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**13. ABSTRACT *(Maximum 200 Words)***

This project examined the relationship between a 4-C multi-compartment model for the estimation of percent body fat (%BF) and the estimation of %BF from Army and Navy anthropometric prediction equations and the Lohman and Segal bioelectrical impedance (BIA) prediction equations in a group of 377 individuals including Caucasians, African-American, Asian, Hispanic, Pacific Islands and Filipina women. Results demonstrated that use of a multi-compartment model did not increase the error associated with the estimation of %BF. Furthermore, it was shown that BIA estimation of total body water (TBW) was not different from results obtained by deuterium oxide dilution. Analysis of variance for %BF, as the outcome variable, indicated no significant method by race interaction. Correlation coefficients for the association between 4-C %BF and the other 4 predictions of %BF ranged from r = 0.84 to 0.92. Furthermore, slopes, intercepts, and the 95% confidence intervals for the regression of %BF from each prediction equation against the 4-C %BF were similar. Because Army & Navy anthropometric estimates of %BF, and the Lohman & Segal BIA estimates of %BF were comparable to results obtained from the 4-C model it was concluded that new prediction equations for specific racial groups are not needed.

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## IV. INTRODUCTION

All branches of the military have established standards for accession and retention. The accession standards are based on indirect determinations of body composition from weight for height (W/H) tables, while the retention standards include an assessment of a body composition based on W/H measurements and a test of aerobic fitness. Periodic review of W/H is conducted within all branches of the armed forces. Failure to meet the these standards results in anthropometric assessment and determination of percent body fat (% BF) from regression equations based on circumference measurements. However, Vogel et al (1988) reported that due to difficulties encountered in predicting body density in African-American females, primarily hydrophobia, the equation selected for use with females was developed from the White population studied. *This means that for technical reasons, the population used to develop the current Army equation did not contain any minority women. This also raises the question of the appropriateness of this equation for broad use within an Army where 53% of the females soldiers are members of minority ethnic groups.*

The work outlined below proposes: to determine the accuracy and precision of the Army and Navy equations to predict percent body fat in minority and non-minority female soldiers across representative ranges of age and body fat; to develop new prediction models using a modern, non-parametric tree-structured model that will be applicable to minority and non-minority female soldiers across all ages and ranges of body fat; and to test the validity of the new prediction models using cross-validation, a computationally-intensive technique.

The results of the proposed work will provide the Armed Forces with a scientifically based litmus test of the equations currently being used to estimate %BF, to determine promotion rate and/or retention in the armed forces, and to ensure the health promotion and disease prevention of all minority and non-minority females soldiers.

## V. BODY

### A HYPOTHESES

1. The Army and Navy regression equations for estimation of percent body fat apply to minority and non-minority military or military-eligible females across all applicable ranges of age and body fat with less than 5 soldiers out of 100 mis-classified for retention.

2. The agreement between the Army and Navy regression equations and the four compartment model criterion method will show an acceptable concordance correlation.

3. The new prediction equations for estimation of percent body fat apply to minority and non-minority military or military-eligible females across all applicable ranges of age and body fat with less than 5 soldiers out of 100 mis-classified for retention.

4. The accuracy and precision of the new equations for predicting the body fat or lean body mass developed from the four compartment criterion method will be acceptable based on the concordance correlation coefficient.

### B. TECHNICAL OBJECTIVES

1. To determine the accuracy and precision of the Army and Navy equations to predict percent body fat in minority and non-minority female soldiers across all ages and ranges of body fat.

2. To develop new prediction models using a modern, non-parametric tree-structured model that will be applicable to minority and non-minority female soldiers across all ages and ranges of body fat.

3. To test the validity of the new prediction models using cross-validation, a modern computationally-intensive technique.

### C. STATISTICAL ANALYSIS

1. Initial phase of the project focused on determination of the reliability of the two- and four-compartment models. Reliability was determined by repeated testing of volunteers with a one week period. Analysis of variance (ANOVA), intra-class correlation (ICC) and descriptive statistics were used. Technical error of measurement (TEM) was calculated and generalizability theory was used to determine the variance (VAR) and percent variance (%VAR) due to subjects, days and subject x days interactions. Additionally, the effect of varying different aspects of the 4-C model by one TEM on the estimation of percent body fat (%BF) was

examined. Results for these findings are presented in the **RESULTS** section **"Reliability of Four-Compartment Model"**. Additionally, comparisons were made between the estimation of percent body fat (%BF) based on a four-compartment model using deuterium oxide dilution for the determination of total body water and bioelectrical impedance with the Kushner and Schoeller equation to estimate TBW. These results were analyzed using analysis of variance to determine if significant differences exist between the methods and among the racial groups.

2. Phase 2 included data collection with minority women including African-American, Hispanic, Asian, Filipino, and Pacific Islanders. Statistical analysis included descriptive statistics and multi-variate analysis of variance (MANOVA) using the Navy %BF prediction and adjusting for race interaction. Results from these findings are presented in the **RESULTS** section **"Validity of Circumference-Based Body Fat Estimation Equations in Minority Women"**.

## D. RESULTS

### Phase I: Reliability of Four-Compartment Model

Reliability of the four-compartment body composition equation of Friedl et al. (1992) was assessed on 13 men and 7 women. Four-compartment body composition was assessed on each of two days within one week. In addition to calculating TEM and ICC, generalizability theory (Cronbach, 1963) was used to determine the VAR due to subjects and days main effects as well as the VAR due to subject by day interaction.

Subjects were twenty active duty Navy and Marine Corps personnel (13 men, 7 women). Ten men were Caucasian, 2 were African-American, and 1 was Hispanic. Five women were Caucasian and 2 were African-American. Subjects were informed of the risks and benefits of the study and each gave written informed consent. A Xitron 4000B bioimpedance analyzer (Xitron Technologies, San Diego, CA) was used to determine whole body resistance at 50kHz. Total body water was calculated using the gender-specific equations of Kushner and Schoeller (1986). Whole-body bone mineral content was determined using a Hologic QDR 1500 (Hologic, Inc., Bedford, MA) dual energy X-ray absorptiometer. Total body bone mineral (TBBM) was calculated as BMC*1.0436. Residual 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 PC with software developed at NHRC. Body density was calculated according to the formula of Buskirk (1961). Two-compartment body composition (SIRI BF) was estimated by the Siri (1961) equation. Four-compartment body composition (4-COMP BF) was calculated according to Friedl et al. (1992):

$$\%BF=[2.559/BD-0.734(TBW/WT)+0.983(TBBM/WT)-1.841]*100.$$

Descriptive statistics, ANOVA, and intra-class correlation coefficients (ICC) were obtained using the SPSS 8.0 statistical package for PC (SPSS, Inc., Chicago, IL). Technical error of measurement (TEM) (Pedersen and Gore, 1996) was calculated as:

$$\text{TEM} = (\text{mean square error})^2$$

Percent TEM (%TEM) was calculated as:

$$\%\text{TEM} = \text{TEM}/\text{mean}(\text{day } 1 + \text{day } 2)*100.$$

Generalizability theory (Cronbach, 1963) was used to determine VAR and % VAR due to subjects, days, and the subject by day interaction according to the procedures of Morrow (1989).

Tables 1a and 1b give subject characteristics for days 1 and 2. For males, RV had the lowest ICC (0.925) and highest %TEM (5.26). RV is used in calculating DB; however, its effect on DB in males appears to be minor since the ICC and %TEM for DB are 0.976 and 0.19, respectively. There was little difference in ICC among the variables for women. SIRI BF actually had the highest % TEM for women, followed by RV and BMC.

Table 1a. Subject characteristics, all subjects combined (n = 20).

| | DAY 1 | DAY 2 |
|---|---|---|
| **AGE (yr)** | 30.6±6.9 | 30.6±6.9 |
| **HT (cm)** | 171.3±10.0 | 171.3±9.9 |
| **WT (kg)** | 79.7±19.8 | 79.5±19.5 |
| **BMC (g)** | 2890±624 | 2919±636 |
| **TBW (l)** | 45.5±10.9 | 45.3±11.0 |
| **RV (l)** | 1.500±0.418 | 1.499±0.378 |
| **DB (g/cm3)** | 1.0488±0.0130 | 1.0503±0.0133 |
| **SIRI BF (%)** | 22.0±5.8 | 21.4±6.0 |
| **4-COMP BF (%)** | 21.7±5.9 | 21.5±5.8 |

HT = stature; WT = body mass; BMC = bone mineral content; TBW = total body water; RV = residual lung volume; DB = body density; SIRI BF = percent body fat by two-compartment analysis; 4-COMP BF = percent body fat by four-compartment analysis.

Table 1B. Subject characteristics, males (n = 13) and females (n = 7).

| | MALES | | FEMALES | |
|---|---|---|---|---|
| | DAY 1 | DAY 2 | DAY 1 | DAY 2 |
| **AGE (yr)** | 29.5±5.3 | 29.5±5.3 | 32.4±9.3 | 32.4±9.3 |
| **HT (cm)** | 176.0±6.7 | 175.9±6.8 | 162.6±9.4 | 162.7±9.4 |
| **WT (kg)** | 90.0±15.4 | 89.6±15.3 | 60.8±10.7 | 60.7±10.4 |
| **BMC (g)** | 3150±553 | 3209±535 | 2407±452 | 2407±452 |
| **TBW (l)** | 52.0±7.1 | 51.8±7.5 | 33.4±4.1 | 33.3±3.7 |
| **RV (l)** | 1.576±0.312 | 1.537±0.270 | 1.359±0.567 | 1.428±0.547 |
| **DB (g/cm3)** | 1.0501±0.1207 | 1.0514±0.0124 | 1.0464±0.0152 | 1.0481±0.0156 |
| **SIRI BF (%)** | 21.4±5.4 | 20.8±5.6 | 23.1±6.8 | 22.4±7.0 |
| **4-COMP BF (%)** | 20.5±5.5 | 20.4±5.5 | 23.9±6.3 | 23.5±6.4 |

HT = stature; WT = body mass; BMC = bone mineral content; TBW = total body water; RV = residual lung volume; DB = body density; SIRI BF = percent body fat by two-compartment analysis; 4-COMP BF = percent body fat by four-compartment analysis.

Table 2 gives the ICC, TEM and % TEM for SIRI BF, 4-COMP BF and variables used in the BF calculations.

Table 2. Intraclass correlation coefficients and technical error of measurement.

| | | **WT** | **BMC** | **TBW** | **RV** | **DB** | **SIRI BF** | **4-COMP BF** |
|---|---|---|---|---|---|---|---|---|
| **MALES n = 13** | **ICC** | 0.999 | 0.979 | 0.990 | 0.925 | 0.976 | 0.976 | 0.989 |
| | **TEM** | 0.52kg | 86.02g | 0.71L | 0.08L | 0.002g/cm3 | 0.91%BF | 0.56%BF |
| | **%TEM** | 0.58 | 2.70 | 1.37 | 5.26 | 0.19 | 4.31 | 2.74 |
| **FEMALES n = 7** | **ICC** | 0.999 | 0.979 | 0.988 | 0.997 | 0.983 | 0.983 | 0.985 |
| | **TEM** | 0.33kg | 92.53g | 0.40L | 0.06L | 0.002g/cm3 | 1.0%BF | 0.78%BF |
| | **%TEM** | 0.54 | 3.87 | 0.59 | 4.00 | 0.21 | 4.37 | 3.29 |
| **ALL n = 20** | **ICC** | 0.999 | 0.980 | 0.997 | 0.997 | 0.979 | 0.979 | 0.988 |
| | **TEM** | 0.46kg | 88.35g | 0.62L | 0.07L | 0.002g/cm3 | 0.94%BF | 0.64%BF |
| | **%TEM** | 0.58 | 3.04 | 1.36 | 4.9 | 4.9 | 4.33 | 2.97 |

ICC = intraclass correlation coefficient; TEM = technical error of measurement;
%TEM = percent technical error of measurement.

Table 3 gives the %VAR for SIRI BF, 4-COMP BF and variables used in the BF calculations. In most cases, greater than 97% of the VAR is due to the between subjects variability. Exceptions are RV and BMC. For RV, 7.5% of the VAR was accounted for by the subjects by days interaction for the males. For BMC, 4.9% of the VAR was accounted for by the subjects by days interaction for the females.

Table 3. Percent of variance due to subjects, days, and interaction.

| | | WT | BMC | TBW | RV | DB | SIRI BF | 4-COMP BF |
|---|---|---|---|---|---|---|---|---|
| **MALES n = 13** | **$\%\sigma^2$ S** | 99.9 | 97.5 | 99.0 | 92.3 | 97.4 | 97.4 | 98.9 |
| | **$\%\sigma^2$ D** | 0 | 0.4 | 0 | 0.2 | 0.2 | 0.2 | 0 |
| | **$\%\sigma^2$ S x D** | 0.1 | 2.1 | 1.0 | 7.5 | 2.4 | 2.3 | 1.1 |
| **FEMALES n = 7** | **$\%\sigma^2$ S** | 99.9 | 95.1 | 98.8 | 99.5 | 98.2 | 98.2 | 98.5 |
| | **$\%\sigma^2$ D** | 0 | 0 | 0 | 0.2 | 0.1 | 0.1 | 0 |
| | **$\%\sigma^2$ S x D** | 0.1 | 4.9 | 1.2 | 0.3 | 1.7 | 1.7 | 1.5 |
| **ALL n = 20** | **$\%\sigma^2$ S** | 99.9 | 98.0 | 99.7 | 96.4 | 97.4 | 97.5 | 98.8 |
| | **$\%\sigma^2$ D** | 0 | 0.0 | 0 | 0 | 0.5 | 0.5 | 0 |
| | **$\%\sigma^2$ S x D** | 0.1 | 2.0 | 0.3 | 3.6 | 2.1 | 2.0 | 1.2 |

$\%\sigma^2$ S = percent of variance due to subjects; $\%\sigma^2$ D = percent of variance due to days; $\%\sigma^2$ S x D = percent of variance due to subjects by days interaction

These data provide further evidence that, despite an increased number of measurements, propagation of error does not render 4-COMP BF less reliable than SIRI BF. In fact, TEM and % TEM were less for 4-COMP BF compared to SIRI BF for both men and women.

An examination of the effect on the estimation of 4-COMP BF of varying different variables by one TEM reveals that the single largest effect is due to TBW (0.60 % BF for males, 0.51% BF for females). DB has the second largest effect (0.47 % BF for males and 0.48 % BF for females). The effects of a one TEM difference in DB on 4-COMP BF are not as great as they are on SIRI BF (approximately 0.90% BF for a difference of 0.002 g/cm$^3$ for males and females) due to the moderating effects of TBW and TBBM in the 4-COMP BF prediction equation. Additionally, errors in measurement of the variables used in 4-COMP BF estimation are not additive. If every variable in the 4-COMP BF equation is varied by one TEM, a difference of 0.74 % BF for males and 0.61 % BF females was observed.

The great majority of the variance in 4-COMP BF (and SIRI BF) is due to between subjects variability, not day-to-day variability in measurement. RV measurement has the greatest subjects by days interaction effect in males, accounting for 7.5% of the total variance. RV measurement, like hydrostatic weighing, requires a considerable amount of subject compliance and motivation. It therefore is not surprising that there would be some slight differences in subject performance on different occasions. The women were more consistent in RV measurement from one day to the next, with more than 99% of the total variance due to subjects variability. The greatest percentage of subjects by days variance for the women was in BMC measurement (4.9%). This could have several explanations, including technician error (although the same experienced technician performed all scans), machine error, or error resulting from small movements by the subjects as they were being scanned (Cawkwell, 1998).

Eighty-four volunteers were used to test for significant differences in the estimate of %BF based on deuterium oxide dilution for TBW compared to bioelectrical impedance with the Kushner-Schoeller equation for the estimate of TBW. The 4-compartment model was used to determine %BF with the exception of the method for determination of TBW in the compartment model. Data presented in Table 4 indicated slight differences in the two estimates of %BF with the largest differences observed for the Pacific Islanders of 5.9%. These differences, however, were not significant, based on ANOVA, between methods or across ethnic groups. Thus BIA using the Kushner - Schoeller equation for TBW appears to be an acceptable method for the estimation of TBW in an ethnically diverse group of women..

Table 4. Comparison of Percent Body Fat Estimate from 4-C Model Using $D_2O$ or BIA to Determine Total Body Water

| | Caucasian | African-American | Hispanic | Asian | Filipino | Pacific Islander |
|---|---|---|---|---|---|---|
| N | 6 | 1 | 37 | 19 | 18 | 3 |
| 4-C $D_2O$ | 35.8 (13.5) | 33.8 (0.0) | 32.1 (8.1) | 29.3 (9.2) | 28.8 (9.6) | 24.0 (5.8) |
| 4-C BIA | 33.4 (5.9) | 34.4 (0.0) | 30.7 (7.7) | 29.1 (5.8) | 29.4 (6.0) | 30.1 (6.7) |

Values are means ± standard deviations. No significant differences were observed between method and ethnic group interactions, $p = 0.77$; $r = 0.89$.

## Summary

In summary, 4-COMP BF is highly reliable. Variables used in the estimation of 4-COMP BF can be measured with great reliability and measurement errors due to different variables are not linearly additive when estimating 4-COMP BF. Additional examination of the estimation of %BF from 4-compartment models using 2 different methods for the determination of TBW indicate no differences in %BF whether the 4-C model used deuterium oxide or BIA to measure TBW. Furthermore, no method by race interactions were observed. These result suggest that BIA using the Kushner & Schoeller prediction of TBW are equivalent to the estimate of TBW from traditional laboratory dilution methods and no affect was found on the estimation of %BF.

## Phase II: Validity of Circumference-Based Body Fat Estimation Equations in Minority Women

Data were collected on Caucasian, Africa-American, Hispanic, Asian, Filipino and Pacific Islander, women. A total sample size of 377 women completed all testing. This final sample size was 127 women more than, or a 51% increase, over the original sample indicated in the statement of work (SOW). Four-compartment body composition was assessed using total body water (TBW) determined by whole body bioelectrical impedance. Respiratory water for deuterium oxide ($D_2O$) determination of TBW was also collected. Descriptive statistics are given in Table 4 for all racial groups. It should be noted that the increased sample size represents an overall increase in the number of minority women, 56% compared to the estimated 40% projected in the SOW. This increase was 34% African- American, 11% Hispanic, 11% for Asian and Pacific Islanders. The relative increase in the Hispanic and Asian/Pacific Islander/Filipino women is double the projected value in the SOW. Unfortunately, Native Americans are not included in the sample. Thus, about 1% of military personnel are not represented.

Overall mean values for the three groups are similar, however, Hispanic women were significantly shorter than Caucasian and African-American women and Filipina women were significantly shorter than all other women. Similarly, Hispanic women were lighter than African-American women and Filipina women weighted less than all other groups of women (Table 4). Group means demonstrated no significant differences among the groups in percent body fat (%BF) derived from either the Navy equation or the 4-compartment model. Generally, the mean values for the Hispanic/Pacific Islander/Asian groups fell between those for Caucasians and African-Americans for body mass, 4-compartment body fat percentage, and Navy circumference equation (NAVY BF) body fat percentage (Table 4).

Additional comparisons were made, using multivariate analysis of variance (MANOVA), to determine if significant differences occurred in the estimate of %BF from the Lohman et. al. and Segal et. al. BIA equations compared to results obtained by the 4-C model and the NAVY FAT equation (Table 5). Results from the two BIA equations indicated an interaction with race (Lohman $p < 0.004$; Segal $p < 0.002$) when compared to results from the NAVY FAT equation. Similarly, a significant difference by race was observed when the Lohman and Segal equations were compared to results obtained by the 4-C model (Lohman $p < 0.009$; Segal $p < 0.03$) (Table 5). The Lohman estimate of %BF was significantly different from the Navy estimate of %BF for Pacific Islanders but not the 4_c estimate. The Segal equation resulted in a significantly different estimate of %BF compare to the 4-C model for Pacific Islanders as well. Lohman and Segal equations are as follows:

Lohman BIA equation:

If (sex = male) lohffm = (0.485*(htcm**2/res50))+(0.338*wtkg)+5.32.
If (sex = female) lohffm = (0.475*(htcm**2/res50))+(0.295*wtkg)+5.49.

compute lohfat = ((wtkg - lohffm)/wtkg)*100.

Segal, et al. BIA equation:

```
If (sex = male) segffm = (0.0013*htcm**2)-(0.044*res50)+(0.305*wtkg)-(0.168*age)+22.668.
If (sex = female) segffm = (0.0011*htcm**2)-(0.021*res50)+(0.232*wtkg)-(0.068*age)+14.595.
```

```
compute segfat = ((wtkg - segffm)/wtkg)*100.
```

The Army prediction equation, based on anthropometric, was also compared to results obtained from the 4-C model for the estimate of percent body fat. No significant interactions with race were observed and thus results were not different from those by the 4-C model across racial groups (Table 5). The Army %BF prediction equations is:

Army Anthropometric equation:

```
If (sex=male) armyfat = (76.462 * lg10(ab2c-neckc)) - (68.678 * lg10(htcm)) + 46.892.

If (sex=female) armyfa t= (105.328 * lg10(wtkg)) - (0.2 * wristc)- (0.533 * neckc) - (1.574 * farmc)
                        + (0.173 * hipc) - (0.515 * htcm) - 35.601.
```

Army, Navy, Lohman and Segal estimates of %BF are compared to the 4-C model estimates in Figure 1. Correlation coefficients ranged from r = 0.84 for the Army %BF to r = 0.92 for the Navy estimate of %BF. Regression coefficients and 96% confidence intervals were similar for all regression equations.

## SUMMARY

Table 4. Descriptive statistics.

| | Caucasian | African-American | Hispanic | Asian | Pacific Islander | Filipino |
|---|---|---|---|---|---|---|
| N | 166 | 128 | 41 | 20 | 3 | 19 |
| Age | 30.6 (7.4)$^{+}$ | 29.1 (6.8)$^{+}$ | 31.7 (8.6) | 34.0 (10.3) | 27.0 (4.4) | 37.0 (12.8) |
| Height | 164.4 (6.9) | 165.3 (6.3) | 161.2(5.9)$^{*\wedge\wedge}$ | 162.7 (4.8) | 170.5 (8.7) | 156.4(5.7)$^{**\wedge\wedge}$ $_{\#\$}$ |
| Weight | 67.3 (10.8) | 70.5 (10.9) | 64.2 (10.3)^ | 64.3 (7.7) | 69.4 (10.9) | 59.0(7.8)$^{*\wedge\wedge}$ |
| BMI | 24.8 (3.4) | 25.8 (3.5) | 24.7 (3.6) | 24.4 (3.2) | 23.7 (1.4) | 24.2 (3.3) |
| Neck Circ. | 32.9 (1.9)^ | 33.7 (1.7) | 32.7 (2.0)^ | 32.8 (1.5) | 33.5 (0.4) | 32.7 (2.0) |
| Abd Circ. | 75.8 (8.1) | 77.7 (8.1) | 75.6 (9.3) | 74.8 (6.9) | 74.2 (4.9) | 74.3 (7.4) |
| Hip Circ. | 101.5 (8.1) | 103.0 (7.80 | 100.2 (8.9) | 98.6 (5.7) | 97.4 (4.4) | 95.7(5.9)$^{*\wedge\wedge}$ |
| Navy Fat % | 30.5 (6.4) | 31.6 (6.6) | 30.7 (7.5) | 29.3 (5.8) | 26.1 (3.0) | 29.3 (5.9) |
| 4-C Fat, % | 28.8 (6.7) | 30.2 (7.0) | 30.1 (7.7) | 28.9 (5.9) | 22.7 (7.2) | 27.3 (6.3) |

Height and circumferences are in cm, weight in kg. BMI = body mass index; Navy Fat = % fat estimated by navy circumference equation; 4-Comp Fat = % fat estimated by four-compartment body fat

*Significantly less than Caucasian, $p < 0.05$

**Significantly less than Caucasian, $p < 0.01$

^Significantly less than African-American, $p < 0.05$

^^Significantly less than African-American, $p < 0.01$

$^{\#}$Significantly less than Asian, $p < 0.05$

$^{\$}$Significantly less than Pacific-Islander, $p < 0.01$

$^{+}$Significantly less than Filipino, $p < 0.01$

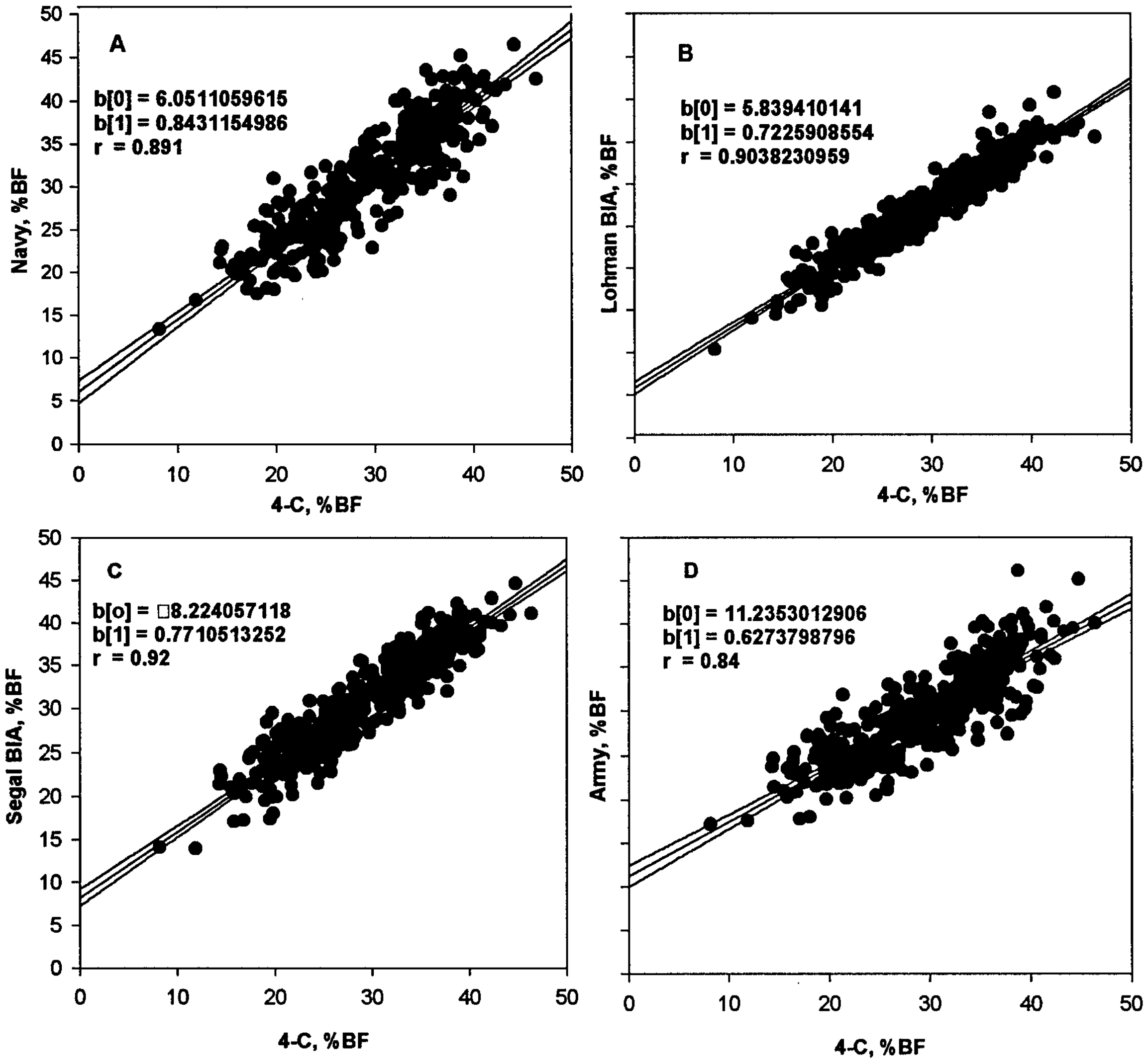
Table 5. Comparison of Percent Body Fat from 4-C Model and Prediction Equations by Race

| | Caucasian | African-American | Hispanic | Asian | Pacific Islander | Filipino |
|---|---|---|---|---|---|---|
| N | 166 | 128 | 41 | 20 | 3 | 19 |
| 4-C | 28.8 (6.7) | 30.2 (7.0) | 30.1 (7.7) | 28.9 (5.9) | 22.7 (7.2) | 27.3 (6.3) |
| Navy | 30.5 (6.4) | 31.6 (6.6) | 30.7 (7.5) | 29.3 (5.8) | 26.1 (3.0) | 29.3 (5.9) |
| Lohman* | 26.2 (5.2) | 28.2 (5.2) | 27.6 (5.6) | 26.7 (4.4) | 21.2 (4.9)* | 25.5 (4.5) |
| Segal# | 30.2 (5.7) | 31.9 (5.8) | 30.9 (6.2) | 30.4 (5.3) | 26.8 (3.3)# | 30.2 (5.7) |
| Army | 29.5 (4.9) | 29.9 (5.6) | 30.3 (5.4) | 29.3 (4.4) | 26.5 (2.4) | 28.7 (4.6) |

* Significant race interaction compared to 4-C ($p < 0.009$) and Navy ($p < 0.004$) estimates.

# Significant race interaction compared to 4-C ($p < 0.03$) and Navy ($p < 0.002$) estimates.

Figure 1: Relationship Between Methods



## KEY RESEARCH ACCOMPLISHMENTS

- Completion and approval of Institutional Review Board human subjects protocol.
- Completion of 2- and 4- compartment model reliability.
- Completion of $D_2O$ and BIA comparisons for the estimation of TBW.
- Completion of comparison between 4- compartment model and prediction equation estimates of %BF in minority women and majority women from Navy circumference equation.
- Completion of comparison between 4- compartment model and prediction equation estimates of %BF in minority women and majority women from Lohman and Segal BIA equations.
- Completion of comparison between 4- compartment model and prediction equation estimates of %BF in minority women and majority women from Army anthropometric equation.

## REPORTABLE OUTCOMES

- Kujawa, K.I., Reading, J.E., Glover, W.L., Hodgdon, J.A. Reliability of a four-compartment body fat estimation technique. Med Sci in Sports & Exer 31: S203, 1999. (Abstract).
- Kujawa, K.I., Van Loan, M., Conway, J.M., Stewart, W.L., Hodgdom, J.A. Validity of Navy circumference body fat equation in women of African-American, Asian, Hispanic, and Filipina Descent. Med. Sci in Sports & Exer 34: 2002. (Abstract).

## CONCLUSIONS

The majority of the variance in 4-COMP BF (and SIRI BF) is due to between subjects variability, not day-to-day variability in measurement. RV measurement has the greatest subjects by days interaction effect in males, accounting for 7.5% of the total variance. RV measurement, like hydrostatic weighing, requires a considerable amount of subject compliance and motivation. It therefore is not surprising that there would be some slight differences in subject performance on different occasions. The women were more consistent in RV measurement from one day to the next, with more than 99% of the total variance due to subjects variability. The greatest percentage of subjects by days variance for the women was in BMC measurement (4.9%). This could have several explanations, including technician error (although the same experienced technician performed all scans), machine error, or error resulting from small movements by the subjects as they were being scanned (Cawkwell, 1998). In conclusion, 4-COMP BF is highly reliable. Variables used in the estimation of 4-COMP BF can be measured with great reliability and measurement errors due to different variables are not linearly additive when estimating 4-COMP BF.

Bioelectrical impedance analysis, using the Kushner and Schoeller equation for the prediction of total body water, provides results similar to those obtained from traditional deuterium oxide dilution techniques. The Kushner and Schoeller estimate of TBW may be an appropriate substitute to use in a multi-compartment model for the estimate of percent body fat.

These data from minority women (African-American, Hispanic, Asian, Pacific Islander, or Filipino) indicate that no differences existed between a 4-compartment model and the Army or Navy anthropometric equation for the estimation of %BF. Additionally, no differences were found between the 4-C estimate of %BF and the Lohman or Segal bioelectrical impedance predictions equations for %BF. Furthermore, the present data show no method by race interaction; suggesting that the previously developed Army and Navy anthropometric based prediction equations for %BF, as well as the Lohman and Segal BIA equations do serve as acceptable methods for body composition assessment of both minority and majority women. Based on these findings the development of new %BF prediction equations is not necessary.

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## APPENDICES

A. Reliability of a four-compartment body fat estimation technique (Abstract and Poster Paper).

B. Validity of Navy circumference body fat equation in women of African-American, Asian, Hispanic, and Filipina descent (Abstract).

# Reliability of a Four-Compartment Body Fat Estimation

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## ABSTRACT

RELIABILITY OF A FOUR-COMPARTMENT
BODY FAT ESTIMATION TECHNIQUE
K. I. Kujawa, J. E. Reading, W. L. Glover, and J. A. Hodgdon (FACSM)

Preliminary data on reliability of a four-compartment body composition model (Friedl et al., 1992) are presented. Twenty active-duty U.S. Navy personnel (13 men, 7 women) were tested twice within one week. Measurements included bone mineral content (BMC) by DXA (Hologic 1500), total body water (TBW) by bioimpedance (Kushner and Schoeller, 1986), residual lung volume (RV) by helium dilution, and hydrostatic weighing (HYDRO). Two-compartment body fat (SIRI BF) was calculated from body density (DB) using the Siri equation. Four-compartment body fat (4-COMP BF) was calculated as: [2.559/DB - 0.734(TBW/WT) + 0.983(TBBM/WT) - 1.841]*100 where WT is weight in kg and TBBM is BMC*1.0436. Mean SIRI BF percent was 22.0"5.8% and 21.4"6.0% for days 1 and 2; means for 4-COMP BF were 21.7 " 5.9% and 21.5 " 5.8%. Mean values for BMC were 2890 " 624 g and 2919" 636 g; TBW 45.5 " 10.9 L and 45.3 " 11.0 L; RV 1.500 " 0.418 L and 1.499 " 0.378 L; and DB 1.0488 " 0.0130 g/cm3 and 1.0503" 0.0133 g/cm3. Intraclass correlation coefficients (ICC) and technical error of measurement (TEM) were determined from ANOVA between day one and day two values. TEM was calculated as: TEM = (mean square error)2 and percent TEM (%TEM) was calculated as: %TEM= TEM/ mean(day1 + day2)*100. Generalizability theory (Cronbach et al., 1963) was used to determine variance (VAR) due to subjects, day, and subject by day interaction. The majority of VAR (>96%) was due to subject variability. Day accounted for 0-0.5% of the VAR, while up to 3.6% of the VAR was due to subject by day interaction. In conclusion, ICC was slightly higher and TEM slightly lower for 4-COMP BF compared with SIRI BF. Reliability of 4-COMP BF, therefore, compares favorably to SIRI BF reliability, confirming the work of Friedl et al. (1992).

## INTRODUCTION

The greater reliability of the 4-compartment body composition equation of Friedl et al. (1992) than the 2-compartment equation of Siri (1961) has been reported for 10 males (Cronbach's a = 0.93 for 4 compartments, 0.90, for 2). However, Withers et al. (1999), using the 4-compartment body composition equation of Heymsfield and coworkers (1990) which differs in its assumption of the density of the residual mass, reported a technical error of measurment (TEM) of 0.6 % body fat and a reliability (intra-class correlation: ICC) of 0.989 for 8 males, but report TEM of 0.4% body fat and an ICC of 0.996 for a two-compartment analysis (Brozek, 1963) on 17 subjects (including the 8 upon whom the 4-compartment analysis was done).

We report on the reliability of the four-compartment equation of Friedl et al. (1992) on 13 men and 7 women.

Four-compartment body composition was assessed on each of two days within one week. In addition to calculating TEM and ICC, generalizability theory (Cronbach, 1963) was used to determine the variance (VAR) due to subjects and days main effects as well as the VAR due to subject by day interaction.

## METHODS

Subjects.
20 active duty Navy and Marine Corps personnel
  13 men: *10 Caucasian, 2 African-American, 1 Hispanic*
  7 women: *5 Caucasian, 2 African-American*
Subjects were informed of the risks and benefits of the study and each gave written informed consent.

Total Body Water (TBW).
Whole-body electrical impedance at 50kHz:
  Xitron 4000B bioimpedance analyzer
    (Xitron Technologies, San Diego, CA)
Gender-specific equations of Kushner and Schoeller (1986).

Bone Mineral Content (BMC).
Dual-energy X-ray absorptiometry
  Hologic QDR 1500 (Hologic, Inc., Bedford, MA)
Total body bone mineral (TBBM) calculated as BMC*1.0436.

Body Density (DB).
Residual volume (RV) measured prior to hydrostatic weighing by helium dilution (Ruppel, 1975)
  Modular Lung Analyzer, Model 03002
    (Warren E. Collins, Inc., Braintree, MA).
Weights underwater determined using an electronic scale
  (Model TI 2100 ,West Weigh Scale Co., Inc., San Diego, CA).
Body density (DB) calculated according to Buskirk (1961).

Body Fat (BF) Determination.
*Two-compartment body composition* (SIRI BF) estimated from Siri (1961).
*Four-compartment body composition* (4-COMP BF) estimated from Friedl et al. (1992):

$$\%\,\text{Body Fat} = \left(\frac{2.559}{DB} - 0.734 \times \frac{TBW}{\text{Body Mass}} + 0.983 \times \frac{TBBM}{\text{Body Mass}} - 1.841\right) \times 100$$

where:
  DB = Body Density (g·ml⁻¹)
  TBW = Total Body Water (L)
  TBBM = Total Body Bone Mineral (kg)
  Body Mass = Total Body Mass (kg)

Statistical Analysis. Descriptive statistics, ANOVA, and intra-class correlation coefficients (ICC) were obtained using the SPSS 8.0 statistical package for PC (SPSS, Inc., Chicago, IL).

TEM (Pederson and Gore, 1996) was calculated as:

$$TEM = \sqrt{\text{mean square error}}$$

Percent TEM (%TEM) was calculated as:

$$\%TEM = \frac{TEM}{\left[\dfrac{(meas_1 + meas_2)}{2}\right]}$$

where:
  $meas_1$ = mean value of the 1st measurement
  $meas_2$ = mean value of the 2nd measurement

Generalizability theory (Cronbach, 1963) was used to determine VAR and % VAR due to subjects, days, and the subject by day interaction according to the procedures of Morrow (1989).

## RESULTS

Table 1a. SUBJECT CHARACTERISTICS, TOTAL SAMPLE (N = 20).

| | DAY 1 | DAY 2 |
|---|---|---|
| AGE (yr) | 30.6 ± 6.9 | 30.6 ± 6.9 |
| HT (cm) | 171.3 ± 10.0 | 171.3 ± 9.9 |
| WT (kg) | 79.7 ± 19.8 | 79.5 ± 19.5 |
| BMC (g) | 2890 ± 624 | 2919 ± 636 |
| TBW (l) | 45.5 ± 10.9 | 45.3 ± 11.0 |
| RV (l) | 1.500 ± 0.418 | 1.499 ± 0.378 |
| DB (g/cm$^3$) | 1.0488 ± 0.0130 | 1.0503 ± 0.0133 |
| SIRI BF (%) | 22.0 ± 5.8 | 21.4 ± 6.0 |
| 4-COMP BF (%) | 21.7 ± 5.9 | 21.5 ± 5.8 |

Table 1b. SUBJECT CHARACTERISTICS, MALES (N = 13) AND FEMALES (N = 7).

| | MALES DAY 1 | MALES DAY 2 | FEMALES DAY 1 | FEMALES DAY 2 |
|---|---|---|---|---|
| AGE (yr) | 29.5 ± 5.3 | 29.5 ± 5.3 | 32.4 ± 9.3 | 32.4 ± 9.3 |
| HT (cm) | 176.0 ± 6.7 | 175.9 ± 6.8 | 162.6 ± 9.4 | 162.7 ± 9.4 |
| WT (kg) | 90.0 ± 15.4 | 89.6 ± 15.3 | 60.8 ± 10.7 | 60.7 ± 10.4 |
| BMC (g) | 3150 ± 553 | 3209 ± 535 | 2407 ± 452 | 2407 ± 452 |
| TBW (l) | 52.0 ± 7.1 | 51.8 ± 7.5 | 33.4 ± 4.1 | 33.3 ± 3.7 |
| RV (l) | 1.576 ± 0.312 | 1.537 ± 0.270 | 1.359 ± 0.567 | 1.428 ± 0.547 |
| DB (g/cm$^3$) | 1.0501 ± 0.1207 | 1.0514 ± 0.0124 | 1.0464 ± 0.0152 | 1.0481 ± 0.0156 |
| SIRI BF (%) | 21.4 ± 5.4 | 20.8 ± 5.6 | 23.1 ± 6.8 | 22.4 ± 7.0 |
| 4-COMP BF (%) | 20.5 ± 5.5 | 20.4 ± 5.5 | 23.9 ± 6.3 | 23.5 ± 6.4 |

Table 2 gives the ICC, TEM and % TEM for BF, and variables used in the BF calculations.

Table 2: RELIABILITY AND TECHNICAL ERROR OF MEASUREMENT*

| | | WT (kg) | BMC (g) | TBW (L) | RV (L) | DB (g·ml$^{-1}$) | SIRI BF (% of mass) | 4-COMP BF (% of mass) |
|---|---|---|---|---|---|---|---|---|
| MALES n = 13 | ICC | 0.999 | 0.979 | 0.990 | 0.925 | 0.976 | 0.976 | 0.989 |
| | TEM | 0.52 | 86.02 | 0.71 | 0.08 | 0.002 | 0.91 | 0.56 |
| | %TEM | 0.58 | 2.70 | 1.37 | 5.26 | 0.19 | 4.31 | 2.74 |
| FEMALES n = 7 | ICC | 0.999 | 0.979 | 0.988 | 0.997 | 0.983 | 0.983 | 0.985 |
| | TEM | 0.33 | 92.53 | 0.40 | 0.06 | 0.002 | 1.0 | 0.78 |
| | %TEM | 0.54 | 3.87 | 0.59 | 4.00 | 0.21 | 4.37 | 3.29 |
| ALL n = 20 | ICC | 0.999 | 0.980 | 0.997 | 0.964 | 0.979 | 0.979 | 0.988 |
| | TEM | 0.46 | 88.35 | 0.62 | 0.07 | 0.002 | 0.94 | 0.64 |
| | %TEM | 0.58 | 3.04 | 1.36 | 4.9 | 0.20 | 4.33 | 2.97 |

ICC = intraclass correlation coefficient (reliability)
TEM = technical error of measurement
%TEM = percent technical error of measurement
* Units apply only to the TEM

For males:
  RV had the lowest ICC (0.925) and highest %TEM (5.26), but the effects of RV on DB in males appear to be minor.
For women:
  There was little difference in ICC among the variables
  SIRI BF actually had the highest % TEM for women, followed by RV and BMC.

Table 3 gives the %VAR for BF and variables used in the BF calculations.

Table 3. Percent of variance due to subjects, days, and interaction.

| | | WT | BMC | TBW | RV | DB | SIRI BF | 4-COMP BF |
|---|---|---|---|---|---|---|---|---|
| MALES n = 13 | $\%\sigma^2$ S | 99.9 | 97.5 | 99.0 | 92.3 | 97.4 | 97.4 | 98.9 |
| | $\%\sigma^2$ D | 0 | 0.4 | 0 | 0.2 | 0.2 | 0.2 | 0 |
| | $\%\sigma^2$ S x D | 0.1 | 2.1 | 1.0 | 7.5 | 2.4 | 2.3 | 1.1 |
| FEMALES n = 7 | $\%\sigma^2$ S | 99.9 | 95.1 | 98.8 | 99.5 | 98.2 | 98.2 | 98.5 |
| | $\%\sigma^2$ D | 0 | 0 | 0 | 0.2 | 0.1 | 0.1 | 0 |
| | $\%\sigma^2$ S x D | 0.1 | 4.9 | 1.2 | 0.3 | 1.7 | 1.7 | 1.5 |
| ALL n = 20 | $\%\sigma^2$ S | 99.9 | 98.0 | 99.7 | 96.4 | 97.4 | 97.5 | 98.8 |
| | $\%\sigma^2$ D | 0 | 0.0 | 0 | 0 | 0.5 | 0.5 | 0 |
| | $\%\sigma^2$ S x D | 0.1 | 2.0 | 0.3 | 3.6 | 2.1 | 2.0 | 1.2 |

$\%\sigma^2$S = percent of variance due to subjects
$\%\sigma^2$D = percent of variance due to days
$\%\sigma^2$S x D = percent of variance due to subjects by days interaction

97% or more of VAR is between-subjects variability.
Exceptions are RV and BMC
In male subjects, the *subjects by days interaction* accounted for 7.5% of the VAR in RV.
In female subjects, the *subjects by days interaction* accounted for 4.9% of the VAR in BMC.

## DISCUSSION AND CONCLUSIONS

1. These data provide further evidence that, despite an increased number of measurements, propagation of error does not render 4-COMP BF less reliable than SIRI BF. TEM and % TEM were less for 4-COMP BF compared to SIRI BF for both men and women.
2. An examination of the effect on the estimation of 4-COMP BF of varying different variables by one TEM reveals that:
   a. The single largest effect is due to TBW (0.60 % BF for males, 0.51% BF for females).
   b. DB has the second largest effect (0.47 % BF for males and 0.48 % BF for females).
   c. The effects of a one TEM difference in DB on 4-COMP BF are not as great as they are on SIRI BF (approximately 0.90% BF for a difference of 0.002 g/cm3 for males and females) due to the moderating effects of TBW and TBBM in the 4-COMP BF prediction equation.
   d. Errors in measurement of the variables used in 4-COMP BF estimation are not additive. If every variable in the 4-COMP BF equation is varied by one TEM, a difference of 0.74 % BF for males; 0.61 % BF for females is observed.
3. The great majority of the variance in 4-COMP BF (and SIRI BF) is due to between subjects variability, not day-to-day variability in measurement.
   a. RV measurement has the greatest subjects by days interaction effect in males, accounting for 7.5% of the total variance.
      - RV measurement, like hydrostatic weighing, requires a considerable amount of subject compliance and motivation. It therefore is not surprising that there would be some slight differences in subject performance on different occasions.
   b. The women were more consistent in RV measurement from one day to the next, with more than 99% of the total variance due to subjects variability.
   c. The greatest percentage of subjects by days variance for the women was in BMC measurement (4.9%).
      - This could have several explanations, including technician error (although the same experienced technician performed all scans), machine error, or error resulting from small movements by the subjects as they were being scanned (Cawkwell, 1998).

In conclusion, 4-COMP BF is highly reliable. Variables used in the estimation of 4-COMP BF can be measured with great reliability and measurement errors due to different variables are not linearly additive when estimating 4-COMP BF

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# VALIDITY OF NAVY CIRCUMFERENCE BODY FAT EQUATION IN WOMEN OF AFRICAN-AMERICAN, ASIAN, HISPANIC, AND FILIPINA DESCENT

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PURPOSE: Currently, the Navy and Air Force use circumference equations for women that predict body fat from height and the $\log_{10}$ sum of neck, waist, and hip circumferences. These equations were developed on Caucasian subjects using a two-compartment body fat technique as the criterion measure. Therefore, it was deemed necessary to validate the Navy's circumference equations in other ethnicities using a four-compartment body composition model as the criterion.
METHODS: One hundred sixty-five women (41 Caucasian (C), 41 African-American (A-A), 41 Hispanic (H), 20 Asian (A) 19 Filipina (F), and 3 Pacific Islander (PI)) volunteered for the study. All subjects gave informed consent. Anthropometry, DXA, bioimpedance, residual volume, and hydrostatic weighing were all done on the same day with subjects in a fasted state.
RESULTS: There were no differences in abdominal or neck circumferences, BMI, waist-to-hip ratio, or body fat among the different racial groups. Filipinas had significantly smaller hip circumferences than A-A and C. Four-compartment body fat (4-C fat) averaged 29.2±7.0\% overall (C = 28.6±6.6; A-A = 30.3±7.2; H = 30.1±7.7; A = 28.9±5.9; F = 27.3±6.3; PI = 22.7±7.2). Navy circumference body fat (Navfat) averaged 30.3±6.5\% overall (C = 30.4±6.5; A-A = 31.0±6.5; H = 30.7±7.5; A = 29.3±5.8; F = 29.3±5.9; PI = 26.1±3.0). MANOVA analysis, using 4-C fat as the dependent variable, showed no significant race by method interaction, indicating no difference by race in the prediction of 4-C fat by Navfat.
CONCLUSION: The Navy's circumference body fat equation is valid for African-American, Asian, Hispanic and Filipina women. There were too few women of Pacific Island descent in the current sample to draw firm conclusions on the validity of the equation in this group.