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UNITED STATES NAVY

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SUMMARY

Problem.

The U. S. Navy employs equations that use height and body circumferences to estimate percent body fat. However, many sailors question the accuracy of the Navy's body fat estimation equations. The Health and Physical Fitness Branch (Pers 601) of the Naval Bureau of Personnel frequently receives requests to substitute a percent body fat obtained with skinfold- or bioimpedance-based body fat estimation equations (Pers 601, personal communication). There may be a perception that skinfold- or bioimpedance-based equations are more accurate than circumference-based equations since the former equations are more commonly used in settings such as health clubs.

Objective.

The purpose of this study was to compare the accuracy of the Navy's circumference-based equations to the accuracy of three well-known skinfold- and bioimpedance-based equations. Skinfold equations were those of Behnke and Wilmore, Durnin and Womersley, and Jackson and Pollock. Bioimpedance equations were those of Segal et al. and Lohman. Accuracy was compared for both Caucasian and African-American sailors. The criterion for accuracy was percent body fat determined by hydrostatic weighing.

Approach.

Body fat was determined by hydrostatic weighing in 505 active duty Navy and Marine Corps personnel: 266 men (138 Caucasians, 128 African-Americans) and 239 women (128 Caucasians, 111 African-Americans). Body circumferences and skinfold thicknesses were measured and were used to estimate percent body fat using the Navy's body fat estimation equations and three well-known body fat estimation equations that employ skinfold measurements. Bioimpedance was used to determine resistance to a 50 kHz current. This value was used in two equations designed to predict body fat from bioimpedance. The predicted values from each of the estimation equations were then compared statistically to the percent body fat obtained by hydrostatic weighing.

Results.

There were no differences in predictive ability between the Navy equation and any of the other equations for women. The standard errors of the estimate were also similar among the equations. This held for the entire group of women as well as for Caucasians and African-Americans separately. There were also no significant differences between Caucasians and African-Americans for any of the techniques. For men, the Navy equation was the best predictor of body fat determined by hydrostatic weighing. The differences seem to have been primarily due to the greater predictive

ability of the Navy equation for African-American men; the Navy equation was significantly better than all but the Segal et al. equation in predicting body fat from hydrostatic weighing in African-American men.

Conclusion.

The Navy's body fat estimation equation predicts body fat of Navy men better than three well-known skinfold-equations and two bioimpedance-equations. Body fat of Navy women is predicted as well by the Navy's equation as by the skinfold or bioimpedance equations. The Navy's circumference method also has an advantage over skinfold equations in that measurement of circumferences is more precise than skinfold measurements and is easier to learn; and the method has an advantage over bioimpedance in cost and technical considerations. Improvements can and are being made in body fat estimation of Navy personnel, with particular emphasis on prediction of body fat for women and ethnic minorities.

INTRODUCTION

Hydrostatic weighing has long been considered the "gold standard" for estimating body fat in humans. An individual's weight underwater can be used to determine body volume. From volume, body density can be calculated. Percent fat is then estimated using the equation developed by Siri (1961). However, hydrostatic weighing has drawbacks in that it requires specialized equipment and trained technicians to conduct the testing. Another consideration is that some individuals have difficulty performing the test correctly due to either physical conditions or psychological factors. Time is also a factor, with an individual test taking approximately one hour to complete. For these reasons, various "field" methods of estimating percent body fat have been developed. These field methods utilize body measurements (anthropometry) or body tissues' varying resistance to electrical current conductance (bioimpedance). Bioimpedance is based upon the physics of electrical conductance in living tissues. Fat resists electrical current to a greater degree than muscle tissue and body water. Resistance to electrical current for the whole body can be measured at specific electrical frequencies and the relationship between the resistance and body composition can be determined by the use of mathematical equations; the equations are validated against body composition determined by hydrostatic weighing. Anthropometry capitalizes on the association between body measurements such as skinfold thicknesses or circumferences and body fat. Measurements are taken and then used in equations that calculate body density and percent body fat. All of the anthropometry-based equations currently in use, including the circumference-based equations used by the U. S. Navy, have been validated against body fat determined by hydrostatic weighing.

U. S. Navy personnel are required to pass a weight-for-height screen approximately every six months as part of the semi-annual physical readiness testing program. Those whose weight exceeds allowable limits for their height then are evaluated for percent body fat using the equations developed by Hodgdon and Beckett (1984a, b). These equations use height and body circumferences to determine body density; percent fat is then determined by use of the Siri equation (1961). However, many sailors question the accuracy of the Navy's body fat estimation equations. The Health and Physical Readiness Branch (Pers 601) of the Naval Bureau of Personnel frequently receives requests to substitute a percent body fat obtained with a skinfold- or bioimpedance-based body fat estimation equation (LCDR Rene Hernandez, MSC, USN, personal communication). There may be a perception that skinfold-based equations or bioimpedance are more accurate than circumference-based equations since the former equations are more commonly used in settings such as health clubs and Navy gyms. It is natural for military personnel to question why they get different estimates of percent body fat by different methods and to be concerned about which method is the most accurate. Although there are published reports comparing other circumference equations to skinfold equations (Wright et al., 1980; Wright et al., 1981; Tran and Weltman, 1988; Vanderburgh, 1992) and validating the Navy circumference equation against hydrostatic weighing for women (Bathalon et al., 1995), there are no published, systematic comparisons of the Navy equation to other skinfold and bioimpedance prediction equations.

The purpose of this study was to compare the accuracy of the Navy's height and circumference-based equations to the accuracy of several well-known skinfold- and bioimpedance-based equations. Accuracy was compared for both Caucasian and African-American sailors. Since all of the equations considered were developed using hydrostatic weighing as the criterion measure for body composition, hydrostatic weighing is used as the criterion in the present study.

METHODS

Subjects. Five hundred and five active duty Navy and Marine Corps personnel participated in the study: 266 men (138 Caucasian; 128 African-American) and 239 women (128 Caucasian; 111 African-American). Subjects reported to the laboratory in a fasted state. Fluids were allowed prior to testing. Subjects were informed of the risks and benefits of the study and each signed an informed consent document that had been approved by the Naval Health Research Center Committee for the Protection of Human Subjects.

Hydrostatic Body Fat Determination (HYDROFAT). Residual lung volume was determined prior to hydrostatic weighing by the helium dilution method of Ruppel (1975) using a Modular Lung Analyzer, Model 03002 (Warren E. Collins, Inc., Braintree, MA). Weights from hydrostatic weighing were determined using a Model TI 2100 electronic scale (West Weigh Scale Co., Inc., San Diego, CA). The signal from the scale was smoothed and stable weights obtained on a microcomputer with software developed at NHRC. Body density was calculated according to the formula of Buskirk (1961) and percent body fat was calculated according to the formula of Siri (1961).

Bioimpedance. Whole-body bioelectrical impedance was measured with a Xitron 4000B bioimpedance analyzer (Xitron, Inc., San Diego, CA). Measurements were made within five minutes of subjects assuming a supine position on a non-conducting, flat surface. A tetrapolar electrode arrangement was used, with electrodes on the right hand and wrist and the right ankle and foot. The resistance at 50 kHz (res50) was recorded and used in the following equations to determine fat free mass (FFM):

Lohman (LOHFFM) (Lohman, 1992):

Men: $FFM = (0.485*(htcm^2/res50))+(0.338*wtkg)+5.32$
Women: $FFM = (0.475*(htcm^2/res50))+(0.295*wtkg)+5.49$

Segal et al. (SEGFFM) (Segal et al., 1988):

Men: $FFM = (0.0013*htcm^2)-(0.044*res50)+(0.305*wtkg)-(0.168*age)+22.668$

Women: $FFM = (0.0011*htcm^2)-(0.021*res50)+(0.232*wtkg)-(0.068*age)+14.595$

where htcm = height in centimeters and wtkg = body weight in kilograms.

Percent body fat from bioimpedance (LOHFAT or SEGFAT) was calculated with the following formula:

$$\% \text{ fat} = ([wtkg-FFM]/wtkg)*100$$

Anthropometry. Height (ht; in centimeters) and weight (wt; in kilograms) were measured on a balance scale with an attached anthropometer (Detecto, Webb City, Mo). Neck (neckc), abdomen I (ab1), abdomen II (ab2), hip (hipc) circumferences; and subscapular (subsf), chest (chestsf), biceps (bicsf), triceps (trisf), abdomen (absf), and mid-thigh (thisf) skinfolds were taken following the procedures in Beckett and Hodgdon (1984). Iliac crest skinfold (iliacsf) was taken according to the procedure of Durnin and Womersley (1974). Circumferences were measured to the nearest 0.1 centimeter and skinfolds to the nearest 0.1 millimeter.

Anthropometric Body Fat Determination. Body density (bd) was calculated from anthropometric measurements according to the following formulae:

Navy (NAVFAT) (Hodgdon and Beckett, 1984a,b):

Men: $bd = -[0.19077 * \log_{10}(ab2c - neckc)] + [0.15456 * \log_{10}(ht)] + 1.0324$
Women: $bd = -[0.35004 * \log_{10}(ab1c + hipc - neckc)] + [0.221 * \log_{10}(ht)] + 1.29579$

Behnke and Wilmore (BWFAT) (Behnke and Wilmore, 1974):

Men: $bd = 1.08543 - (0.00086 * absf) - (0.0004 * thisf)$
Women: $bd = 1.06234 - (0.00068 * subsf) - (0.00039 * trisf) - (0.00025 * thisf)$

Durnin and Womersley (DWFAT) (Durnin and Womersley, 1974):

Men: $bd = 1.1765 - [0.0744 * \log_{10}(bicsf + trisf + subsf + iliacsf)]$
Women: $bd = 1.1567 - [0.0717 * \log_{10}(bicsf + trisf + subsf + iliacsf)]$

Jackson and Pollack three site (JP3FAT) (Jackson and Pollack, 1978; Jackson et al., 1980):

Men: $\quad bd = 1.10938 - 0.0008267 * (chestsf + absf + thisf) + 0.0000016 * (chestsf + absf + thisf)^2 - 0.0002574 * (age)$

Women: $\quad bd = 1.0994921 - 0.0009929 * (trisf + iliacsf + thisf) + 0.0000023 * (trisf + iliacsf + thisf)^2 - 0.0001392 * (age)$

Percent body fat was then computed from bd using the Siri equation (1961):

$$\%fat = 100 * ([4.95/bd]-4.5)$$

Statistical Analysis. Descriptive statistics were calculated using the SPSS 7.5 statistical package for PC (SPSS, Inc., Chicago, IL). Body fat, estimated from each of the anthropometric methods (the independent variable), was used to predict HYDROFAT (the dependent variable) using the simple linear regression routine of SPSS 7.5. Z transformations of the resulting regression coefficients (R) were statistically compared to one another using the following formula (Diem, 1962):

$$\frac{|z_1 - z_2|}{\sqrt{\frac{1}{n_1 - 3} + \frac{1}{n_2 - 3}}}$$

where z_1 is the z-transformation of R for the first equation, z_2 the z-transformation of R for the second equation, and n_1 and n_2 are the respective sample sizes. This formula calculates a significance limit, the $|c_\alpha|$ statistic. A table is then used to convert $|c_\alpha|$ to a probability (p) level (Diem, 1962). Probability for a significant difference between two regression coefficients was set at $p<0.05$. Since this comparison of the anthropometric methods to HYDROFAT can be considered to be a cross-validation of the anthropometric methods, the pure error was calculated as:

$$PE = \sqrt{\sum_{I=1}^{n} \frac{(y_1 - y_2)^2}{n}}$$

where PE is the pure error, y_1 is predicted body fat, y_2 is the criterion body fat, and n is sample size. The pure error is a measure of how well a predictive equation predicts the criterion on a subject sample different from that upon which the predictive equation was developed (Guo and Chumlea, 1996).

RESULTS

Subject characteristics are given in Table 1. Of the men, approximately 87% were enlisted and 13% officers, while for the women, the percentages were 74% and 26%, respectively. For each gender, there were no significant differences between Caucasians and African-Americans in age, height, or weight.

Table 1. Subject characteristics, mean ± standard deviation.

	MEN			WOMEN		
	ALL	C	A-A	ALL	C	A-A
N	266	138	128	239	128	111
AGE	31.45±6.84	30.62±7.13	32.36±6.43	30.35±6.98	31.19±7.03	29.39±6.83
HT	177.29±7.14	177.76±6.57	176.78±7.70	164.50±6.15	164.25±6.41	164.78±5.85
WT	90.07±14.11	88.88±13.79	91.35±14.39	68.87±10.65	67.53±10.74	70.42±10.38

C = Caucasian; A-A = African-American.

Table 2 gives the mean ± SD for HYDROFAT and the anthropometric and bioimpedance estimates of body fat. There were no differences for anthropometrically-derived body fat between Caucasians and African-Americans. HYDROFAT was significantly different between races for men,

while the bioimpedance estimates of body fat were significantly different between races for both men and women.

Table 2. Mean ± SD percent body fat.

	MEN			WOMEN		
	ALL	C	A-A	ALL	C	A-A
HYDRO	20.23±7.40	21.10±7.80	19.30*±6.85	28.42±7.29	28.54±6.74	28.29±7.91
NAV	21.35±6.21	21.79±6.13	20.88±6.28	31.27±6.59	30.72±6.55	31.90±6.60
BW	20.53±6.38	20.45±6.74	20.62±5.99	29.55±4.81	29.10±4.50	30.06±5.11
DW	25.26±6.34	24.67±6.81	25.90±5.76	32.97±5.93	32.32±5.89	33.71±5.92
JP3	18.08±7.31	18.32±7.89	17.82±6.64	29.08±7.30	28.64±7.02	29.58±7.61
LOH	18.88±5.35	18.10±5.83	19.71*±4.65	27.32±5.20	26.55±5.06	28.21*±5.23
SEG	24.63±5.51	23.64±5.82	25.69*±4.95	31.25±5.65	30.56±5.52	32.05*±5.72

HYDRO = hydrostatic body fat; NAV = Navy circumference equation;
BW = Behnke and Wilmore skinfold equation; DW = Durnin and Womersley skinfold equation; JP3 = Jackson and Pollock 3-site skinfold equation; LOH = Lohman bioimpedance equation; SEG = Segal et al. bioimpedance equation.
*significantly different from Caucasian, $p < 0.05$.

Table 3 gives the results (regression coefficients and standard errors of estimate) of the regression analyses for men, while Table 4 gives the results for women. The purpose of the regression analyses was to determine how well the different anthropometric and bioimpedance methods of estimating body fat predicted the measured fat. The regression coefficients from the three skinfold techniques (BWFAT, DWFAT, and JP3FAT) and two bioimpedance equations (LOHFAT and SEGFAT) then were compared statistically to the regression coefficient for NAVFAT in order to determine if any of the skinfold or bioimpedance equations predicted HYDROFAT better than NAVFAT. For women, there were no differences in predictive ability between NAVFAT and any of the other five equations. The standard errors of estimate also were similar among the methods. This held for the entire group of women as well as the Caucasians and African-Americans. There also were no significant differences between Caucasians and African-Americans for any of the equations. For men, NAVFAT was the best predictor of HYDROFAT; the R for NAVFAT was significantly greater than that for any of the skinfold or bioimpedance equations. The differences seem to have been primarily due to the greater predictive ability of NAVFAT in African-American men, since only BWFAT was significantly less accurate in predicting HYDROFAT in Caucasian men. For African-American men, SEGFAT was the only equation not significantly different from NAVFAT.

Table 5 gives the values for pure error for the anthropometrically and bioimpedance predicted body fat values compared to HYDROFAT. These values are interpreted much the same as values for standard errors: the smaller the value, the better the equation predicts the criterion. There is no set value for pure error above which an equation is said to be invalid, however. In general, cross-validation is said to be good when the pure error value is similar to the standard error for the equation for the subject sample upon which the equation was originally developed (Guo and Chumlea, 1996). The standard errors for the Navy equations for the development samples were 3.52 for men and 3.72 for women (Hodgdon and Beckett, 1984a, b). Hodgdon and Beckett (1984a, b) also cross-validated their equations and obtained values for the standard error of 2.70 for men and 4.36 and 4.04 for women. The pure error for NAVFAT for men in the present sample is 3.56 (3.66 for Caucasians; 3.45 for African-American males). This indicates excellent agreement for the NAVFAT equation in the present sample. The pure errors for all of the skinfold equations are greater than that for NAVFAT. While accuracy is not poor for these equations, none is as good as NAVFAT. For women, the pure error of 5.04 for NAVFAT is 35% greater than that obtained by Hodgdon and Beckett (1984b) in their original sample. Most of this error seems to come from the lesser accuracy in predicting body fat in African-American women. The pure error for African-American women for NAVFAT is 5.76, while the pure error for Caucasian women is 4.31. However, none of the skinfold equations does significantly better than NAVFAT in predicting body fat in women.

Table 3. Regression coefficients (R) and standard errors of the estimate (SE) for men for anthropometric and bioimpedance estimates of body fat predicting HYDROFAT.

	MEN					
	ALL		CAUCASIANS		AFRICAN-AMERICANS	
	R	SE	R	SE	R	SE
NAVFAT	0.89	3.37	0.89	3.53	0.89	3.09
BWFAT	0.80**	4.43	0.81*	4.55	0.80**	4.10
DWFAT	0.83**	4.16	0.88	3.71	0.80*	4.09
JP3FAT	0.83*	4.09	0.85	4.13	0.82*	3.95
LOHFAT	0.78**	4.59	0.85	4.17	0.78**	4.30
SEGFAT	0.81**	4.35	0.86	3.98	0.84	3.72

* = $p < 0.05$ ** = $p < 0.01$ significantly different from NAVFAT.

Table 4. Regression coefficients (R) and standard errors of the estimate (SE) for women for anthropometric and bioimpedance estimates of body fat predicting HYDROFAT.

	WOMEN					
	ALL		CAUCASIANS		AFRICAN-AMERICANS	
	R	SE	R	SE	R	SE
NAVFAT	0.82	4.13	0.84	3.65	0.82	4.52
BWFAT	0.81	4.31	0.80	4.05	0.82	4.51
DWFAT	0.82	4.20	0.82	3.87	0.84	4.35
JP3FAT	0.82	4.18	0.80	4.03	0.84	4.29
LOHFAT	0.82	4.14	0.83	3.73	0.84	4.26
SEGFAT	0.84	3.99	0.84	3.66	0.86	4.10

Table 5. Values for pure error for anthropometrically and bioimpedance predicted body fat with HYDROFAT as the criterion.

	MEN			WOMEN		
	ALL	C	A-A	ALL	C	A-A
NAVFAT	3.56	3.66	3.45	5.04	4.31	5.76
BWFAT	4.45	4.58	4.31	4.57	4.15	5.01
DWFAT	4.49	3.82	5.13	5.18	4.67	5.71
JP3FAT	4.74	5.11	4.31	4.42	4.30	4.55
LOHFAT	4.79	5.17	4.35	4.34	4.24	4.46
SEGFAT	6.19	4.78	7.42	4.90	4.15	5.64

DISCUSSION

The goal of anthropometrically-based body fat estimation methods is to find anthropometric measures that will serve as valid representatives of total body density and thus body fat. However, there are a number of problems associated with this endeavor, which has led to the many different prediction equations currently available. Guo and Chumlea (1996) list the factors that can affect the accuracy of a prediction equation as follows:

- Validity of the criterion
- Precision of measurement of the anthropometric variables
- Biological and statistical relationships among the anthropometric variables
- Biological and statistical relationships between the anthropometric variables and the criterion
- Statistical methods employed to formulate the equation
- Size and nature of the sample

Precision of measurement of the anthropometric variables can affect accuracy in two ways. The first is in the original development of the equation and the second is in the application of the equation. During equation development, the error associated with measurement of each variable is incorporated into the total error of the resulting equation, affecting its accuracy. Thus, if a particular variable cannot be measured with great precision, it will have a large associated error of measurement and the effect will be a less accurate equation. However, even if all the variables included in a given equation can be measured with a great deal of precision, the accuracy of the equation will still be compromised in everyday use if great care is not taken to measure all variables as precisely as possible every time body fat is evaluated on individuals. This is the reason for careful standardization of the sites of measurement of the anthropometric variables and the recommendation to obtain at least two measurements of the same site that are within some specified criterion. For the present sample, the criterion was ±1% for circumference measurements and ±5% for skinfold measurements. Note that circumferences can be measured more precisely than skinfolds (Roche, 1996), which has the effect of decreasing the proportion of error in prediction of percent body fat due to measurement of the anthropometric variables. It has also been shown that individuals can learn to measure circumferences accurately, more quickly, and more easily than skinfolds (Heaney, 1998). Factors that may affect the accuracy of bioimpedance measurements include electrode placement, hydration status, food consumption, body position, ambient air and skin temperatures, recent physical activity, and conductance of the surface upon which the individual is lying (Dunbar et al., 1994; NIH Technology Assessment Conference Statement, 1994; Gudivaka et al., 1996; Chumlea and Guo, 1997). These factors can make standardization and accurate measurements with bioimpedance more difficult than standardization of circumference measurements.

The biological relationships among the anthropometric variables and the criterion measure are obviously of great importance. If a particular anthropometric variable has no relation to percent body fat, it would be a poor addition to a prediction equation. Skinfold thicknesses and many circumferences correlate well with body fatness (Roche, 1996). However, assumptions are made when using these anthropometric measures in equations to predict whole body fatness. A subscapular skinfold measurement, for example, gives an accurate representation of the amount of subcutaneous fat at that particular location. That localized representation then is used as a proxy, along with a small number of other localized representations of subcutaneous fat, for total body fat. However, not all fat in the body is located just below the skin; varying amounts of fat are located inside the abdominal cavity and the muscles (internal fat) and these amounts can change with changing total body fatness. Therefore, the assumption must be made that the relationship between subcutaneous fat and internal fat remains the same across varying ages, levels of body fatness, and ethnicity (Roche, 1996). This is probably not the case and represents a source of error in prediction equations. Circumference measurements measure not only the fat at a particular location on the body but also the muscle, bones, and internal organs present at that location. The assumption is made that increases or decreases in circumferences are due to increases and decreases in fat and not some other component of the body, such as muscle or body water. The assumptions made about the relationships between anthropometric measurements and body fat may introduce error into prediction of percent body fat, particularly for individuals who differ substantially in some way from the average of the sample upon which the equation was developed originally. Likewise, the bioimpedance method makes assumptions about total body water and the hydration of lean and fat tissue. The electrical current utilized in bioimpedance travels primarily through the body's water component, and bioimpedance is, thus, a good method for measuring total body water. When measuring body composition, assumptions are made that there is little conductance through the body's fat tissue due to the hydrophobic nature of lipids. The body's fat free mass, on the other hand, is predicted from the total body water measurement obtained by bioimpedance assuming an average hydration level of 73%. However, hydration levels can vary day to day in individuals and may vary systematically with such factors as age, gender, and some physiological conditions (Chumlea and Guo, 1997).

Validity of the criterion is another important issue in developing body fat estimation equations. Even with a criterion measure of body fat, assumptions are made. In the case of percent body fat determination by hydrostatic weighing, the assumption is that the densities of the fat mass and lean mass do not vary among individuals. This is probably true for the fat mass, but lean mass density is known to vary substantially among individuals (Going, 1996) and some of this variation is ethnically-based (Schutte et al, 1984; Ortiz et al., 1992). These differences can lead to inaccuracies in determining an individual's body fat. However, in the present study, since all the equations analyzed, including the bioimpedance equations, used the same criterion of two-compartment body composition (fat and fat free mass) determined by hydrostatic weighing, legitimate comparisons can be made among them. For comparative purposes among equations, the criterion is not an issue. The problems with percent body fat determination by hydrostatic weighing, though, should be kept in mind when considering the issue of sample characteristics.

As mentioned above, anthropometric variables used in body fat prediction equations must have some biological relationship to the criterion. The equations used in this study all use variables that are biologically valid, at least in the samples upon which they were developed. However, it does not necessarily follow that an anthropometric variable that has a strong relationship to body fat in one group of people also has the same strong relationship in another group. This is particularly true when the two groups are quite different, e.g., of different genders, ages, ethnicities, or average body fatness. It is, therefore, generally believed that equations are sample-specific; i.e., they work best for the group of people on whom they were developed. This is probably due to the fact that most equations were developed using samples that were relatively homogenous with respect to such factors as age, ethnicity, and relative fatness (Jackson, 1984). Generalizability of body composition estimation equations therefore needs to be tested by cross-validation before the equations are used on new groups that differ in some way from the original group. The NAVFAT equations were developed on active duty Navy and Marine Corps personnel (602 men and 214 women) (Hodgdon and Beckett, 1984a,b). As has been shown, they cross-validate very well for men and Caucasian women on this new sample of active-duty Navy and Marine Corps personnel. The BWFAT equations were developed on 133 young men and 128 young women, most of whom were college students (Behnke and Wilmore, 1974); the DWFAT equations were developed on 209 Scottish men and 272 Scottish women, ranging in age from 16 to 72 years (Durnin and Womersley, 1974); and the JP3FAT equations were developed on 308 men (age 18-61 years) and 331 women (age 18-55 years) of varying sizes and physical activity levels (Jackson and Pollock, 1978; Jackson et al., 1980). Although they are all legitimate estimators of percent body fat, they do not cross-validate better (or as well, in some cases) on the present sample of military personnel than do the NAVFAT equations.

None of the samples upon which the anthropometrically-based body fat equations were developed included significant numbers of African-Americans or other ethnicities. This most likely explains why cross-validation of these equations, including NAVFAT, was less strong for

African-American women than for Caucasian women; although it is interesting to note that NAVFAT cross-validates very well for African-American men. Differences among ethnic groups in anthropometric variables as well as variations in body density are well established (Schutte, et al., 1984; Ortiz et al., 1992; Malina, 1996). There also may be differences in prediction of total body water and body composition from bioimpedance among ethnic groups, but this issue has not been studied extensively (Zillikens and Conway, 1991; Wang et al., 1995; Chumlea and Guo, 1997). Equations to estimate body fat, therefore, must be cross-validated on different ethnic groups to determine accuracy because it is possible that the measurements used in these equations do not share the same relationship to body fat or fat free mass in, for example, African-American women that they do in Caucasian women. The criterion measure of body fat also must be free of ethnic bias to the extent possible. This has led, in recent years, to the development of a four-compartment body composition model that corrects for individual differences in lean body density and body water. This, in theory, gives a better measure of percent body fat for an individual than percent body fat determination by hydrostatic weighing (Friedl et al., 1992). The issues of an improved criterion measure for body fat and for cross-validation of prediction equations in ethnic minorities have been recognized by the military forces. Work is currently underway at Naval Health Research Center to address these issues.

CONCLUSIONS

In summary, the Navy's body fat estimation equation predicts body fat of Navy men better than three well-known skinfold equations and two bioimpedance equations. Body fat of Navy women is predicted as well by the Navy's equation as by the skinfold or bioimpedance equations. The Navy's circumference method has an advantage over skinfold equations in that measurement of circumferences is more precise and easier to learn than skinfold measurements. Bioimpedance has technical factors such as proper placement of electrodes that must be considered when attempting to obtain accurate estimates of body fat and is considerably more expensive than the circumference method. Improvements can and are being made in body fat estimation of Navy personnel, with particular emphasis on prediction of body fat for women and ethnic minorities.

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13. ABSTRACT (Maximum 200 words

The purpose of this study was to compare the accuracy of the Navy's circumference-based equations to well-known skinfold- and bioimpedance-based equations. Body fat was determined by hydrostatic weighing in 505 active duty Navy and Marine Corps personnel: 266 men (138 Caucasians, 128 African-Americans) and 239 women (128 Caucasians, 111 African-Americans) and compared to percent body fat estimated by the Navy's body fat estimation equations, three well-known skinfold-based equations and two bioimpedance-based equations. There were no differences in predictive ability between the Navy equation and any of the other equations for women. There were also no significant differences between Caucasians and African-Americans for any of the techniques. For men, the Navy equation was the best predictor of body fat determined by hydrostatic weighing. The differences seem to have been primarily due to the greater predictive ability of the Navy equation for African-American men; the Navy equation was significantly better than all but one bioimpedance equation in predicting body fat of African-American men. The Navy's circumference method has an advantage over skinfold equations in that measurement of circumferences is more precise than skinfold measurements and is easier to learn; and the method has an advantage over bioimpedance in cost and technical considerations.

14. SUBJECT TERMS

percent body fat; Navy body fat estimation equation; hydrostatic weighing; skinfolds, bioimpedance

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