VALIDITY OF IMPEDANCE PREDICTIONS AT VARIOUS LEVELS OF FATNESS

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SUMMARY

Results of whole body electrical resistance (RES) measurements have been proposed as estimates of total body water and of fat-free mass. The validity of RES to predict percent body fat (%BF) was evaluated in a sample of 403 male (Mean values: age: 32.1 yr, stature: 178.6 cm, weight: 87.5 kg, %BF: 21.7%), and 135 female (Mean values: age: 27.1 yr, stature: 164.6 cm, weight: 62.6 kg, %BF: 26.2%) military personnel. There was general over-prediction of individuals having lower %BF values and under-prediction of individuals having higher %BF values using equations supplied by the manufacturer of the RES measurement device. This problem of non-generalizability was not alleviated by 1) re-determination of regression constants using the variables contained in the manufacturer's equations on this particular sample; 2) incorporation of anthropometric variables in models involving RES and stature (HT); and 3) weighting of the cases to provide equal power at all percent body fat values. Subcutaneous adipose tissue mass was estimated from skinfold thickness and body surface area. The difference between this subcutaneous adipose tissue mass and total fat mass predicted from hydrodensitometry (residual fat) was compared with accepted values for "essential" fat for men and women. In this sample, over-prediction of low %BF individuals occurred at approximately the %BF value at which predicted residual fat becomes less than accepted "essential" fat values. This finding suggests that problems of non-generalizability of equations containing RES values may be associated with violation of the assumptions of the fixed-density, two-compartment model used for conversion of body density values to percent body fat values, which are the criterion measure for most equation development, rather than with the use of RES as a predictor.

INTRODUCTION

Whole body electrical resistance (RES) measurement has been proposed as an estimate of total body water and fat-free mass. An instrument to measure RES has been developed and marketed as a rapid, non-invasive device for estimation of fat-free mass in humans (RJL Systems, Detroit, MI). This instrument operates on the principle that the electrical conductance of fat-free tissue is much greater than that of fat tissue, due to their differing electrolytic properties. Keller and Katch (1985) and Miles and Stevens (1985) have suggested that equations involving whole body electrical resistance did not generalize well across the full range of percent body fat values. Errors in prediction were greater at the extremes of the percent fat range than nearer the population mean values. These errors tended to be systematic, at least for low percent body fat values. Percent fat predicted by RES, stature and weight, using equations supplied by the equipment manufacturer (RJL Systems 1984), tended to be greater than the percent body fat determined from hydrodensitometry (%BF), the accepted criterion measure for such evaluations.

The purpose of this study was to determine if alternative equations could be developed that would decrease systematic errors in the prediction of body composition over a wide range of levels of body fat. Several strategies were utilized: a) new equations using variables contained in the manufacturer's equation were developed; b) anthropometric dimensions commonly used in the prediction of body composition were included as independent variables; and c) a weighting scheme to provide equal predictive power across the range of %BF values was tested.

MATERIALS AND METHODS

<u>Subjects</u>. Stature (HT), body weight (WT), RES, eight skinfold thicknesses (SF), and eleven body circumference (CIRC) measures were collected on a sample of 403 male and 135 female military personnel. Characteristics of this population sample are provided in Table 1.

<u>Anthropometric Assessment</u>. During anthropometric assessment, subjects were clad in swimsuits or shorts. Stature was measured to the nearest 0.635

Table 1. DESCRIPTIVE CHARACTERISTICS OF THE SUBJECTS.[1]

Variable	Male (N=403)	Female (N=135)
AGE (yrs)	32.1 ± 6.6 (19.0 - 51.0)	27.1 ± 5.7 (18.0 - 48.0)
STATURE (cm)	178.6 ± 6.8 (158.8 - 197.5)	164.6 ± 7.0 (148.0 - 186.7)
WEIGHT (kg)	87.5 ± 13.4 (55.9 - 125.8)	62.6 ± 9.4 (44.8 - 90.0)
%BF (%)	21.7 ± 7.9 (2.2 - 40.9)	26.2 ± 7.3 (10.3 - 46.1)
RESISTANCE (ohms)	432.1 ± 48.6 (322.0 - 608.0)	560.9 ± 62.7 (422.0 - 761.0)

[1] Values shown are mean ± std. dev. Range included in parentheses below.

cm (0.25 in) and weight recorded to the nearest 0.114 kg (0.25 lb), including swimsuit. Skinfold and circumference measurements were obtained by one of two trained investigators. A series of skinfold thickness and circumference measurements was made twice in sequence. If the difference exceeded 5% between successive skinfold thicknesses at a given site, or 1 cm between successive circumferences at a given site, a third measurement was taken. The mean of all measurements taken at each site was used in subsequent analysis.

Skinfold Measurement. During skinfold assessment, the subject stood relaxed. Measurements were taken on the right side of the body with a Harpenden skinfold caliper (British Indicators Ltd., St. Albans, Herts, UK) and recorded to the nearest 0.1 mm. Skinfold thicknesses were measured at the biceps, triceps, subscapular, and chest sites according to the method of Behnke and Wilmore (1974). Anterior suprailiac, abdominal and anterior thigh skinfolds were measured according to the method of Carter (1982). The midaxillary site was identified using the method of Yuhasz (1974).

Circumference Measurement. All circumference measurements were made with the subject standing relaxed. Each measurement was made in a plane orthogonal to the long axis of the body segment being measured. Measurements were made with a calibrated, fiberglass measuring tape (Scoville Dritz). The tape was applied so that it conformed to but did not depress the skin surface. Measurements were recorded to the nearest 1.0 mm. Chest and abdominal circumferences were measured at the end of a normal expiration. All limb circumferences were measured on the right side of the body.

Circumferences were measured at the neck, shoulders, hip, upper thigh, calf, extended arm, maximal forearm and wrist according to the method of Behnke and Wilmore (1974). The relaxed arm site was chosen according to Carter (1982). Chest measurements (I and II) were made just inferior to the axilla and at the nipple line as described by Beckett and Hodgdon (1985) and Behnke and Wilmore (1974), respectively. Abdominal measurements (I and II) were made at the level of the minimal abdominal width, approximately midway between the xiphoid process and the umbilicus, and at the level of the umbilicus, respectively, according to the method of Behnke and Wilmore (1974).

Residual Lung Volume Determination. Residual lung volume (RV) was measured by closed-circuit helium dilution (Ruppel 1975) prior to underwater weighing with the subject in a position similar to that assumed during the underwater weighing: seated and bent forward at the waist.

Underwater Weighing. Underwater weighing was performed using the method of Goldman and Buskirk (1961), with the two following modifications: 1) RV was determined outside the weighing tank prior to immersion; and 2) A load cell accurate to 10 g and desk-top calculator with supporting software were used to determine the stable weight values which occurred during each weighing. All subjects completed at least six underwater weighings. Final underwater weight was computed as an average of the two heaviest readings. Body density (BD) was calculated using the formula of Buskirk (1961) and converted to %BF using the formula of Siri (1961). The means, standard deviations and ranges of the subject %BF values are included in Table 1.

Measurement of Resistance. Whole-body electrical resistance was measured using a bioelectrical impedance analyzer (Model BIAC-103, RJL Systems, Inc., Detroit, MI). Electrodes for the RES measurement were placed according to the manufacturer's instruction. The arms were abducted slightly (approximately 30 degrees) to avoid contact between the medial surface of the arm and the lateral surface of the thorax. It was found that such contact affected the RES values.

Statistical Procedures. The equations supplied by RJL Systems in 1984 were as follows:

Males:

$$\text{Body Density (g/ml)} = 1.1411 - 0.0763 \times WT \times RES/HT^2 \qquad \text{(eq 1)}$$

and percent body fat was calculated using the formula of Siri (1961).

Females:

$$\text{Lean Mass (kg)} = 0.3981 \times HT^2/RES + 0.3066 \times WT + 0.0953 \times (HT - 100) + 0.7414 \qquad \text{(eq 2)}$$

and

$$\text{Body Fat (\%)} = 100 \times (WT - \text{Lean Mass})/WT$$

Equations published by the manufacturer of the RES measuring device were evaluated for strength of association with %BF values. Additional models were constructed to improve the relationship between RES and body composition. These models were developed 1) using RES/HT^2, and WT to determine the effect of differences between our sample and that of RJL Systems on prediction; 2) including skinfold thicknesses, and body circumferences to determine their impact on prediction; 3) incorporating a weighting scheme to allow equal power of prediction across the %BF range.

Models including skinfold thickness and circumference measurements were developed according to the following rationale: Body resistivity was assumed to be proportional to body fat content. The resistance measured along an electrical conductor is directly proportional to the resistivity and length of the conductor, and inversely proportional to the cross-sectional area of the conductor. Therefore, **body resistivity = RES x Area / Length.** For our modelling, the conductor length was proportional to stature. Average body cross-sectional area was proportional to the mean body circumference squared, since circumferences and radii of circles are linearly related. If the subcutaneous adipose tissue is treated as an insulating covering to the body conductor, then resistivity, and %BF would be related to the square of the difference between the mean circumference value (MEANCR) and the mean skinfold thickness (MEANSF), since the radius of the major conducting volume is the total body radius minus the thickness of the adipose layer. Thus, relative fat content should be proportional to RES/HT x $(\text{MEANCR} - \text{MEANSF})^2$ or, by expansion, RES/HT x $(\text{MEANCR}^2 - 2 \times \text{MEANCR} \times \text{MEANSF} + \text{MEANSF}^2)$.

The following summary anthropometric variables were then constructed for use in the predictive model. The mean value of all the circumferences (MEANCR) which lay on the assumed current path from the ankle to the wrist (i.e. all but neck) was calculated. The square of this mean (MEANCRSQ) was also calculated. In a parallel fashion, the mean of all the skinfold thickness values (MEANSF) was calculated. In this instance, all the skinfold thicknesses measured lay along the assumed current path. The square of the mean skinfold thickness (MEANSFSQ) was also calculated, as was the cross-product of MEANCR and MEANSF.

The summary anthropometric variables were then each multiplied by RES/HT in accordance with the resistivity model described above. The products of RES/HT with MEANCR and MEANSF, while not a part of the model suggested above, were included in the analysis to account for variation from the cylindrical model upon which the analysis was based.

The new equations were developed using stepwise, multiple regression with %BF determined from hydrodensitometry using the equation of Siri (1961) as the criterion variable. The addition of terms to an equation was stopped when the addition of a new variable did not increase the variance accounted for by at least one percent. Multiple regressions were performed using the REGRESSION procedure in SPSSX (SPSS, Inc.), implemented on a VAX/780 computer (Digital Electronics Corporation).

To improve the fit of equations to the extremes of the distribution, a weighting scheme was tried on the male sample. The variables that contributed to the "best" male equation, determined from the procedures described above, were used again for the construction of the equation utilizing weighted cases. Percent fat categories (N=42) were developed based on the rounded integer value of %BF. The cases were weighted according to their percent fat category. The number of cases in each integer percent fat category was determined, and a weight equal to the total sample size (403) divided by the number of cases in the integer category was applied.

Generalizability of the predictive equations was determined by developing contingency tables indicating the accuracy of prediction as a function of %BF. %BF categories were determined based on thirds of the %BF range. Error magnitude categories were constructed as follows. Differences between %BF and the predicted fat values were calculated; and the differences between %BF and percent fat predicted from each of the equations were classified as falling into one of the following groups: 1) differences less than -8%; 2) differences greater than or equal to -8% but less than -4%; 3) differences greater than or equal to -4% and less than or equal to +4%; 4) differences greater than +4% but less than or equal to +8%; and 5) differences greater than +8%. Contingency tables were then constructed using the CROSSTABS procedure of SPSSX, comparing %BF categories with error categories. Associations between %BF range and magnitude of error categories were assessed using the chi-squared statistic. Relative comparisons between equations were based on comparisons contingency coefficients (Nie et al, 1975).

Equations developed on this sample were cross-validated on a second sample of 61 male (Mean values: age: 27.9 yr, stature: 177.4 cm, weight: 81.4 kg, %BF: 17.3%, RES: 408.9 ohm), and 26 female (Mean values: age: 27.8 yr, stature: 165.7 cm, weight: 61.7 kg, %BF: 24.3%, RES: 533.4 ohm) military personnel participating in another study. Cross-validation statistics (correlation and standard error of measurement with %BF) are reported with the equations.

RESULTS

In our sample, the correlation between %BF and that predicted from the RJL equation was 0.79 for males with a standard error of measurement (sem) of 5.01 %BF. For females, the correlation was 0.82 with a sem of 4.25 %BF.

Table 2. CONTINGENCY TABLE FOR EQUATION 1. (MALES)
DISTRIBUTION OF PREDICTION ERRORS BY FRACTION OF THE % FAT RANGE

Count (Row %)	Error Distribution: error < -8%	-8% < error < -4%	-4% < error < +4%	+4% < error < +8%	+8% < error	Row Total (SAMP %)	R	Std. Error Meas.
1st 1/3rd Range			38 (43.2%)	35 (39.8%)	15 (17.0%)	88 (21.8%)	0.34	3.45
2nd 1/3rd Range		40 (19.3%)	146 (70.5%)	21 (10.1%)		207 (51.4%)	0.57	3.46
3rd 1/3rd Range	19 (17.6%)	54 (50.0%)	33 (30.6%)	2 (1.9%)		108 (26.8%)	0.39	3.73
Total: (SAMP %)	19 (4.7%)	94 (23.3%)	217 (53.8%)	58 (14.4%)	15 (3.7%)	403 (100%)		

Inspection of the scatterplots of predicted fat with %BF (Figure 1, for males , Figure 2, for females), indicates general over-estimation of percent body fat for %BF values in the lower one third of the range and general under-estimation for %BF values in the upper one third of the range.

A contingency table showing the distribution of prediction errors relative to %BF range category for equation 1 (RJL Systems equation for males) is provided as Table 2. Values within the table are reported as cell counts with row (range category) percentages below in parentheses. A preponderance of counts in the positive error categories indicates general over-estimation of %BF. A preponderance of counts in the negative categories indicates

FIGURE 1. % Fat from Manufacturer's Equation and Hydrodensitometry (males)

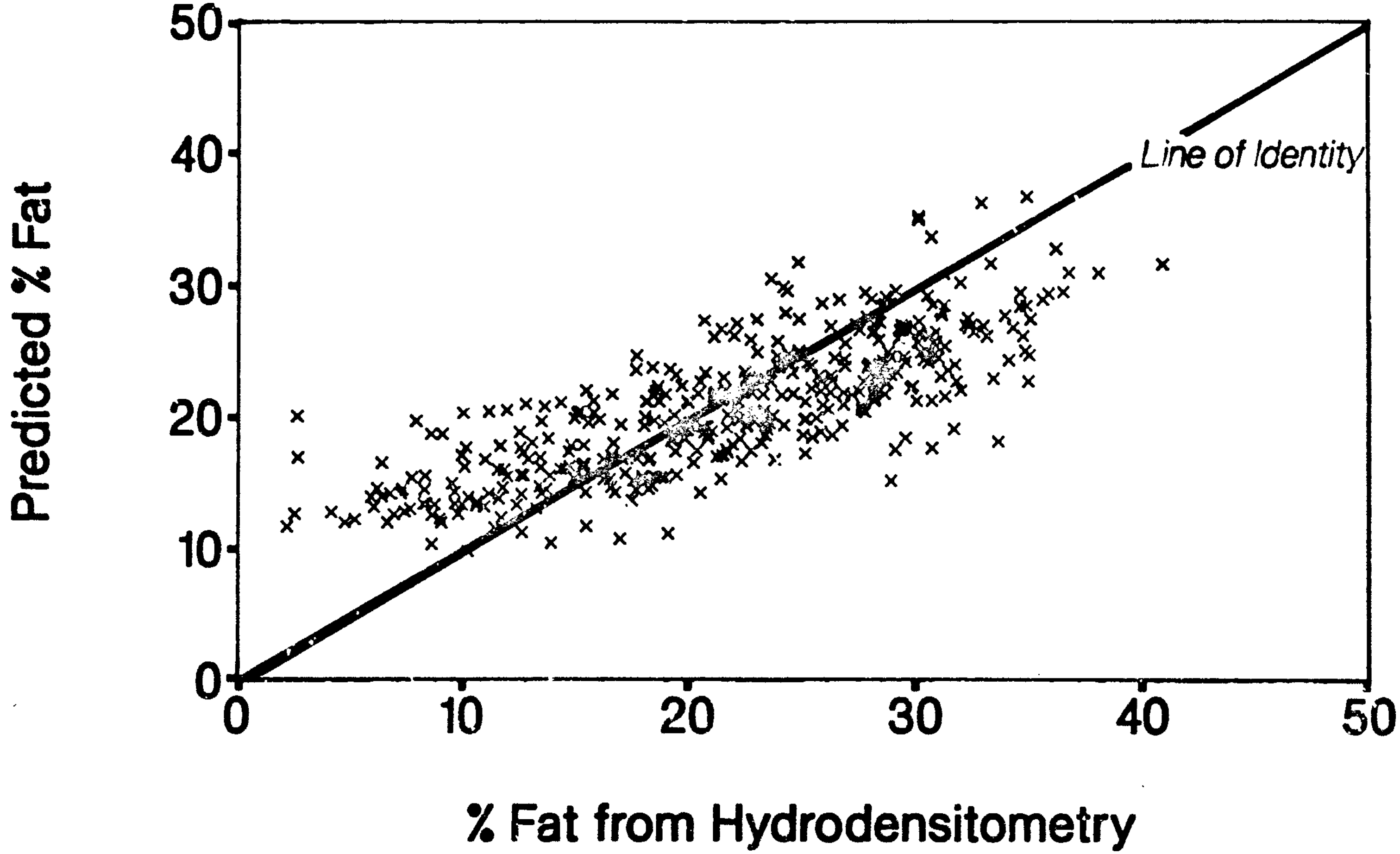
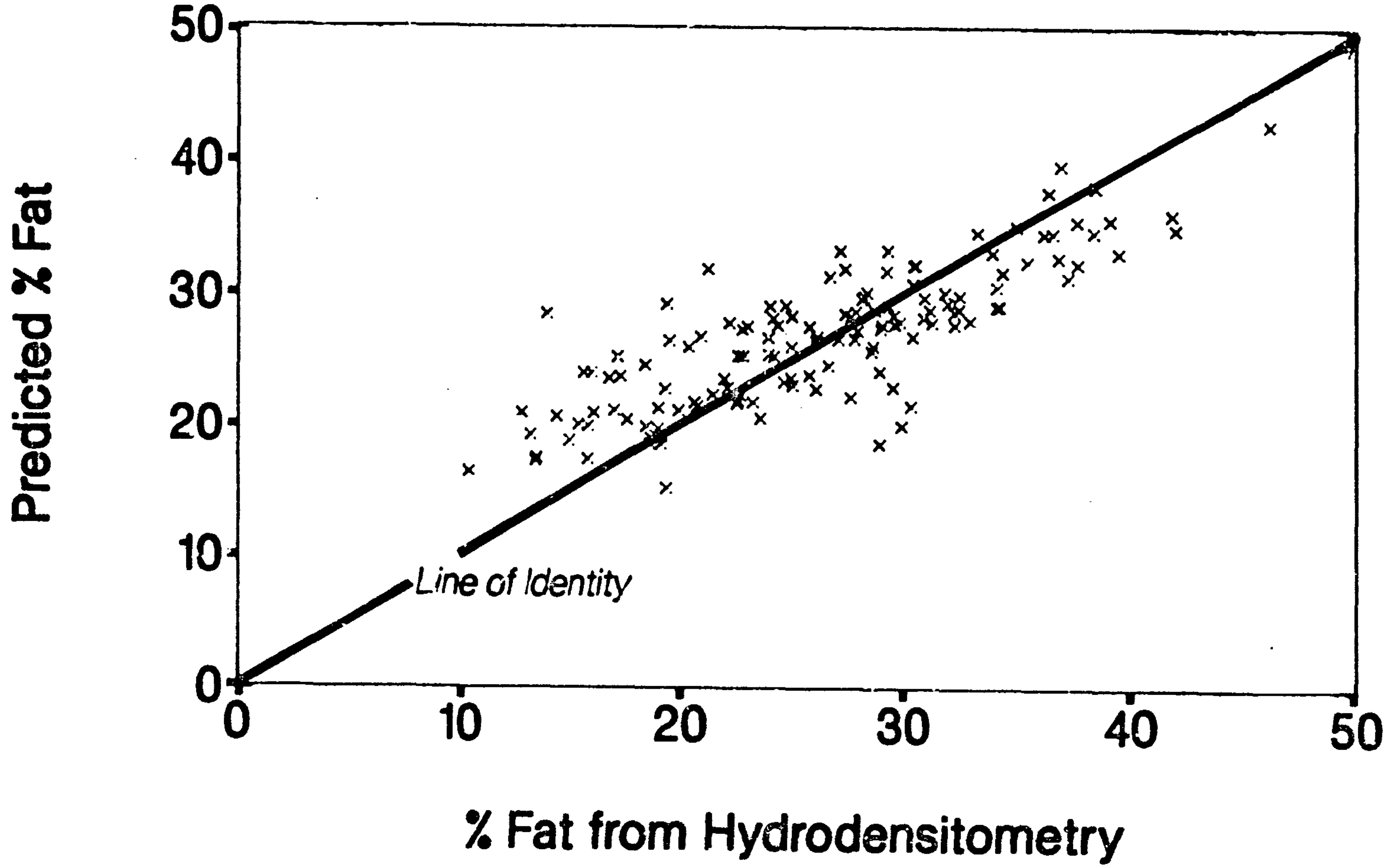


FIGURE 2. % Fat from Manufacturer's Equation and Hydrodensitometry (females)



under-estimation. Range and error category totals are provided along the right side and bottom of the table respectively with the percentages of the total sample they represent reported below in parentheses. In addition, the value of the correlation coefficient between predicted %BF and %BF from hydrodensitometry and the standard error of measurement for that prediction are provided for each range category. The value of chi-squared for this joint distribution is 237.71 with 8 degrees of freedom and is highly significant ($p<0.00001$). The contingency coefficient was 0.609.

Table 3 shows the joint frequency distribution for the prediction errors and %BF categories using the RJL Systems equation for females (equation 2). For this distribution, chi-squared is equal to 55.33 (degrees of freedom = 8), again highly significant ($p<0.00001$) and the contingency coefficient was 0.539.

Table 3. CONTINGENCY TABLE FOR EQUATION 2. (FEMALES)
DISTRIBUTION OF PREDICTION ERRORS BY FRACTION OF THE % FAT RANGE

Count (Row %)	Error Distribution: error < -8%	-8% < error < -4%	-4% < error < +4%	+4% < error < +8%	+8% < error	Row Total (SAMP %)	R	Std. Error Meas.
1st 1/3rd Range		1 (2.4%)	18 (43.9%)	15 (36.6%)	7 (17.1%)	41 (30.4%)	0.42	3.60
2nd 1/3rd Range	3 (4.4%)	4 (5.9%)	52 (76.5%)	9 (13.2%)		68 (50.4)	0.39	3.44
3rd 1/3rd Range		9 (34.6%)	17 (65.4%)			26 (19.3%)	0.72	3.53
Total: (SAMP %)	3 (2.2%)	14 (10.4%)	87 (64.4%)	24 (17.8%)	7 (5.2%)	135 (100.0%)		

Equations involving RES/HT^2, and WT. To determine whether the lack of fit for the manufacturer's equations was due to differences between our population samples, the best model to predict %BF in our sample from RES/HT^2, and WT was determined. Age in years (AGE) was added to the list of predictors because previous experience had shown it to contribute significantly to the prediction of %BF. We found that RES/HT^2 and WT produced a better prediction when entered separately, rather than as the product found in the RJL prediction for males. Additionally, AGE entered the regression as a significant predictor for males, but not for females. The resultant equations and their associated correlation coefficients and sem values for both development and cross-validation samples are:

Males:

$$\text{Body Fat (\%)} = 0.5724 \times WT + 2598.3149 \times RES/HT^2 + 0.2235 \times AGE - 70.6476 \qquad \text{(eq 3)}$$

(Develop: R = 0.82, sem = 4.47 %BF)

(Cross-val: R = 0.79, sem = 4.82 %BF)

Females:

$$\text{Body Fat (\%)} = 0.7244 \times WT + 1321.2384 \times RES/HT^2 - 46.6149 \qquad \text{(eq 4)}$$

(Develop: R = 0.79, sem = 4.31 %BF)

(Cross-val: R = 0.81, sem = 4.27 %BF)

Table 4 shows the joint frequency distribution for the male equation (equation 3). The chi-squared for this distribution is 103.86, the contingency coefficient, 0.453. Compared to equation 1, equation 3 offers improved prediction of %BF. The contingency coefficent is less, the correlation coefficient higher, and the sem less. Comparison of Tables 2 and 4 shows the percentage of the predictions falling into the $\pm 4\%$ "window" to be increased (61.3% of the predictions with equation 3, 53.8% with equation 1). Table 5 shows the joint frequency distribution for the female equation (equation 4). Chi-squared equals 38.56 ($p<0.00001$) and the contingency

Table 4. CONTINGENCY TABLE FOR EQUATION 3. (MALES)
DISTRIBUTION OF PREDICTION ERRORS BY FRACTION OF THE % FAT RANGE

Count (Row %)	Error Distribution: error < -8%	-8% < error < -4%	-4% < error < +4%	+4% < error < +8%	+8% < error	Row Total (SAMP %)	R	Std. Error Meas.
1ST 1/3rd Range			53 (60.2%)	25 (28.4%)	10 (11.4%)	88 (21.8%)	0.35	3.75
2nd 1/3rd Range	1 (0.5%)	33 (15.9%)	141 (68.1%)	25 (12.1%)	7 (3.4%)	207 (51.4%)	0.62	3.82
3rd 1/3rd Range	12 (11.1%)	38 (35.2%)	53 (49.1%)	5 (4.6%)		108 (26.8%)	0.43	4.02
Total: (SAMP %)	13 (3.2%)	71 (17.6%)	247 (61.3%)	55 (13.6%)	17 (4.2%)	403 (100.0%)		

Table 5. CONTINGENCY TABLE FOR EQUATION 4. (FEMALES)
DISTRIBUTION OF PREDICTION ERRORS BY FRACTION OF THE % FAT RANGE

Count (Row %)	Error Distribution: error < -8%	-8% < error < -4%	-4% < error < +4%	+4% < error < +8%	+8% < error	Row Total (SAMP %)	R	Std. Error Meas.
1st 1/3rd Range			23 (56.1%)	15 (36.6%)	3 (7.3%)	41 (30.4%)	0.50	3.03
2nd 1/3rd Range	3 (4.4%)	10 (14.7%)	52 (76.5%)	2 (2.9%)	1 (1.5%)	68 (50.4%)	0.39	3.70
3rd 1/3rd Range	1 (3.8%)	7 (26.9%)	16 (61.5%)	2 (7.7%)		26 (19.3%)	0.76	3.74
Total: (SAMP %)	4 (3.0%)	17 (12.6%)	91 (67.4%)	19 (14.1%)	4 (3.0%)	135 (100.0%)		

coefficient equals 0.471. As was the case with the male equation, there is an improved fit when compared to the RJL Systems equation (equation 2). Although the prediction is improved in these samples by developing curves based on them, it is evident that the problem of under-estimation of individuals with high relative body fat levels and over-estimation of individuals with low relative body fat levels is still present.

<u>Equations involving circumferences and skinfolds</u>. For males, the resultant equation involving circumferences and skinfolds was:

Body Fat (%) = 0.0115 x RES/HT x MEANCR x MEANSF
- 0.0129 x RES/HT x MEANSFSQ
- 0.0556 x RES/HT x MEANCR
+ 7.1359 (eq 5)

(Develop: R = 0.90, sem = 3.51 %BF)
(Cross-val: R = 0.87, sem = 3.90 %BF)

The MEANCRSQ term, predicted to be part of the model, failed to enter, while the linear MEANCR term, which was not a part of the model, did enter.

For females, the best equation involving RES/HT and anthropometric variables was:

Body Fat (%) = 0.0120 x RES/HT x MEANCR x MEANSF
- 0.0131 x RES/HT x MEANSFSQ
- 0.1098 x RES/HT x MEANCR
+ 20.3129 (eq 6)

(Develop: R = 0.87, sem = 3.56 %BF)
(Cross-val: R = 0.87, sem = 3.61 %BF)

This equation is identical in form to the male predictive equation (equation 5). Tables 6 and 7 show the distribution of errors across %BF range categories for equations 5 and 6, respectively. The chi-squared associated with Table 6 is 50.84 and the contingency coefficient, 0.335, still highly significant ($p<0.00001$). For Table 7, chi-squared equals 25.73 ($p<0.0012$) and the contingency coefficient, 0.400. Comparisons with the preceding error

Table 6. CONTINGENCY TABLE FOR EQUATION 5. (MALES)
DISTRIBUTION OF PREDICTION ERRORS BY FRACTION OF THE % FAT RANGE

Count (Row %)	Error Distribution: error < -8%	-8% < error < -4%	-4% < error < +4%	+4% < error < +8%	+8% < error	Row Total (SAMP %)	R	Std. Error Meas.
1st 1/3rd Range			74 (84.1%)	12 (13.6%)	2 (2.3%)	88 (21.9%)	0.69	2.50
2nd 1/3rd Range	1 (0.5%)	25 (12.1%)	146 (70.9%)	31 (15.0%)	3 (1.5%)	206 (51.2%)	0.66	3.48
3rd 1/3rd Range	6 (5.6%)	25 (23.1%)	76 (70.4%)	1 (0.9%)		108 (26.9%)	0.40	3.28
TOTAL: (SAMP %)	7 (1.7%)	50 (12.4%)	296 (73.6%)	44 (10.9%)	5 (1.2%)	402 (100.0%)		

TABLE 7. CONTINGENCY TABLE FOR EQUATION 6. (FEMALES)
DISTRIBUTION OF PREDICTION ERRORS BY FRACTION OF THE % FAT RANGE

Count (Row %)	Error Distribution: error < -8%	-8% < error < -4%	-4% < error < +4%	+4% < error < +8%	+8% < error	Row Total (SAMP %)	R	Std. Error Meas.
1st 1/3rd Range			30 (73.2%)	10 (24.4%)	1 (2.4%)	41 (30.4%)	0.59	3.09
2nd 1/3rd Range		11 (16.2%)	53 (77.9%)	3 (4.4%)	1 (1.5%)	68 (50.4%)	0.55	3.17
3rd 1/3rd Range	1 (3.8%)	5 (19.2%)	20 (76.9%)			26 (19.3%)	0.71	3.27
Total: (SAMP %)	1 (0.7%)	16 (11.9%)	103 (76.3%)	13 (9.6%)	2 (1.5%)	135 (100.0%)		

distribution tables, show improved fit over the previously presented models. Overall for males, 73.5% of the values lay within 4% of the corresponding %BF value. The figure for females was 76.3%. In addition to improved fit for the whole sample, there were decreases in the degree of over-prediction of individuals with low %BF, and under-prediction of individuals with high %BF for both men and women. However, there remains a strong association between error category and %BF range category.

<u>Weighting of the cases</u>. Differential weights were applied to the variables for each case in the male sample as described above. The resultant equation was:

$$\begin{aligned}\text{Body Fat (\%)} = {} & 0.0134 \times \text{RES/HT} \times \text{MEANCR} \times \text{MEANSF} \\ & - 0.0147 \times \text{RES/HT} \times \text{MEANSFSQ} \\ & - 0.0755 \times \text{RES/HT} \times \text{MEANCR} \\ & + 6.5943 \qquad \text{(eq 7)}\end{aligned}$$

(Develop: R = 0.90, sem = 3.73 %BF)

(Cross-val: R = 0.87, sem = 3.93 %BF)

Table 8. CONTINGENCY TABLE FOR EQUATION 7. (MALES)
DISTRIBUTION OF PREDICTION ERRORS BY FRACTION OF THE % FAT RANGE

Count (Row %)	Error Distribution: error < -8%	-8% < error < -4%	-4% < error < +4%	+4% < error < +8%	+8% < error	Row Total (SAMP %)	R	Std. Error Meas.
1st 1/3rd Range		4 (4.5%)	78 (88.6%)	5 (5.7%)	1 (1.1%)	88 (21.[illegible]%)	0.70	2.72
2nd 1/3rd Range	3 (1.5%)	26 (12.6%)	133 (64.6%)	39 (18.9%)	5 (2.4%)	206 (51.2%)	0.66	4.06
3rd 1/3rd Range	6 (5.6%)	11 (10.2%)	81 (75.0%)	10 (9.3%)		108 (26.9%)	0.40	3.72
Total: (SAMP %)	9 (2.2%)	41 (10.2%)	292 (72.6%)	54 (13.4%)	6 (1.5%)	402 (100.0%)		

The contingency data for this equation are provided as Table 8. Chi-squared for this distribution is 29.683 ($p<0.0002$). The contingency coefficient is 0.262. It appears that weighting the male cases had little effect on the overall prediction. The relationship between error category and %BF range was decreased, as indicated by a decreased contingency coefficient. This decreased relationship was achieved at a cost (although modest) in overall prediction accuracy, as indicated by an increased standard error of measurement and decreased percentage of cases in the $\pm$ 4 %BF error category.

DISCUSSION

All of the equations developed on this sample cross-validated well on the second, similar sample. The equations appear to be stable for use in military populations such as this one. Their applicability to other populations remains to be assessed.

Percent body fat from the Siri equation was used as the criterion measure for equation development because, in the authors' experience, it is the most commonly used density to %BF transformation, and forms the basis for most of the published generalized %BF equations. Use of the other common transformation equation (Brozek et al, 1963) would decrease the %BF range somewhat, but the equations do not differ enough to markedly effect the systematic over-prediction of low, and under-prediction of high %BF individuals.

One of the major findings of this study is that inclusion of anthropometric variables in equations involving RES can improve the prediction of %BF over that offered by RES, HT, and WT alone. It is difficult to assess the contribution of the RES measurement in the prediction with skinfold thicknesses and circumferences since the standard errors of measurement associated with equations 5, 6 and 7 are not markedly different from those seen on cross-validation of generalized equations relying on anthropometry alone in similar military samples (see Hodgdon and Beckett, 1984a; 1984b).

The proposed resistance anthropometric model was not completely supported.

The MEANCRSQ term did not account for significant variance to enter the model, and was replaced by the linear MEANCR term. Furthermore the signs of the terms were opposite our expectations. Deviation from the form of the model is not suprising because the body is not a linear, cylindrical conductor. Reversal of the signs implies a negative relationship between resistivity and %BF, which does not make intuitive sense. Again, it may be that the RES term contributes little to the prediction and the signs of the terms of the equation represent a predominantly anthropometric model.

Equations presented by the manufacturer of the resistance measuring device, and those of others (Lukaski et al. 1985) using this device, utilize RES/HT^2 and WT as predictors of body composition. Such models when applied to a general population sample, yield systematic errors in prediction at the extremes of the population. From the results presented here, it appears that 1) redetermination of an equation in these variables for the specific sample under consideration; 2) inclusion of body circumferences and skinfold thicknesses; and 3) the weighting of cases in a fashion to increase the relative importance of extreme %BF values, do not eradicate this trend.

One approach to solving this problem is to fit separate equations to the different portions of the percent fat range. One is then faced with the need to determine the part of the range to which an individual belongs before applying an equation. We have been unable to determine such a selection procedure. We have found no anthropometric variable which allows classification into percent fat groups in a fashion which improves the overall accuracy of the prediction. This is not surprising since such a variable would already have entered into the prediction during model development. Variables which did not enter during the regression analysis are unlikely to provide additional power in selection to percent fat groups.

The recent work of Martin (1984) suggested that the problem with prediction of body composition at the extremes may be a problem with the criterion measure (%BF). In his doctoral dissertation, Martin shows that for some muscular, lean individuals, the assumptions of the Siri transformation from body density to percent must be violated. The Siri model assumes that lean mass has a density of 1.1 gm/ml. Martin was able to show for a set of

Canadian football players, if one estimated the mass of subcutaneous adipose tissue from the skinfold thickness measures, and compares that value with the body density determined from underwater weighing, that the density of the remaining mass must be greater than 1.1 gm/ml. Martin also cited the phenomenon, well-known to any who do underwater weighing, of finding individuals whose computed body fat percentage is close to zero. Possible sources of variation in the density of lean mass include: varying levels of hydration among individuals; and varying bone density with race and level of physical activity (Behnke and Wilmore, 1974).

Behnke (1961), and others (Behnke and Wilmore, 1974; Carter, 1983), have stated that there appears to be some essential fat in all individuals. This fat is found in the nervous tissue, and surrounding the internal organs. The amount of this "essential" fat has been estimated to be 3% of body weight in males, and 7% in females (Carter 1983).

To determine the approximate percent body fat value where deviations from the Siri relationship might have an effect on the validity of the %BF values determined from hydrodensitometry, the mass of the subcutaneous adipose tissue in our subjects was estimated using the method outlined by Martin (1984). The average skinfold thickness was determined from the eight skinfold thicknesses measured. Body surface area was estimated from WT and HT using the equation of Dubois and Dubois (1916). Martin and his colleagues (1984) have shown this formula to be a rather valid predictor of body surface area measured on 25 cadavers. Using the density value of 0.94 gm/ml for adipose tissue and estimating that 0.6 of the fold thickness represented adipose tissue, a subcutaneous adipose tissue mass was determined. This estimated adipose tissue mass is not strictly analogous to the fat mass which would be calculated under Siri's model. However, as an approximation of the subcutaneous fat, it was deemed suitable for the demonstration provided here.

Using the fat mass calculated from %BF, we estimated the "internal" fat mass as the difference between "Siri" fat mass and subcutaneous adipose tissue mass. If a calculated internal fat mass represented less than 3% of body weight for men or 7% of body weight for women, one would suspect that the Siri relationship was breaking down, since the values of 3% and 7% represent the minimum expected fat if there was no subcutaneous fat.

Figures 3 and 4 show scatterplots of estimated internal fat for men and women, respectively. Internal fat is expressed as a percentage of body weight, versus percent body fat from hydrodensitometry using the Siri transformation. The value of 3% is indicated on Figure 3 by a horizontal line. In a similar fashion, the value of 7% is indicated on Figure 4. On Figure 3, one can note for males that below %BF values of 18%, internal fat values of less the 3% begin to appear. Below %BF values of 6%, all the estimated fat values are less than 3%. In fact, below %BF values of 4%, the estimated internal fat values were less than zero, a finding of dubious physiologic validity.

In a similar fashion, from Figure 4, one should note that internal fat values less than 7% begin to occur below %BF values of 20. Below %BF values of 14, all the internal fat values were estimated to be less than 7%. Returning to Figure 1, the scattergram of percent body fat predicted from the RJL equation, one notes that, for men, the deviation of the scatter of the predicted fat values from the line of identity begins at an approximate %BF value of 18%, the value suggested above as the point at which there begins to be meaningful deviations from the Siri formula. Similarly, looking at Figure 2, one can see the deviation of fat predicted using the RJL equations for women from the line of identity appears to begin at %BF values of about 20%.

At this point we are left with the suggestion that part of the reason these predictive equations cannot be made to match the Siri model, is that the assumptions of the Siri model may be violated, at least at the low %BF extreme. It is difficult to judge, then, which are the more valid indicators of body composition: variables such as the ones included in predictive equations here, or the estimations from whole-body density which have served so long as the criterion measures. This problem can only be resolved by improvements in the methods of direct measurement of fat mass in the body.

FIGURE 3. Estimated Internal % Fat with Total % Fat (males)

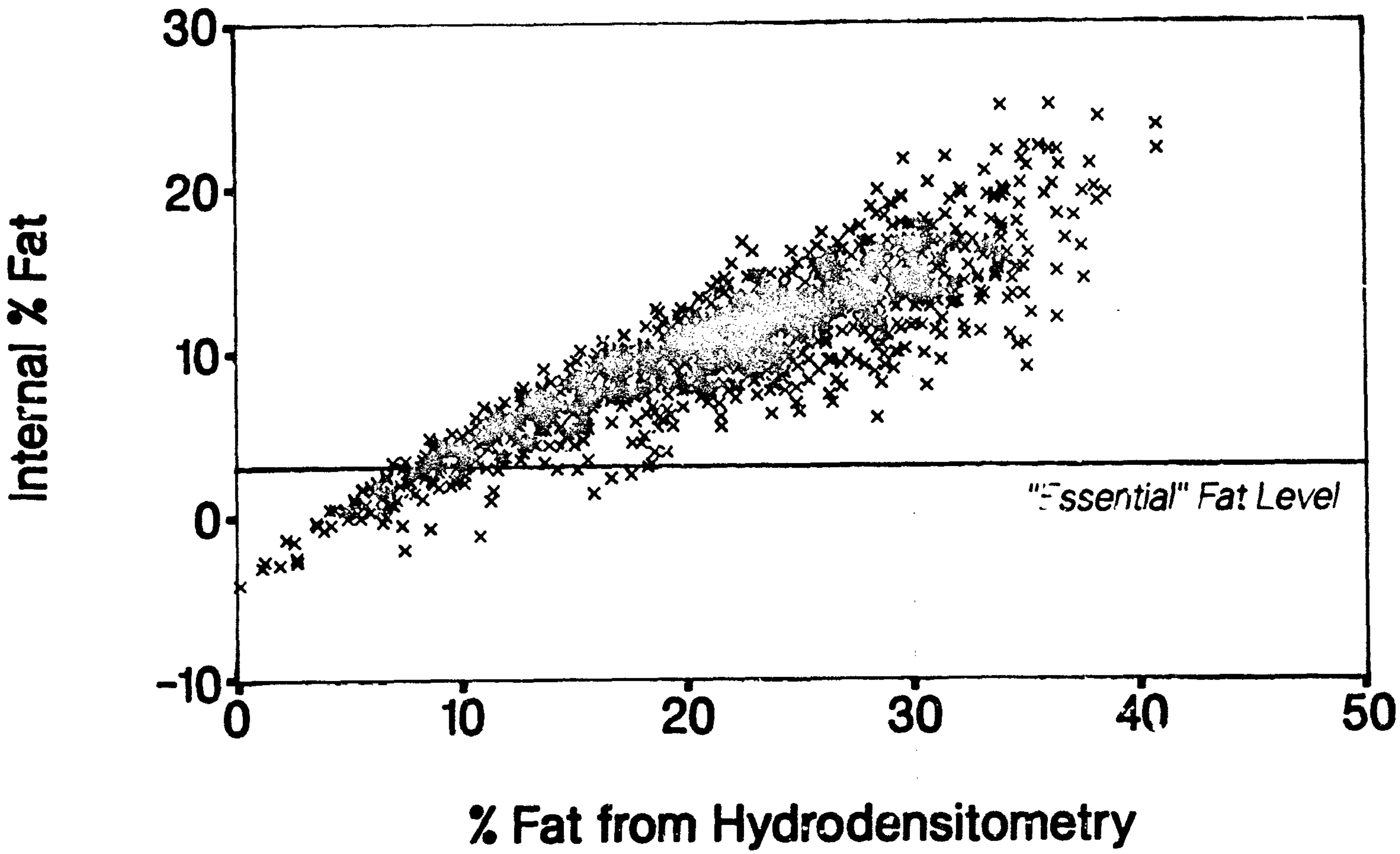
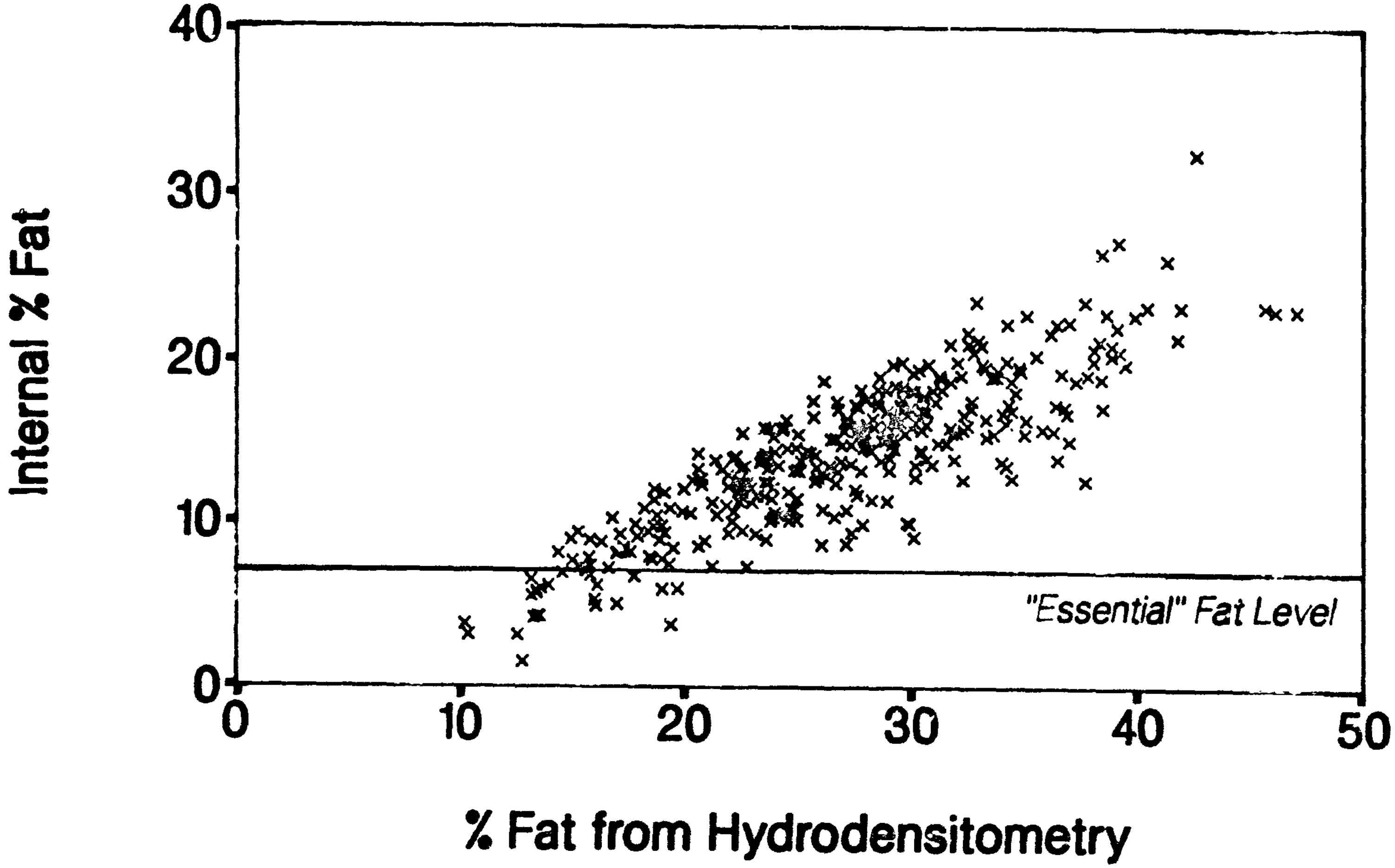


FIGURE 4. Estimated Internal % Fat with Total % Fat (females)



REFERENCES

Beckett, M.B. and J.A. Hodgdon 1984 Technique for measuring body circumferences and skinfold thicknesses. Report No. 84-39. Naval Health Research Center, San Diego, CA.

Behnke, A.R. 1961 Comment on the determination of whole body density and a resume of body composition data. In: J. Brozek and A. Henschel (eds.), Techniques for Measuring Body Composition. National Academy of Sciences National Research Council, Washington, D.C.

Behnke, A.R. and J.H. Wilmore 1974 Evaluation and Regulation of Body Build and Composition. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Brozek, J., F. Grande, J.T. Anderson, and A. Keys 1963 Densitometric analysis of body composition: revision of some quantitative assumptions. Annals N.Y. Acad. Sci. 110: 113-140.

Buskirk, E.R. 1961 Underwater weighing and body density: A review of procedures. In: J. Brozek and A. Henschel (eds.), Techniques for Measuring Body Composition. National Academy of Sciences National Research Council, Washington, D.C.

Carter, J.E.L. (ed) 1982 Physical Structure of Olympic Athletes, Part I: Montreal Olympic Games Anthropological Project. S. Karger, Basel, Switzerland.

Carter, J.E.L. 1983 Kinanthropometry Notes. San Diego State University, San Diego, CA.

DuBois, D. and E.F. DuBois 1916 A formula to estimate the approximate surface area of the body if height and weight be known. Arch. Int. Med., 17: 863-71.

Goldman, R.F. and E.R. Buskirk 1961 Body volume measurement by underwater weighing: Description of method. In: J. Brozek and A. Henschel (eds.), Techniques for Measuring Body Composition. National Academy of Sciences National Research Council, Washington, D.C.

Hodgdon, J.A. and M.B. Beckett 1984a Prediction of percent body fat for U.S. Navy men from body circumferences and height. Report No. 84-11. Naval Health Research Center, San Diego, CA.

Hodgdon, J.A. and M.B. Beckett 1984b Prediction of percent body fat for U.S. Navy women from body circumferences and height. Report No. 84-29. Naval Health Research Center, San Diego, CA.

Keller, B. and F.I. Katch 1985 Validity of bioelectrical resistive impedance for estimation of body fat in lean males. Med. sci. Sports. Exerc. 17: 272.

Lukaski, H.C., P.E. Johnson, W.W. Bolonchuk and G.I. Lykken 1985 Assessment of fat free mass using bioelectrical impedance measurements of the human body. Am. J. Clin. Nutr. 41: 810-817.

Martin, A.D. 1984 An anatomical basis for assessing human body composition: Evidence from 25 dissections. Doctoral Dissertation, Simon Fraser University, Burnaby, British Columbia, Canada.

Miles, D.S. and A.G. Stevens 1985 Body composition measured by bioelectrical impedance and hydrostatic weighing. Med. Sci. Sports. Exerc., 17: 272-273.

Nie, N.H., C.H. HUll, J.G. Jenkins, K. Steinbrenner, and D.H. Bent 1975 SPSS, Statistical Package for the Social Sciences. McGraw-Hill Book Co., New York, NY.

RJL Systems 1984 BIAC-103B USER Reference Manual. RJL Systems. 9930 Whittier Blvd., Detroit, Michigan 48224.

Ruppel, G. 1975 Manual of Pulmonary Function Testing. C.V. Mosby Company, St. Louis, Missouri.

Siri, W.E. 1961 Body composition from fluid spaces and density: Analysis of methods. In: J. Brozek and A. Henschel (eds.), Techniques for Measuring Body Composition. National Academy of Sciences National Research Council, Washington, D.C.

Yuhasz, M.S. 1974 Physical Fitness Manual. University of Western Ontario, London, Canada.

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Results of whole body electrical resistance (RES) measurements have been proposed as estimates of total body water and of fat-free mass. The validity of RES to predict percent body fat (%BF) was evaluated in a sample of 403 male (Mean values: age: 32.1 yr, stature: 178.6 cm, weight: 87.5 kg, %BF: 21.7%), and 135 female (Mean values: age: 27.1 yr, stature: 164.6 cm, weight: 62.6 kg, %BF: 26.2%) military personnel. There was general over-prediction of individuals having lower %BF values and under-prediction of individuals having higher %BF values using equations supplied by the manufacturer of the RES measurement device. This problem of non-generalizability was not alleviated by 1) redetermination of regression constants using the variables contained in the manufacturer's equations on this particular sample; 2) incorporation of anthropometric variables in models involving RES and stature; and 3) weighing of the cases to provide equal power at all percent body fat values. Subcutaneous adipose tissue mass was estimated from skinfold thickness and body surface area. The difference between this subcutaneous adipose tissue mass and total fat mass predicted from hydrodensitometry

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(residual fat) was compared with accepted values for "essential" fat for men and women. In this sample, over-prediction of low %BF individuals occurred at approximately the %BF value at which predicted residual fat becomes less than accepted "essential" fat values. This finding suggests that problems of non-generalizability of equations containing RES values may be associated with violation of the assumptions of the fixed-density, two-compartment model used for conversion of body density values to percent body fat values, which is the criterion measure for most equation development, rather than with the use of RES as a predictor.