (f) Futrex and BMI, $r = .22$. These correlations were significant at the $p < .01$ level except for the Futrex and BMI correlation of $r = .22$ which is significant at the $p < .05$ level.

Table 2 combines males and females and indicates the Pearson product-moment correlations for all subjects. The Futrex had a correlation coefficient of $r = .71$ with hydrostatic weighing. The skinfold correlation coefficient was $r = .85$ with the criterion measure, hydrostatic weighing. The BMI score produced a correlation coefficient with hydrostatic weighing of $r = .12$.

A $t$ test was used to test for differences between the percent fat means calculated by hydrostatic weighing and the Futrex-5000. The mean percent fat measure using hydrostatic weighing was 19.3%. The mean percent fat measure using the Futrex-5000 was 21.6%. The
A t test was used to test for differences between the percent fat means calculated by skinfolds and the Futrex-5000. The mean percent fat measure using skinfolds was 17.4%. The mean percent fat measure using the Futrex-5000 was 21.6%. The t test indicated a significant difference between the means found by skinfolds and the Futrex-5000, $t(197) = 12.03, p < .01$.

The concurrent validity coefficients for the total group of 200 subjects between HW and skinfolds was $r = .85$ and between HW and Futrex was $r = .71$. Both of these coefficients were significant at $p < .01$. The very low correlations between BMI and NW and BMI and skinfolds, when looking at all 200 subjects, were expected when male and female scores were combined.

Discussion

The findings of this study were in opposition to Gullstrand's (1988) results. Gullstrand's correlation coefficient was $r = .89$ ($p < .001$) (between the Futrex-5000 and skinfold technique). Sawai et al. (1989) reported a correlation coefficient of $r = .88$ between...
hydrostatic weighing and the Futrex-5000. Correlation coefficients of $r = .83$ between the Futrex-5000 and the skinfold technique were also reported ($p < .001$) (Sawai et al., 1989). The correlation coefficient in this study between skinfolds and the Futrex-5000 was $r = .72$. The correlation coefficient between hydrostatic weighing and the Futrex-5000 was $r = .71$, $p < .01$. The descriptive data were not that different from this study to Sawai's et al. (1989). Sawai et al. (1989) reported a mean percent body fat of 14.1% with a standard deviation of 5.2 for males and a mean percent fat of 23.7% with a standard deviation of 4.6 for females. The results of this study show 13.4% for the mean percent body fat for males and 24.5% for females with standard deviations of 5.3 and 4.8, respectively.

Bardo and Snyder's (1990) study, which compared the Futrex-5000 to hydrostatic weighing, has similar results to this study. The results of Bardo and Snyder's (1990) study included correlation coefficients of $r = .63$ between hydrostatic weighing and the Futrex-5000, $p < .05$. This study has a higher correlation coefficient between hydrostatic weighing and the Futrex-5000, $r = .71$ than Bardo and Snyder's (1990) study. However, the number of subjects was much larger in this study and the subject sample was slightly more heterogeneous. The results of Bardo and Snyder's (1990) study indicated that the Futrex-5000 produced consistently higher values for the subject's percent body fat than did hydrostatic weighing. The mean percent body fat measure was 19.3% with hydrostatic weighing and 22.1% with the Futrex-5000.
Table 1 clearly indicates that the sample used in the study was very lean. Percent body fats of typical young men and young women were listed in Lamb (1984) as 15% and 27%, respectively. Hydrostatic weighing and skinfolds used for men resulted in lower percent fat levels than Lamb's averages for typical young men. All three methods used to determine percent body fat for women resulted in lower percent fat levels than Lamb's averages for typical young women. BMI suggested a lean group which was consistent with the results of the other body fat measures. The table also indicates that compared to hydrostatic weighing and skinfolds, the Futrex-5000 consistently produced higher percent fat values.

Pearson product-moment correlations produced between skinfolds and the Futrex-5000 were lower, in the female group, compared to the correlation coefficients between hydrostatic weighing and the Futrex-5000. This was due to the homogeneity of the sample. The male sample in this study had a higher standard deviation in percent fat as measured by hydrostatic weighing 5.3% than did the female group at 4.8%. The higher standard deviation indicated a greater difference in the male sample compared to the female sample. Higher correlations will exist with a more heterogenous group (Hopkins, Glass, & Hopkins, 1987). The male distribution was more positively skewed with the mean percent fat measure being within two standard deviations of the minimum score and within three standard deviations from the maximal measure. The positive skewness of the male sample may account for the standard deviation of percent fat measures being...
greater than for the female sample's standard deviation.

Skinfolds provided the most accurate percent fat estimates, compared to the criterion measure hydrostatic weighing, for males. The body mass index is included for comparative purposes as many studies have shown correlations of at least .7 between BMI and hydrostatic weighing (Brodie, 1988a). BMI was not expected to correlate at all when comparing BMI to all the subjects in the study. BMI had a correlation coefficient of \( r = .12 \) compared to hydrostatic weighing when looking at all subjects.
CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of the study was to determine the validity of the Futrex-5000, a near infrared technique, as a measure of body composition. The reason for testing the Futrex-5000 was that its simplicity compared to other techniques would make it practical for widespread use.

Summary

The subjects consisted of 115 females and 85 males. The subject's body composition was measured three different ways, hydrostatic weighing, skinfold technique, and the Futrex-5000. The body mass index was also calculated for comparison purposes.

The subjects in the study participated as part of their Health for Better Living (PEPR 100) class. Subjects, however, could still choose not to participate in one or more of the measurement techniques. All subjects were measured by skinfold technique. Two of the female subjects were not measured on the Futrex-5000. Subjects for the criterion measure, hydrostatic weighing, consisted of 86 females and 77 males.

Pearson product-moment correlations were computed between the variables. Reliability of the Futrex-5000 and the reliability of the skinfold measures were indicated by the intraclass coefficient utilizing a one-way ANOVA model for reliability (Baumgartner, 1989).
To compare mean percent body fats between Futrex-5000 and hydrostatic weight and between Futrex-5000 and skinfold, *t* tests were utilized.

### Findings

The Futrex-5000's intraclass reliability was tested using intraclass reliability coefficients with a one-way ANOVA (Baumgartner, 1989). The Futrex-5000's reliability coefficient was $r = .997$, which was very high. The reliability coefficients of the skinfold measures were: (a) chest, $r = .999$; (b) abdomen, $r = .997$; and (c) thigh, $r = .999$.

Pearson product-moment correlation coefficients were calculated to show concurrent validity. The correlation coefficients indicated the relationship between hydrostatic weighing and skinfolds was $r = .85$, $p < .01$. The correlation coefficient between hydrostatic weighing and the Futrex-5000 was $r = .71$, $p < .01$. Skinfold technique was correlated with the criterion, hydrostatic weighing, at $r = .83$ with males and $r = .48$ with females as compared to the Futrex-5000's correlations with hydrostatic weighing of $r = .32$ for females and $r = .61$ for males.

A *t* test was used to test for differences between the percent fat means calculated by hydrostatic weighing and the Futrex-5000. The *t* test indicated a significant difference between the means for HW and the Futrex-5000. The mean for HW was 19.3% while the mean for the Futrex-5000 was 21.6%. The difference of 2.3% was significant, $t(161) = -5.21$, $p < .01$. 

---

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
A *t* test was used to test for differences between the percent fat means calculated by skinfolds and the Futrex-5000. The *t* test indicated a significant difference between the means for skinfolds and the Futrex-5000. The mean for skinfolds was 17.4% while the mean for the Futrex-5000 was 22.1%. The difference of 4.7% was significant, \( t(197) = 12.03, p < .01 \).

Conclusions

This study resulted in the following conclusions:

1. The intraclass reliability coefficient of the Futrex-5000 was extremely high and comparable to hydrostatic weighing and skinfolds.

2. The Futrex-5000 was not as valid a technique as hydrostatic weighing.

3. The Futrex-5000 was not as valid a technique as skinfolds.

Recommendations

The Futrex-5000 may be more valid if used on more than one body site (biceps). The subjects in this study were quite lean. Future research should include a greater number of fatter subjects to better represent the typical fatness of the U.S. population.
Appendix A

Informed Consent Form
INFORMED CONSENT

The purpose of this research study is to determine the validity of the infrared technique in measuring body composition. Three different tests will be administered for comparison purposes: hydrostatic weighing, skinfolds, and infrared technique.

Procedures for measuring body fat include the following:

1. Infrared technique requires the subject to sit with the right arm relaxed and resting on a table. A lightweight is placed on the bicep while the infrared device reads arm density.

2. Hydrostatic weighing requires the measurement of each subject’s lung capacity. This involves breathing into the lung function analyzer. Also, the subject is placed in a water tank four feet by four feet. While in the tank the subject sits on a t-bar and when ready voluntarily submerges the entire body. After the body is submerged an underwater weight is read. This procedure is repeated several times until a consistent weight is obtained.

3. Skinfolds are measured with skin calipers at three body sites for both men and women. Skin calipers are used to measure the thickness of a fold of skin and fat at specific sites on the body. The sites used in this study are: chest, abdomen, and thigh for men and triceps, suprailium, and thigh for women.

The expected duration for the subjects’ participation is approximately 30-45 minutes.

There are no risks or discomforts to the subjects.

Subjects will benefit from the study by learning their percent body fat and how they compare to the norms.

All records will be kept confidential. Subjects will not be referred to by name.

Subjects may contact Jim Hill about questions regarding the research.

Participation is voluntary. Refusal to participate will involve no penalty or loss of benefits. Subjects may discontinue participation at any time without penalty or loss of benefits to which the subject is otherwise entitled.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Research subjects will look to their own health insurance program for payment of medical expenses incurred while participating in the research.

Signature ____________________________ Date_____________

Jim Hill  387-3262
Appendix B

WMU Human Subjects Institutional Review Board Approval
Date: November 19, 1990
To: Jim Hill
From: Mary Anne Bunda, Chair
Re: HSIRB Project Number 90-10-08

This letter will serve as confirmation that your research protocol, "A Comparison of Percent Body Fat Calculated by Three Methods: Hydrostatic Weighing, Skinfolds, and Near Infrared Technique," has been approved after expedited review by the HSIRB. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the approval application.

You must seek reapproval for any change in this design. You must also seek reapproval if the project extends beyond the termination date.

The Board wishes you success in the pursuit of your research goals.

xc: Mary Dawson, HPER

Approval Termination: November 19, 1991

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
BIBLIOGRAPHY


