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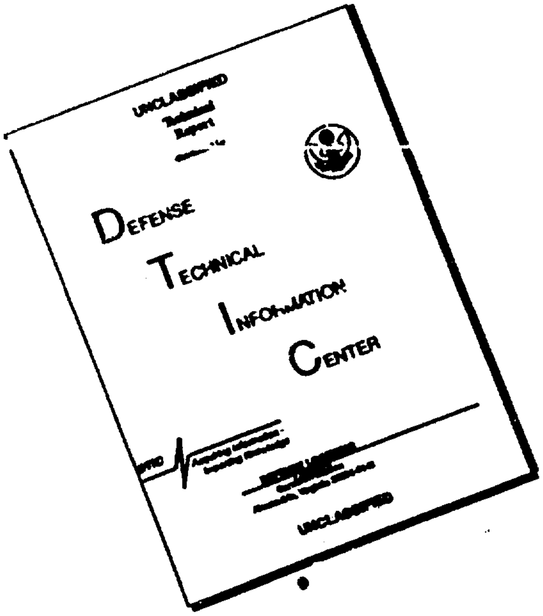

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Predicting Percent Body Fat from Circumference Measurements

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All U.S. Navy service members are required to meet percent body fat (%BF) standards as a condition of military service. Naval personnel who exceed standards for %BF can be separated from active duty. Currently, %BF predictions are determined by circumference measurements and a prediction equation (circumference equation = CEQ). In view of the importance these prediction results have for personnel retention, a validation study was undertaken to determine the accuracy of %BF prediction for a population determined to be overfat by the CEQ. The population for the validation study comprised men with 22%BF or greater and women with 30%BF or greater. Values for %BF were determined for 49 men and 50 women by hydrostatic weighing (HW) and circumference measurements at the Naval Submarine Medical Research Laboratory (NSMRL) using a regression equation developed at the Naval Health Research Center (NHRC), San Diego, California. The HW and CEQ values were compared to a superset of the original NHRC population. The correlation coefficients for the NSMRL validation group were lower than those reported in the original NHRC group. The results are attributed to the restricted range of NSMRL data and greater error of prediction at extreme ranges of values. A medical diagnostic model was used to evaluate the sensitivity, specificity, and predictive value of CEQ. It shows that the Navy's current procedures produce a 6.8 to 18% false positive rate for individuals declared as having excess body fat. The data suggest that caution should be utilized when using the CEQ method for individual career decisions.

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Introduction

The United States Navy, in an effort to increase operational effectiveness, has mandated that all Naval personnel "shall achieve and maintain standards of physical readiness and participate in a lifestyle that promotes optimal health" (OPNAVINST 6110.1D). Part of this program includes weight/fat control. Navy standards for fat control are currently quite specific. For each gender there are two categories of overfat. Overfat is defined as 23–25.9% or 31–35.9% body fat (%BF), and obese as 26 or 36%BF or greater for men and women, respectively. Individuals determined to be overfat must participate in mandatory physical conditioning; failure to meet standards may result in delayed advancement. Individuals who are determined to be obese by the circumference measurement can be denied advancement, and can also be administratively separated from the Navy. The consequences of these determinations are extreme. Therefore, it is essential that the measurement method used accurately predicts %BF for any given individual.

Percent body fat predictions are currently made using circumference measurements. The manner and location of the measurements is clearly delineated in OPNAVINST 6110.1D.

Numerous investigators have used anthropometric measurements to predict %BF. From 1981 to 1984, the Navy used a method developed by Wright, Dotson and Davis.[1] Hodgdon and Beckett[2] pointed out that there was a nonlinearity in the relationship between predicted %BF and measured (HW) %BF. The original equation[1] overestimated %BF for individuals below 18% and underestimated it for individuals above 22%. Hodgdon and Beckett at the Naval Health Research Center (NHRC) minimized this curvilinearity and proposed a revised equation to predict %BF from circumference measurements. This is the equation currently used by the Navy.

Because of the extreme importance of the results of these measurements to individual Navy members and their Commands, a validation study was conducted utilizing individuals who exceed the current %BF standards. Two methods of determining %BF were used at the Naval Submarine Medical Research Laboratory (NSMRL): (1) hydrostatic weighing, and (2) circumference measurements. A medical diagnostic model[3,4] is used to evaluate the sensitivity, specificity, and predictive accuracy of the methods for men and women who exceeded Navy %BF standards.

Methods

Navy personnel were recruited through various Command Fitness Coordinators. The Coordinators solicited 49 male volunteers who had been determined by their local commands to be 22 %BF or greater and 50 female volunteers determined to be 30 %BF or greater utilizing the then-current Navy instruction (OPNAVINST 6110.1C, now OPNAVINST 6110.1D).

Subjects were given instructions on 24-hour pre-test fluid intake, body elimination, and abstinence from alcohol and vigorous exercise. The protocol followed that of Hodgdon and Beckett.[2,5]

Anthropometric Assessment

The anthropometric assessment used the technique recommended by OPNAVINST 6110.1D. Standing height was measured to the nearest 0.25 inch using a Siber precision GPM anthropometer. Body weight was measured to the nearest 0.25 lb. with a calibrated (Detecto) scale.

Circumference measurements were taken twice in sequence (Lufkin metal tape measure) at two sites (neck and abdomen) for men and three sites for women (neck, abdomen, and hip). Measurements were made to the nearest 0.125 inch and rounded to the nearest 0.25 inch in accordance with OPNAVINST 6110.1D. If the difference between two circumferences exceeded 0.25 inches at any given site, a third measurement was repeated at that site. The mean of all measurements taken at a site was used for analysis.

Body density (BD) was estimated from the circumferential measurements according to the following regression equations (CEQ) of Hodgdon and Beckett.[2,5]

For men

$$\text{BD} = -[0.19077 \times \log_{10}(\text{abdomen (in)} - \text{neck (in)})] + [0.15456 \times \log_{10}(\text{height (cm)})] + 1.0324$$

For women

$$\text{BD} = -[0.35004 \times \log_{10}(\text{abdomen (in)} + \text{hip (in)} - \text{neck (in)})] + [0.22100 \times \log_{10}(\text{height (cm)})] + 1.29579$$

Percent body fat was derived from the calculated BD by means of the Siri equation[6]

$$\%\,\text{BF} = \frac{495}{\text{BD}} - 450$$

Residual Lung Volume Determination

Residual lung volume (RV) was measured prior to HW by closed circuit helium dilution[7] using the MED SCIENCE Pulmonary Function Computer System (Model 570, Wedge Spirometer recorder system in line with a 1200 Series Flapple dual disk drive Apple II computer and compatible pulmonary testing interface).

All subjects completed the pulmonary function test at least twice, resulting in a minimum of four RV values. All acceptable RV values were averaged and recorded.

Hydrostatic Weighing

Hydrostatic weighing, which is universally accepted as the "gold standard" for body composition studies,[8] was performed according to the method of Goldman and Buskirk,[9] with the following two modifications: (1) RV was determined outside the weighing tank prior to immersion (subjects were in a position similar to that assumed during HW, e.g., seated and bent forward at the waist), and (2) all subjects completed at least six underwater weighings. Only those readings free of any known movement artifacts were accepted. At least six readings were taken. Final underwater weight was computed as an average of the two heaviest acceptable readings. Body density was calculated using the formula of Buskirk.[10]

$$\text{BD} = \frac{\text{Mass in Air}}{\dfrac{(\text{Mass in Air}-\text{Mass in Water})}{\text{Density of Water}} - (\text{RV} + 0.1\ \text{liter})}$$

Results

The means and standard deviations of all measurements (men > 21.99%; women > 29.99%) for the NSMRL subjects are presented in Table I. Table I also presents, for purposes of comparison, similar statistics for the NHRC populations: (1) the total population of NHRC subjects (men, N = 1,023; women N = 334), and (2) a subset of the total NHRC population which includes only individuals who are over the standard (OS) for %BF, (men > 21.99%, N = 513; women > 29.99%, N = 89). The subset was extracted from the NHRC data to permit comparison between comparable overfat population samples. These data were provided by NHRC to facilitate the comparison of results obtained by the two laboratories. The statistical profiles for NHRC subjects are based on data sets of 1,023 men and 334 women.

A comparison between the OS NHRC and NSMRL populations (male and female) was made using t tests in order to determine the similarities or differences between groups. They revealed a significant (p = 0.05) difference between NHRC men (N = 513) and NSMRL men (N = 49) for height (cm) and RV (ml). No significant difference was found between groups for age, HW, or weight (kg). Although RV for the NSMRL group was determined to be significantly higher than for the NHRC group, it was not found to be significantly different than the RV for a group of 181 male marines (%BF 16.5 ± 6.2).[11] The comparison of subject characteristics revealed a significant difference between NHRC (N = 89) and NSMRL (N = 50) women for weight (kg) and RV (ml) only. The RV was again found to be significantly higher for the NSMRL group. However, comparison of the NSMRL RV to the RV for 181 female marines (%BF 23.1 ± 5.9) revealed that the NSMRL group had significantly lower RVs than the female marines.[12]

The measured RV values were compared to predicted nor-

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All U.S. Navy service members are required to meet percent body fat (%BF) standards as a condition of military service. Naval personnel who exceed standards for %BF can be separated from active duty. Currently, %BF predictions are determined by circumference measurements and a prediction equation (circumference equation = CEQ). In view of the importance these prediction results have for personnel retention, a validation study was undertaken to determine the accuracy of %BF prediction for a population determined to be overfat by the CEQ. The population for the validation study comprised men with 22%BF or greater and women with 30%BF or greater. Values for %BF were determined for 49 men and 50 women by hydrostatic weighing (HW) and circumference measurements at the Naval Submarine Medical Research Laboratory (NSMRL) using a regression equation developed at the Naval Health Research Center (NHRC), San Diego, California. The HW and CEQ values were compared to a superset of the original NHRC population. The correlation coefficients for the NSMRL validation group were lower than those reported in the original NHRC group. The results are attributed to the restricted range of NSMRL data and greater error of prediction at extreme ranges of values. A medical diagnostic model was used to evaluate the sensitivity, specificity, and predictive value of CEQ. It shows that the Navy's current (over)

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TABLE I

MEANS AND STANDARD DEVIATIONS OF ALL MEASUREMENTS FOR NSMRL AND NHRC SUBJECTS

	NSMRL Subject Characteristics			
	Men (N = 49)		Women (N = 50)	
Variable	Mean	SD	Mean	SD
Age (years)	31.6	5.7	26.3	6.5
HW %BF[a]	26.5	4.6	33.6	4.3
NHRC %BF	27.9	2.2	35.8	4.8
Height (cm)	175.5	7.2	161.4	6.4
Weight (kg)	98.4	12.5	74.6	9.3
RV (ml)	1,707.1	441.7	1,249.6	323.2
	Total NHRC Subject Characteristics			
	Men[b] (N = 1,023)		Women[b] (N = 334)	
Variable	Mean	SD	Mean	SD
Age (years)	31.9	6.9	26.5	5.2
HW %BF	21.6	8.1	26.6	6.7
NHRC %BF	21.6	7.0	26.6	5.8
Height (cm)	177.6	7.0	164.4	6.7
Weight (kg)	85.7	14.4	61.8	8.8
RV (ml)	1,433.0	385.6	1,083.6	316.8
	Over Standard NHRC Subject Characteristics			
	Men[b] (N = 513)		Women[b] (N = 89)	
Variable	Mean	SD	Mean	SD
Age (years)	33.0	6.4	27.4	5.7
HW %BF[a]	27.7	4.7	33.7	4.0
NHRC %BF	27.4	3.7	34.0	3.4
Height (cm)	177.8	7.1	163.1	5.9
Weight (kg)	95.2	11.6	70.6	7.4
RV (ml)	1,383.7	354.5	898.8	230.4

[a]Body density determined by HW and %BF calculated from Siri equation.[6]
[b]From Hodgdon and Beckett, data file sent to NSMRL, December 1989.

TABLE II

DESCRIPTION OF DATA SAMPLES FROM NHRC AND NSMRL LABORATORIES

Lab	Sex (M/F)	N	%BF	Comments
NSMRL	M	49		Total data set
NSMRL	F	50		Total data set
NHRC	M	1,123		Total data set
NHRC	F	334		Total data set
NHRC	M	513	>21.99[a]	
NHRC	F	89	>29.99[a]	
NHRC	M	49	>21.99[a]	Random subsample
NHRC	F	50	>29.99[a]	Random subsample

[a]%BF determined by circumference measurements.
Note: It should be pointed out that six of the NSMRL women (who reported for the study) were less than 29.99 %BF as determined by NHRC equation (28.5, 29.8, 29.2, 28.5, 29.1, and 26.5). Of these six, only three were less than 29.99 %BF by HW. All NSMRL subjects were included in statistical calculations.

mal (PN) values determined by commonly used prediction equations.[13,14] (Age, height, and sex are used in the prediction equations.) The mean RV for NSMRL men (1,707.1 ml) fell between two calculated PN values: (1) PN, RV = 1,830 ml, Goldman and Becklake,[13] and (2) PN, RV = 1,458 ml, Boren et al.[14] The mean RV for NSMRL women (1,249.6 ml) was slightly lower than the PN RV value of 1,502 ml;[13] Boren et al.[14] did not predict normal values for women. The mean RV for NHRC OS men (1,383.7 ml) fell below both PN values for the subjects: (1) PN, RV = 1,916 ml,[13] and (2) PN, RV = 1,518 ml.[14] The mean RV for NHRC OS women fell below the PN RV value of 1,566 ml.[13]

Variation in RV values can result from differences in measurement technique, subject comfort and/or learning curve, subject age, height, weight, health differences, smoking habits, and race.

The NSMRL data were analyzed in two ways: regression analysis according to the NHRC method and a medical diagnostic model. In order to further examine the effects of limited range and sample size in the analysis of NSMRL data and data provided by NHRC, data subsets were extracted from the NHRC data. Statistical evaluation was performed on the data sets presented in Table II.

Table III presents the regression results obtained for %BF as determined by HW versus %BF as determined by the NHRC equation. Values for sample size (N), r, r^2, standard error of estimate (S.E.E.), slope, and intercept are listed.

The correlation coefficients (r) for NSMRL subjects (men, N = 49, r = 0.42; women, N = 50, r = 0.64) are significantly lower than those obtained from the analysis of NHRC total data for both sexes, (men, N = 1,023, r = 0.89; women, N = 334, r = 0.83).

Analysis of the NHRC data for a restricted range of men greater than 21.99 %BF (N = 513) and women greater than 29.99 %BF (N = 89) also demonstrated much lower correlation coefficients (r = 0.68 for men; r = 0.62 for women).

Random subsamples of 49 men and 50 women were extracted from the NHRC OS male and female populations. The correlation coefficients from these random subsamples were calculated to obtain comparability in N value and restricted %BF range. The regression coefficients for these NHRC random subsamples again changed to different values; lower for women (r = 0.59) and higher for men (r = 0.71).

The Fishers Z' transformation[15] was employed to test whether the relationship of HW and CEQ was different across data sets. The regression coefficient for NSMRL was significantly lower (N = 49, r = 0.42) than that for total NHRC men (N = 1,023, r = 0.89), NHRC OS men (N = 513, r = 0.68) and NHRC men (subsample) (N = 49, r = 0.71). However, the NHRC men (subsample) r value was also significantly lower than the NHRC (total) men r value. The r value for NSMRL women was significantly lower (N = 50, r = 0.64) than the r value for NHRC total women (N = 334, r = 0.83); however, it was not significantly different than either the NHRC OS women (N = 89, r = 0.62) or the NHRC women (subsample) (N = 50, r = 0.59).

Discussion

Regression statistics were the first phase of the analysis. However, inherent problems exist in the application and comparison of regressions, i.e., establishing regressions on a full range of data and applying them to a restricted range. The r

TABLE III

COMPARATIVE REGRESSION STATISTICS FOR NSMRL AND NHRC (TOTAL DATA AND SUBSETS)

	NSMRL (Total Population)		NHRC (Total Population)		NHRC[a] (OS Population) Restricted Range		NHRC[a] (Randomly Chosen Subsample of Restricted OS Range)	
	Men	Women	Men	Women	Men	Women	Men	Women
N	49	50	1,023	334	513	89	49	50
r	0.42	0.64	0.89	0.83	0.68	0.62	0.71	0.59
r^2	0.18	0.41	0.69	0.69	0.46	0.39	0.49	0.36
S.E.E.	2.00	3.70	3.70	3.20	2.70	2.70	2.60	2.70
Slope	0.20	0.73	0.78	0.71	0.54	0.54	0.57	0.48
Intercept	22.60	11.30	4.80	7.70	12.50	15.70	12.00	17.60

OS > 21.99% fat for men, > 29.99% fat for women.
[a]As determined (OS) by circumference measurements and NHRC equation.

values generated from a restricted range will generally be smaller[16] than those generated from a full range.

The regression equation defined by the NHRC study is optimized for a specific data set over a broad range of %BF. If one applies that same equation in a predictive sense to a restricted range of the same data set, *r* values will typically decline since errors of estimation tend to be larger for extreme values.

A similar decrement in *r* values is also typical when regression equations are "cross-validated" to entirely new data sets drawn from the same nominal population. Regression methods minimize error variance for a specific data set. Some of the error found in a new population may be due to unexplained differences between the original population and another population. Regression coefficients are therefore optimistically biased relative to their application to another sample, and differences in correlation coefficients between different populations would be expected.

High correlation coefficients were obtained from NHRC total population data, while significantly lower correlation coefficients were obtained from the NSMRL data. Selecting for OS individuals, thus restricting the NHRC data in range, resulted in decreased *r* values. Where random subsets were taken from these OS NHRC populations, it was found that the *r* values changed again, yet remained below the original *r* values. The *r* value for OS NHRC men is significantly higher than the NSMRL men *r* value. However, the *r* value for OS NHRC women is lower (not significantly) than the *r* value for NSMRL women.

Hodgdon and Beckett[2,5] report cross-validation studies on data collected on two other (female) data samples and demonstrate high correlation coefficients. One data sample consisted of %BF from anthropometric measures and HW from 66 women in the Canadian Forces (Mr. C. Allen, DCIEM unpublished results). The second data sample consisted of %BF from anthropometric measures and HW from 80 women in the U.S. Navy; measurements were made at the NHRC laboratory. The correlation between measured and predicted %BF was higher for the U.S. Navy cross-validation sample ($r = 0.87$) than for the Canadian sample ($r = 0.80$). The mean %BF from HW was not significantly different from the NHRC (equation) mean %BF for the U.S. Navy sample; however, it was significantly different ($p < 0.05$) in the Canadian sample. Hodgdon and Beckett[2] reported that a third similar study using data on 100 men[17] gave an *r* value of 0.90. These three groups of data provide better cross-validation results than those obtained at NSMRL. Although not explicitly stated in the reports of Hodgdon and Beckett,[2,5] the data indicate that these data samples were from more extended ranges than the NSMRL samples. It would therefore be expected that these cross-validation studies between full range data sets would produce higher values.

The loss of predictive ability observed in this study could be at least partially offset if one was willing to produce new regression equations for each new data set. However, this is not a realistic alternative, since the advantage of using these methods (on a continual basis) for prediction would no longer exist. Nevertheless, new appraisals of regression fit and regression coefficients should be undertaken from time to time to protect from errors due to population shifts. The present study constitutes one such evaluation in a limited population. These findings strongly suggest caution in acceptance of accuracy in regression procedures when applied to new populations, especially in light of the consequences to Navy personnel who exceed %BF standards.

It should also be noted that the reductions which were observed in the correlation coefficients in this study do not imply error or inconsistency in either the NHRC or NSMRL studies. Relatively high *r* values were obtained on full range data from laboratories other than NHRC by Hodgdon and Beckett,[2,5] although they were somewhat lower than those obtained for their own data. This attests to the value of the appropriate application of the NHRC equation in the evaluation of the status of groups of persons over a full range.

Correlation coefficients do not, however, directly address the problem of predicting %BF for an individual. An important point to consider is that one can have a correlation well above 0.90 and still have substantial uncertainty in the predictive value of an individual observation of the independent variable. Cohen and Cohen[16] emphasize "that it is a relatively rare circumstance in the social sciences that a data-based prediction for a given individual will be a substantial improvement over simply predicting that individual at the mean." Therefore, using regression techniques to predict actual %BF on an individual basis may not be providing the Navy with accurate estimates.

Medical Diagnosis Model

After careful evaluation of data collected here and at NHRC, and evaluation of regression statistics in general, it appears that defined regression procedures and equations probably result in estimates that are as accurate as can be expected. Although the NHRC equation or general regression equations may not be equally optimal for various subpopulations, it is unlikely that significant practical improvement is possible. It is also clear that there has not been sufficient emphasis on the utilization of these regression estimates in the context of diagnostic screening (screening individuals and testing for overfat or obese conditions). The second phase of this analysis therefore evaluates the sensitivity, specificity, and predictive values for the circumference measurement procedures (and focuses less on the estimation of prediction accuracy for an individual).

Detailed evaluation of regression equations with respect to r levels and confidence intervals does not necessarily address the implications of various decisions that may result when such criteria are imposed. For example, it is conceivable that improving the accuracy of a regression procedure so that r increases from say 0.80 to 0.90 may have little impact on the proportion of individuals who are incorrectly classified as over the OPNAVINST 6110.1D standards as determined by a medical diagnostic model.

A medical diagnostic model based on Bayes's theorem[3,4] can be used to screen for the "disease" or condition-positive state. In our context, "disease-positive state" is defined as those individuals who are over standard (OS+ > 21.99% men, > 29.99% women); "disease-negative state" is defined as those individuals who are not overstandard (OS− = < 22% men, < 30% women) for %BF as determined by HW. Similarly, regression equation-based estimates (NHRC equation and circumference measurements) of body fat will be defined either as test status positive (Test+) for %BF (>21.99% men, > 29.99% women) or test status negative (Test−) (< 22% men, < 30% women). The diagnosis of, or screening for, actual %BF (OS+, as determined by HW) is frequently accomplished by tests (NHRC equation and circumference measurements) which bear an imperfect relationship to the actual or true state of %BF, defined by a standard measurement, in this case HW.[8]

On the basis of this, the following medical diagnostic model is reviewed in the context of screening for the OS+ state. In addition to presenting an evaluation of data based on current criterion values of the NHRC+ (test-positive) state, the implications of criterion adjustments, particularly on false-positive rates, will be suggested and recommendations made.

As shown in Figure 1, individuals may exist in one of four cells where TP = true positive = the number of positives (Test+) among the diseased (OS+); FP = false positive = the number of positives (Test+) among the nondiseased (OS−); FN = false negative = the number of negatives (Test−) among the diseased (OS+); and, TN = true negative = the number of negatives (Test−) among the nondiseased (OS−). Sensitivity = TP/(TP + FN) = an estimate of the probability of a positive test result, given that the disease exists. Specificity = TN/(TN + FP) = an estimate of the probability of a negative test result, given the disease does not exist. Positive predictive value = TP/(TP + FP) = the probability that a person who has a positive test (Test+) result has the disease (OS+).

		Disease State HW OS +	Disease State HW OS -
Circumference Test Status	Equation Result (Test+)	TP	FP
	(Test-)	FN	TN

Fig. 1. Medical diagnostic model.

TABLE IV

COMPARISON OF HW AND CEQ RESULTS FOR NHRC AND NSMRL MEN AND WOMEN

	NHRC (*N* = 1,023) Men	NSMRL (*N* = 49) Men	NHRC (*N* = 334) Women	NSMRL (*N* = 50) Women
Sensitivity	86.5%	100.0%	70.2%	93.2%
Specificity	88.5%	0.0%	93.0%	50.0%
Positive Predictive Value	88.9%	83.7%	82.0%	93.2%
100− Positive Predictive Value	11.1%[a]	16.3%[a]	18.0%[a]	6.8%[a]

[a]Those individuals who are determined OS by the NHRC regression equation who are not OS by the HW methods.

A comparison of HW and CEQ results for NHRC and NSMRL men and women is shown in Table IV.

It is clearly a policy issue as to what are acceptable values for sensitivity, specificity, and diagnostic value. The medical diagnostic model indicates that, across all samples, 12.1% (84/695 of subjects) who were considered OS by the circumference measurement-regression methodology are actually false positives. Further problems are evident from the six people diagnosed as over body fat standards at their local command but not confirmed as such at this laboratory.

Since the prediction that an individual is over standard may result in significant sanctions against the individual, it may be appropriate to readjust the %BF criterion (OPNAVINST 6110.1D). Increasing the predicted %BF standards would result in a decrease in sensitivity, an increase in specificity, and a decrease in the false-positive rate relative to the true state. The opposite would occur if one decreased the predicted %BF standards. Adjusting the standards for %BF, though, does not solve the problem for those individuals who are incorrectly assessed as being OS when in fact they are not.

Summary

The correlation of HW and CEQ for the NSMRL male and female data sets was much lower than that reported by NHRC for its comparable data sets. The reduction in r values for NSMRL data set is an expected result and is discussed on the basis of the restricted range of the NSMRL data and greater error at extreme values.

The application of the medical diagnostic model as a tool for evaluating the sensitivity, specificity, and predictive value of a screening test was discussed. It showed that current procedures produce a 6.8% to 18% false-positive rate of people declared as having excess body fat when using the NHRC regression equation and circumference measurements.

The U.S. Department of Defense has instituted standards to control excess %BF among military personnel because increased %BF is believed to be associated with a variety of health problems.[18,19] The Department of Defense also believes that elevated %BF may be a limiting factor in physical work capacity,[19] even though some research indicates that physical fitness is not strongly related to %BF estimates.[19,20]

The U.S. Navy is also concerned that an overfat or obese service member presents a health risk.[21] However, this study indicates that an accurate means of measuring %BF on an individual basis is not feasible using the existing method of measurement. Therefore, caution should be utilized when making decisions, particularly if a career is at stake.

Any measurement of %BF should at least be accompanied by measurements of overall fitness[21] and assessment of job performance. More emphasis should be placed on early recognition of fitness/health problems and on preventive health measures.

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References

1. Wright HF, Dotson CO, Davis PO: A simple technique for measurement of percent body fat in man. US Navy Medicine 1981; 72: 23–27
2. Hodgdon JA, Beckett MB: Prediction of Percent Body Fat for U.S. Navy Men from Body Circumferences and Height. Report No. 84-11, 1984a
3. Galen RS, Gambino SR: Beyond Normality. The Predictive Value and Efficiency of Medical Diagnosis. New York, John Wiley and Sons, 1975
4. Woolson RS: Statistical Methods for the Analysis of Biomedical Data. Wiley Series in Probability and Mathematical Statistics. New York, John Wiley and Sons, 1987
5. Hodgdon JA, Beckett MB: Prediction of Percent Body Fat for U.S. Navy Women from Body Circumferences and Height. Report No. 84-29, 1984b
6. Siri WE: Body composition from fluid spaces and density: analysis of methods. In Techniques for Measuring Body Composition, edited by Brozek J, Henschel A, pp 223–244. Washington, National Academy of Sciences—National Research Council, 1961
7. Rupple G: Manual of Pulmonary Function Testing. St. Louis, CV Mosby, 1975
8. Everett WD: A Practical review of obesity in military medicine. Milit Med 1987; 152: 125
9. Goldman RF, Buskirk ER: Body volume measurement by underwater weighing: description of a method. In Techniques for Measuring Body Composition, edited by Brozek J, Henschel A, pp 78–89. Washington, National Academy of Sciences-National Research Council, 1969
10. Buskirk ER: Underwater weighing and body density: a review of procedures. In Techniques For Measuring Body Composition, edited by Brozek J, Henschel A, pp 90–106. Washington, National Academy of Sciences—National Research Council, 1961
11. Wright HF, Wilmore JH: Estimation of relative body fat and lean body weight in a United States Marine Corps population. Aerospace Medicine 1974; 45: 301–306
12. Wright HF, Dotson CO, Davis PO: An investigation of assessment techniques for body composition of women Marines. US Navy Medicine 1980; 71: 15–26
13. Goldman HI, Becklake MR: Respiratory function tests: normal values at median altitudes and the prediction of normal results. American Review of Tuberculosis 1959; 79: 457–467
14. Boren HG, Kory RC, Syner JC: The Veterans Administration-Army cooperative study of pulmonary function II. The lung volume and its subdivisions in normal men. Am J Med 1966; 41: 96–114
15. Ezekiel M, Fox KA: Methods of Correlation and Regression Analysis. New York, John Wiley and Sons, 1967
16. Cohen J, Cohen P: Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences. Hillsdale, NJ, Lawrence Erlbaum Association, 1975.
17. Wright HF, Dotson CO, Bachinski TL: An investigation of fitness and health parameters in a U.S. Navy population. Office of Naval Research, Contract #N0014-80-C-0558, Task #NR206-007, Final Report, November 30, 1980
18. National Institute of Health Consensus Development Panel on the Health Implications of Obesity: Health implications of obesity. Ann Intern Med 1985; 103: 1073–1077
19. Conway TL, Cronan TA, Peterson KA: Circumference-estimated percent body fat vs. height weight indices: relationships to physical fitness. Aviat Space Environ Med 1989; 60: 433–437
20. Slack MC, Ferguson EW, Banata G: Percent body fat alone is a poor predictor of physical fitness. Milit Med 1985; 150: 211–214
21. Marcinik EJ: Healthy Lifestyles (the Navy's health promotion memorandum). Washington, Health and Physical Readiness Branch, Naval Military Personal Command, January 1991