Effect of race and resistance training status on the density of fat-free mass and percent fat estimates

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1Exercise Physiology Laboratory, Department of Health and Performance Sciences, Georgia Institute of Technology, Atlanta 30332-0356; 2Department of Health, Physical Education, and Sport Science, Kennesaw State University, Kennesaw 30144-5591; and 3Department of Exercise Science and Department of Foods and Nutrition, University of Georgia, Athens, Georgia 30602

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Millard-Stafford, Melinda L., Mitchell A. Collins, Christopher M. Modlesky, Teresa K. Snow, and Linda B. Rosskopf. Effect of race and resistance training status on the density of fat-free mass and percent fat estimates. J Appl Physiol 91: 1259–1268, 2001.—The impact of race and resistance training status on the density of fat-free mass (DFFM) and estimates of body fatness via hydrodensitometry (%Fatp) vs. a four-component model (density, water, mineral; %FatD,W,M) were determined in 45 men: white controls (W; n = 15), black controls (B; n = 15), and resistance-trained blacks (B-RT; n = 15). Body density by hydrostatic weighing, body water by deuterium dilution, and bone mineral by dual-energy X-ray absorptiometry were used to estimate %FatD,W,M. DFFM was not different between B and W (or 1.1 g/ml); however, DFFM in B-RT was significantly lower (1.091 ± 0.012 g/ml; P < 0.05). Therefore, %Fatp using the Siri equation was not different from %FatD,W,M in W (17.5 ± 5.0 vs. 18.3 ± 5.4%) or B (14.9 ± 5.6 vs. 15.7 ± 5.7%) but significantly underestimated %FatD,W,M in B-RT (14.0 ± 5.9 vs. 10.4 ± 6.0%; P < 0.05). The use of a race-specific equation (assuming DFFM = 1.113 g/ml) did not improve the agreement between %Fatp and %FatD,W,M, resulting in a significantly greater mean (±SD) discrepancy for B (1.7 ± 1.8% fat) and B-RT (6.2 ± 4.3% fat). Thus race per se does not affect DFFM or estimates of %Fatp; however, B-RT have a DFFM lower than 1.1 g/ml, leading to an overestimation of %Fatp.

body water; hydrodensitometry; bone mineral; body composition; Schutte equation; blacks

BODY COMPOSITION ASSESSMENT is a valuable tool to establish desirable body weight ranges and to track changes that occur with training. An indirect method widely used to assess body composition is densitometry (16). Estimates of body fatness (%fat) from body density (Db) (%Fatp) are based on a two-component model in which the densities of the fat mass and fat-free mass (FFM) are considered known and constant. The commonly used equation for estimating %fat developed by Siri (38) assumes that the densities of these two components are 0.9 and 1.1 g/ml, respectively. The density of fat was determined from adipose tissue samples in humans (12). Moreover, the density of the FFM (DFFM) is based on the assumed relative proportions of water, protein, and mineral (73.8, 19.4, and 6.8%, respectively) and each of their respective densities (e.g., 0.9937, 1.34, and 3.038 g/ml at 36°C) (3). The presumed proportional density and composition of the FFM were determined in white men (3); thus they may vary in other subgroups of the population, resulting in considerable error when %fat is estimated using %Fatp.

The development of multicomponent models, in which Db measurements are combined with water and/or mineral, has allowed researchers to test the validity of the assumed composition of FFM and DFFM. One group in which the DFFM appears to be different than the reference value of 1.1 g/ml is weight trainers with high musculoskeletal development. Recent studies using a four-component model (density, water, mineral) as a criterion (29, 47) concluded that DFFM is significantly lower in white weight trainers (<1.1 g/ml), resulting in an overestimation of %fat when densitometry and the Siri equation (38) (%Fatp, Siri) are used. The lower DFFM in resistance-trained men was based on significantly higher water (W/FFM) and lower mineral (M/FFM) and protein (P/FFM) fractions of the FFM compared with male controls (29).

Because of the increased use of weight training in athletic programs and the rising proportion of black athletes in collegiate and professional sports, it is important to determine the DFFM in resistance-trained black men so that appropriate equations can be used to estimate %Fatp. Whether resistance-trained black men exhibit a DFFM similar to their white counterparts is difficult to predict. It has been theorized that blacks have a higher DFFM than whites, because greater skeletal muscle, bone mineral mass, and bone density have been reported (7, 9, 32, 37, 45). This circumstantial evidence has led to the development and recommendation of race-specific equations (6, 19, 20, 36, 44, 45) in favor of traditional equations (3, 38) that convert Db to %fat. The most widely used equation for %Fatp esti-

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mation in blacks was developed by Schutte et al. (36) and postulates that the \( D_{\text{FFM}} \) is 1.113 g/ml based on calculations derived from hydrometry and hydrodensitometry. To our knowledge, this equation has not been adequately cross-validated with a four-component model. In fact, the few published reports that have assessed \( D_{\text{FFM}} \) in blacks with a multicomponent model are at odds. Only two investigations support the theory of a higher \( D_{\text{FFM}} \) in blacks (32, 45), whereas others suggest that there is no difference in the \( D_{\text{FFM}} \) between blacks and whites (9, 43). No studies have simultaneously evaluated the impact that both race and resistance training status have on \( D_{\text{FFM}} \) in men.

Considering that weight training and high degrees of muscularity are linked to a lower \( D_{\text{FFM}} \) and average black men may or may not have an elevated \( D_{\text{FFM}} \), predicting their combined effects is difficult. If the \( D_{\text{FFM}} \) in black men is significantly >1.1 g/ml, the opposing effects of resistance training status and race may counteract each other so that the \( D_{\text{FFM}} \) in black resistance trainers would be similar to that of white controls (1.1 g/ml). If that is the case, the Siri equation would provide a more accurate estimate of \( \% \text{Fat}_D \) than the race-specific equation (36). However, if \( D_{\text{FFM}} \) is independent of race and <1.1 g/ml in black weight trainers, consistent with results observed in white weight trainers (29, 47), then \( \% \text{Fat}_D \) would be overestimated by both equations.

Therefore, the present investigation had two purposes. First, our aim was to determine whether black men who did not participate in resistance training (B) had a \( D_{\text{FFM}} \) different from their white counterparts (W) and the reference value of 1.1 g/ml. We hypothesized that the \( D_{\text{FFM}} \) of B would not be different from that of W or 1.1 g/ml, resulting in a more accurate estimate of \( \% \text{fat} \) estimated by the four-component model \( \% \text{Fat}_{D,W,M} \) when \( \% \text{Fat}_{D,\text{Siri}} \) equation is used compared with the race-specific equation developed by Schutte et al. (36) \( \% \text{Fat}_{D,\text{Schutte}} \). Our second purpose was to determine whether resistance-trained black men with high musculoskeletal development (B-RT) have a \( D_{\text{FFM}} \) lower than that of B and than 1.1 g/ml. We hypothesized that B-RT would have a higher \( W_{\text{FFM}} \) and lower \( M_{\text{FFM}} \) and \( P_{\text{FFM}} \), leading to a lower \( D_{\text{FFM}} \) than that of B. Consequently, \( \% \text{Fat}_{D,\text{Siri}} \) and \( \% \text{Fat}_{D,\text{Schutte}} \) would overestimate \( \% \text{Fat}_{D,W,M} \) in B-RT.

METHODS

Subjects. Subjects were recruited from the student population as well as from local bodybuilding competitions. Forty-five men were assigned to three groups: W, B, and B-RT. Race was determined via self-report. All subjects reported that both parents were of the same race except for two subjects who indicated 50% black heritage (one each in B and B-RT). The criteria for B-RT selection was involvement in a weight-training program (3 days/wk minimum) for at least 2 yr before the study and a mesomorphy (Meso) rating >5.5, which was \( \sim 1.5 \) points above “average” Meso (5). Eight members of the group were competitive bodybuilders (one acknowledged anabolic steroid use but cessation 6 mo before the study) and the other seven were experienced in resistance training. The mean (minimum to maximum) quantity of resistance training for B-RT was 4 (3–6) days/wk, 86.8 (30–150) min/session, and 9 (2–22) yr of resistance training experience. Members of W and B were physically active but never involved in a resistance training program. All subjects gave written consent in accordance with the policies established by the Institutional Review Board for the use of human subjects.

Data collection protocol. All testing was completed during a single session with subjects reporting to the laboratory in a euhydrated condition after a 12-h fast. A baseline urine specimen was obtained to measure urine-specific gravity with a handheld gravitometer (indicative of hydration status). Based on a normal (1) baseline urine-specific gravity (mean \( \pm SD = 1.021 \pm 0.02 g/ml \)) and the ability to produce urine specimens during the test period, subjects were considered to be adequately hydrated. No exercise was performed by the subjects 12 h before testing.

Musculoskeletal development. Body mass in air was determined on an electronic digital scale to the nearest 0.01 kg, and height was obtained via a stadiometer. Meso was assessed via the Heath-Carter anthropometric somatotype equation (5), which utilizes upper arm and calf circumferences, corrected for skinfold thickness, and elbow and knee joint widths to provide an index of musculoskeletal development relative to height. The following equation was utilized:

\[
\text{Meso} = 0.855 \times (\text{humerus biceps} + \text{humerus biceps}) + 0.601 \times (\text{upper arm girth corrected for skinfold thickness}) + 0.161 \times (\text{calf girth corrected for skinfold thickness}) - 0.131 \times (\text{height}) + 4.5.
\]

The Meso score was used as an index of musculoskeletal development because it is independent of body composition measures and based on the muscle and bone dimensions relative to height. As an additional index, the FFM relative to height (FFM/h^2) was also calculated according to VanItallie et al. (42). The anthropometric measurements were performed by the same experienced technician for all subjects.

Densitometry. \( D_{\text{b}} \) was determined via hydrostatic weighing using a custom-built, stainless steel tank to measure body volume based on Archimedes’ principle (16). Weight under water was measured at residual lung volume (RV) by using a Chantillon autopsy scale to the nearest 0.025 kg. RV was measured simultaneously by using the standard oxygen-rebreathing nitrogen-dilution technique modified from Goldman and Buskirk (17). Nitrogen was measured using a Med Science 505 nitratalor. \( D_{\text{b}} \) was computed using mass and volume with corrections for water density, RV, and gastrointestinal tract gas volume (0.1 liter). The equations of Siri (38) and Schutte et al. (36) were utilized to estimate \( \% \text{fat} \) (via a two-component densitometric model) from \( D_{\text{b}} \) (%Fat_{D,\text{Siri}} and %Fat_{D,\text{Schutte}}, respectively). Our laboratory’s previously published test-retest reliability \( (n = 16) \) for assessing \( D_{\text{b}} \) was \( r = 0.99 \) (40). The technical error of measurement defined as the within-subject standard deviation was 0.001 g/ml (40).

Dual-energy X-ray absorptiometry. Total body bone mineral content, bone mineral density (BMD), and \( \% \text{Fat} \) \( \% \text{Fat}_{\text{DXA}} \) were determined from whole body scans using Lunar DPX-L dual-energy X-ray absorptiometry (DXA) (Madison, WI; software version 1.3Z; medium mode, 3.000 \( \mu \)A). To ensure quality control, the DXA unit was calibrated on a daily basis using the standard calibration block provided by the manufacturer. The calibration block was made of a thermoplastic acrylic resin that contained three bone-equivalent chambers filled with hydroxyapatite. All scans were performed and analyzed by two trained technicians. Our test-retest reliability of the DXA \( (n = 7) \) for assessing %fat was \( r = 0.99 \) with a technical error of measurement of 0.4\% (8).
DXA was assumed to measure bone ash, which is the total bone mineral minus volatile components lost from ashing (water of crystallization and CO₂ from carbonate) (18). Bone mineral ash was multiplied by 1.27 to estimate total body mineral content. The constant 1.27 assumes that 4% of bone mineral is lost during the ashing process and that nonosseous mineral mass is 23% of bone mineral ash (3).

**Total body water.** Total body water was measured by using deuterium oxide dilution as previously described (10, 24). After a baseline blood sample, subjects ingested a dosage of deuterium oxide equivalent to 0.3 g/kg body wt in 100 ml of distilled water. A second blood plasma sample was obtained after a 3-h equilibration period. After centrifugation, blood plasma samples were stored at –70°C until purification. To purify the plasma samples, equal volumes (1.5 ml) of plasma and deionized water were incubated at 37°C for 48 h in Conway diffusion dishes (Bel-Air Products, Pequannock, NJ). Absorbance of the purified water samples was analyzed by using a single-beam infrared spectrophotometer with a 4-μm fixed filter (Miran 1PE, Foxboro, Foxboro, MA) at 16°C. Total body water was corrected for the deuterium lost in urine during the 3-h equilibration period and reduced by 4% to account for hydrogen ion exchange during equilibration (35). The within-subjects SD of duplicate measures of body water obtained within 1 wk in five subjects was 0.75 liter (29).

**Four-component model.** The equation for estimating %fat from a four-component model (%Fat<sub>D,F,W,M</sub>) was derived from the relation of D<sub>b</sub> to its primary chemical constituents according to the following

\[
\frac{1}{D_b} = \frac{F}{D_F} + \frac{W}{D_W} + \frac{M}{D_M} + \frac{P}{D_P}
\]

where F, W, M, and P represent fat, water, mineral, and protein fractions of body mass and D<sub>F</sub>, D<sub>W</sub>, D<sub>M</sub>, and D<sub>P</sub> represent each component’s density, respectively (38). The assumed densities were 0.9007, 0.9937, 3.038, and 1.34 g/ml for D<sub>F</sub>, D<sub>W</sub>, D<sub>M</sub>, and D<sub>P</sub>, respectively.

The criterion method for %fat estimates was %Fat<sub>D,F,W,M</sub>, which was estimated from D<sub>b</sub>, body water, and body mineral based on the following equation of Lohman (22)

\[
\%\text{Fat}_{D,F,W,M} = \left[\frac{(2.747/D_b) - 0.714W + 1.146M}{100}\right]
\]

The protein content of the FFM was calculated by the difference (protein = FFM – water mass – mineral mass) based on the FFM calculated from %Fat<sub>D,F,W,M</sub> and body mass. D<sub>FFM</sub>, W/FFM, M/FFM, and P/FFM were calculated using formulas previously described (11, 29). The within-subject SD of repeated measures of D<sub>FFM</sub> in five subjects tested within a 1-wk time interval was 0.002 g/ml (29).

### Table 1. Subject physical characteristics

<table>
<thead>
<tr>
<th>Measure</th>
<th>Whites (n = 15)</th>
<th>Blacks (n = 15)</th>
<th>Resistance-Trained Blacks (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>22.2 ± 3.8</td>
<td>20.5 ± 1.4</td>
<td>27.6 ± 7.3*</td>
</tr>
<tr>
<td>Height, cm</td>
<td>178.0 ± 8.0</td>
<td>181.4 ± 6.1</td>
<td>176.6 ± 7.3</td>
</tr>
<tr>
<td>Mass, kg</td>
<td>73.0 ± 11.1</td>
<td>76.2 ± 8.5</td>
<td>85.6 ± 13.0*</td>
</tr>
<tr>
<td>Mass, kg/m²</td>
<td>4.5 ± 0.9</td>
<td>4.6 ± 0.9</td>
<td>7.5 ± 1.0*</td>
</tr>
<tr>
<td>FFMM², kg/m²</td>
<td>16.7 ± 1.7</td>
<td>19.4 ± 1.2</td>
<td>24.5 ± 2.5*</td>
</tr>
<tr>
<td>BMD, g/cm²</td>
<td>1.25 ± 0.08</td>
<td>1.35 ± 0.08†</td>
<td>1.40 ± 0.07*</td>
</tr>
<tr>
<td>D&lt;sub&gt;b&lt;/sub&gt;, g/ml</td>
<td>1.059 ± 0.01</td>
<td>1.065 ± 0.013</td>
<td>1.067 ± 0.013</td>
</tr>
</tbody>
</table>

Values are means ± SD. FFM, fat-free mass; FFMM², FFM-height index; BMD, bone mineral density; D<sub>b</sub>, body density measured by underwater weighing. *Significant difference between resistance-trained blacks and both white and black controls (P < 0.05). †Significant difference compared with whites (P < 0.05).

### Table 2. Body mass composition based on a four-component model

<table>
<thead>
<tr>
<th>Component</th>
<th>Whites (n = 15)</th>
<th>Blacks (n = 15)</th>
<th>Resistance-Trained Blacks (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat mass</td>
<td>13.5 ± 4.6</td>
<td>12.3 ± 5.9</td>
<td>9.2 ± 6.5</td>
</tr>
<tr>
<td>FFM</td>
<td>59.5 ± 9.0</td>
<td>64.0 ± 4.6</td>
<td>76.4 ± 10.3*</td>
</tr>
<tr>
<td>Water mass</td>
<td>43.5 ± 6.6</td>
<td>47.0 ± 3.1</td>
<td>52.8 ± 9.3*</td>
</tr>
<tr>
<td>Mineral mass</td>
<td>4.1 ± 0.6</td>
<td>4.6 ± 0.4†</td>
<td>4.8 ± 0.5†</td>
</tr>
<tr>
<td>Protein mass</td>
<td>12.0 ± 2.1</td>
<td>12.3 ± 1.6</td>
<td>13.5 ± 2.3</td>
</tr>
</tbody>
</table>

Values are means ± SD in kg. *Significant difference compared with both the white and black control groups (P < 0.05). †Significant difference compared with whites (P < 0.05).

**Statistical analysis.** Statistical analyses were done with SAS for Windows version 6.12 (SAS Institute, Cary, NC). For comparisons of %fat estimates, the data were analyzed by using a two-way (group x method) ANOVA with repeated measures. Post hoc simple contrasts were used to determine differences between cell means. The Bonferroni adjustment was used for the family of contrasts performed with an alpha level of 0.05. For the other between-group comparisons of body mass composition based on a four-component model and physical characteristics, a one-way ANOVA was used with Tukey post hoc tests. Relationships between variables were described using linear regression analysis and Pearson correlation coefficients. Agreement between methods for estimating %fat was determined using a Bland-Altman plot (2). An alpha level of 0.05 was used for all other significance testing. All values reported are means ± SD unless otherwise noted.

**RESULTS**

Mean subject physical characteristics of W, B, and B-RT are presented in Table 1. W and B were not different in age, height, or weight; however, BR-T subjects were older (by 5 and 7 yr) and heavier (by 12.6 and 9.4 kg) than W and B, respectively. Meso and FFM/h² were not significantly different (P > 0.05) between W and B; however, as expected, B-RT had significantly higher Meso and FFM/h² compared with W and B. The minimum and maximum values for Meso were 2.2–5.4 (W), 2.8–6.1 (B), and 5.7–9.3 (B-RT). The overlap in minimum and maximum values for Meso were 2.2–5.4 (W), 2.8–6.1 (B), and 5.7–9.3 (B-RT). The overlap in Meso for B and B-RT was due to one short B control subject (Meso = 6.1) and one tall muscular body builder (Meso = 5.7); otherwise, all other B and B-RT subjects had Meso <5.5 and >6.3, respectively. B-RT had significantly higher BMD compared with W and B, and B had greater BMD than did W. D<sub>b</sub> was not significantly different among the three groups.

Estimates of the body mass composition based on the four-component model are presented in Table 2. There was no significant difference in fat mass or protein mass among the groups. B-RT had greater (P < 0.05) FFM and water mass compared with B and W. B-RT and B had similar body mineral mass, and both groups had values significantly higher than those of W.

The relative composition of the FFM derived from the four-component model is presented in Table 3. There was no difference (P > 0.05) in D<sub>FFM</sub> between W and B, with values similar to the reference value of 1.1 g/ml (3). However, D<sub>FFM</sub> for B-RT was significantly
The lower DFFM in B-RT compared with B was due to a significantly different from %Fat D,W,M within the same group. However, B-RT had lower (%FatD-Schutte and %FatD,Siri) compared with %FatD,W,M within the same group, there was no difference in %FatD-Siri or %FatD-Schutte between B and B-RT. However, B-RT had significantly lower (P < 0.05) %FatD,W,M than did W and B (by 7.9 and 5.3% fat, respectively) and so were leaner according to the criterion (%FatD,W,M). Tests for simple main effects (within group) also indicated a difference among the methods in all groups. %FatD-Siri was not significantly different (P > 0.05) from %FatD,W,M in W. However, %FatDXA was significantly lower than %FatD,W,M and %FatD-Siri. In B, %FatD-Siri was not significantly different from %FatD,W,M or %FatDXA. However, the %FatD-Schutte was significantly higher in B (P < 0.001) compared with all other %fat estimates (1.7 ± 1.8% higher compared with %FatD,W,M). In B-RT, %FatD-Siri was significantly higher (by 4.5% fat) compared with %FatD,W,M (P < 0.05) but was not different from %FatDXA. Moreover, the discrepancy between %FatD-Schutte and %FatD,W,M was even greater (by 6.2 ± 4.3% fat) in B-RT (P ≤ 0.0001).

Table 3. Density and the relative composition of the fat-free mass based on a four-component model

<table>
<thead>
<tr>
<th>Measure</th>
<th>Whites (n = 15)</th>
<th>Blacks (n = 15)</th>
<th>Resistance-Trained Blacks (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFFM, g/ml</td>
<td>1.102 ± 0.007</td>
<td>1.102 ± 0.005</td>
<td>1.091 ± 0.012^</td>
</tr>
<tr>
<td>Water, %FFM</td>
<td>73.0 ± 1.6</td>
<td>73.6 ± 1.6</td>
<td>75.9 ± 3.3^</td>
</tr>
<tr>
<td>Mineral, %FFM</td>
<td>6.9 ± 0.7</td>
<td>7.2 ± 0.4</td>
<td>6.4 ± 0.7^</td>
</tr>
<tr>
<td>Protein, %FFM</td>
<td>20.1 ± 1.4</td>
<td>19.2 ± 1.7</td>
<td>17.7 ± 2.9</td>
</tr>
</tbody>
</table>

Values are means ± SD. DFFM, density of FFM. *Significant difference compared with both the white and black control groups (P < 0.05). †Significant difference compared with blacks (P < 0.05). ‡Significant difference compared with whites (P < 0.05).

Table 4. Percent fat estimates based on two-, three-, and four-component models

<table>
<thead>
<tr>
<th>Model/Measure</th>
<th>Whites (n = 15)</th>
<th>Blacks (n = 15)</th>
<th>Resistance-Trained Blacks (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-component model</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%FatD,Schutte</td>
<td>17.4 ± 4.9†</td>
<td>16.6 ± 5.2†</td>
<td></td>
</tr>
<tr>
<td>%FatD,Siri</td>
<td>17.5 ± 5.0</td>
<td>14.9 ± 5.6*</td>
<td>14.0 ± 5.9†</td>
</tr>
<tr>
<td>Three-component model</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>%FatDXA</td>
<td>15.7 ± 5.4†</td>
<td>13.5 ± 7.5*</td>
<td>12.6 ± 7.0*</td>
</tr>
<tr>
<td>%FatD,W,M</td>
<td>18.3 ± 5.4†</td>
<td>15.7 ± 5.7*</td>
<td>10.4 ± 6.0*</td>
</tr>
<tr>
<td>Four-component model</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are means ± SD. %Fat, percent body fat; subscripts D, W, M, and DXA represent body density, water, mineral, and dual-energy X-ray absorptiometry, respectively; Schutte and Siri, equations of Schutte et al. (36) and Siri (38), respectively. *Significantly different from %FatD,Schutte within the same group (P < 0.05). †Significantly different from %FatD,W,M within the same group (P < 0.05).

A scatterplot of the relationship between %FatD-Siri and %FatD,W,M is illustrated in Fig. 1A. The correlation for the two estimates was significant (P < 0.05) for W \( r = 0.90, y = 0.97x + 1.31, \) SE of estimate (SEE) = 2.4%, B \( r = 0.95, y = 0.96x + 1.31, \) SEE = 1.8%, and B-RT \( r = 0.70, y = 0.72x + 0.25, \) SEE = 4.4%. A scatterplot of the relationship between %FatD,Schutte and %FatD,W,M is illustrated in Fig. 1B. The correlation for the two estimates was significant (P < 0.05) for B \( r = 0.95, y = 1.09x - 3.31, \) SEE = 1.8%, and B-RT \( r = 0.70, y = 0.82x - 3.30, \) SEE = 4.4% (equation not used for W). On comparing the two graphs (Fig. 1, A and B), the Schutte et al. (36) equation yields a higher %FatD compared with that of Siri (38), especially at the lower range of %fat estimates.

Individual differences between the criterion method (%FatD,W,M) and the other %fat estimates (%FatD-Siri, %FatD-Schutte, %FatDXA) are illustrated in Fig. 2, A, B, and C, respectively. The mean differences between

Fig. 1. A: relationship between estimates of body fatness (%fat) from densitometry and the Siri equation (38) (%FatD,Siri) and criterion method estimated from body density (Db), body water, and body mineral (%FatD,W,M) in whites (W), blacks (B), and resistance-trained blacks (B-RT) (n = 15 per group). B: relationship between %fat from densitometry and the Schutte et al. equation (36) (%FatD,Schutte) and %FatD,W,M. Note that W are included (without using the race-specific equation), and so the data points are identical to those in A for this group. Lines extended through axes, line of identity; short lines, group-specific regression lines.
%FatD-Siri and %FatD,W,M were 0.7, 0.8, and -3.6% fat for W, B, and B-RT, respectively. Individual differences ranged from -3.1 to 4.0% fat in W, -2.5 to 4.1% fat in B, and -10.6 to 3.2% fat in B-RT. The mean differences between %FatD-Schutte and %FatD,W,M were -1.7 and -6.2% fat for B and B-RT, respectively. The individual differences ranged from -4.7 to 1.2% fat in B and from -12.6 to 0.5% fat in B-RT. The mean differences between %Fat DXA and %FatD-W,M were 2.6, 2.2, and -2.2% fat for W, B, and B-RT, respectively. The individual differences ranged from -2.7 to 6.8% fat in W, from -2.1 to 7.1% fat in B, and from -9.6 to 3.3% fat in B-RT. There was a weak relationship \( r = 0.25, P = 0.1 \) between the differences in %FatD-Siri and %FatD,W,M at specific levels of body fatness (Fig. 2A). The correlation for the difference between methods and level of %fat (Fig. 2, B and C, respectively) was significant for %FatD-Schutte \( (r = 0.39, P = 0.0075) \) but not for %FatDXA \( (r = -0.06, P = 0.71) \).

Figure 3 illustrates the relationship between DFFM and the difference between %FatD,Siri and %FatD,W,M. The correlation between the %FatD,W,M - %FatD-Schutte difference and DFFM for all subjects was essentially 1.0 \( (r = 0.996; y = 360x - 396, \text{SEE} = 0.3\%) \). Consequently, the difference between %FatD,W,M and %FatD,Siri is explained by the variability in DFFM. The correlation between the %FatD,W,M - %FatD-Schutte difference and W/FFM (Fig. 4) was also significant \( (P < 0.05) \) \( (r = -0.96; y = -1.36x + 100.5, \text{SEE} = 1.1\%) \). The correlation between the %FatD,W,M - %FatD-Siri differ-

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**Fig. 2.** Agreement between %FatD,W,M and %FatD-Siri (A), %FatD-Schutte (B), and %fat via dual-energy X-ray absorptiometry (%FatDXA; C). Subjects are W, B, and B-RT \((n = 15 \text{ per group})\).

**Fig. 3.** Relationship between the density of the fat-free mass (D_{FFM}) and the difference in %FatD,W,M and %FatD-Siri in W, B, and B-RT \((n = 15 \text{ per group})\).

**Fig. 4.** Relationship between the water fraction of FFM and the difference in %FatD,W,M and %FatD-Siri in W, B, and B-RT \((n = 15 \text{ per group})\). D_{FFM} is show on right axis for reference.
ence and M/FFM (Fig. 5) was not as strong but was significant \((r = 0.74; y = 4.0x - 28.0, \text{SEE} = 2.5\%).\)

Figure 6 illustrates that Meso was significantly related \((r = -0.46, y = -1.0x + 5.0, \text{SEE} = 3.3\%\)) to the difference between \(\%\text{Fat}_{D,W,M}\) and \(\%\text{Fat}_{D,Siri}\). However, BMD was not significantly \((r = -0.08, P > 0.05)\) correlated to the difference between \(\%\text{Fat}_{D,W,M}\) and \(\%\text{Fat}_{D,Siri}\) (Fig. 7).

**DISCUSSION**

The present study addressed two issues. First, despite the widespread notion that \(D_{FFM}\) is elevated in blacks, \(D_{FFM}\) in B was not different from that in W or from 1.1 g/ml. Therefore, \(\%\text{Fat}_{D,Siri}\) was not different from \(\%\text{Fat}_{D,W,M}\) but \(\%\text{Fat}_{D,Schutte}\) overestimated \(\%\text{Fat}_{D,W,M}\). These data suggest that the Siri equation (38), rather than a race-specific equation, should be used to estimate \(\%\text{Fat}_{D}\) in black men who do not engage in resistance training. The second finding was that \(D_{FFM}\) in B-RT was lower than \(D_{FFM}\) in W and B and the reference value of 1.1 g/ml. Consequently, \(\%\text{Fat}_{D,Siri}\) overestimated \(\%\text{Fat}_{D,W,M}\) by 3.6% fat, and \(\%\text{Fat}_{D,Schutte}\) overestimated \(\%\text{Fat}_{D,W,M}\) by an additional 2.6% (6.2% fat). These data support recent investigations that collectively suggest that race per se (43) does not necessitate the use of population-specific equations to accurately estimate \(\%\text{Fat}_{D}\) but that population-specific equations for male resistance trainers may be needed (29, 47).

**Effect of race on \(D_{FFM}\).** The findings of the present study parallel those of Visser et al. (43) that \(D_{FFM}\) is independent of race and are in contrast to previous studies (32, 36, 45) that suggest that race impacts \(D_{FFM}\) (1.1 g/ml for black men). The \(D_{FFM}\) in our B controls was not significantly different from that in W or from 1.1 g/ml. In a large-scale \((n = 703)\) study, Visser et al. (43) observed the \(D_{FFM}\) of black men (aged 20–94 yr) to be 1.099 g/ml and not different from that of whites (1.098 g/ml). A major strength of this study was the large number of black men \((n = 98)\) and women \((n = 96)\) studied, thereby reducing potential sampling error. Similar to our findings, Visser et al. also observed higher M/FFM (7.0 vs. 6.6% FFM) in young adult black men (20–40 yr) compared with whites but no difference in the W/FFM (74.2%).

In large part, the theory that \(D_{FFM}\) is elevated in blacks hinges on the understanding that blacks have greater bone mass compared with whites. Previous data indicated that blacks have a dry fat-free skeleton that is 10–20% heavier than that of whites (28, 37, 41). Of the major chemical constituents of the FFM (water, mineral, and protein), mineral has the highest density. Thus deviations in bone mineral and M/FFM were hypothesized to have a profound effect on \(D_{FFM}\). Yet mineral differences of the magnitude demonstrated between blacks and whites in the present study (difference = 0.4% for M/FFM) have a minimal effect on \(D_{FFM}\) and \(\%\text{Fat}_{D}\) (<1% fat; Ref. 30). Schutte et al. (36) tested black \((n = 15)\) and white men \((n = 19)\) similar in age, height, and weight and observed that \(D_{b}\) tended to be higher \((P > 0.05)\) in blacks, despite no difference in body water and skinfold measurements. However, bone mineral was not measured in that study. Assuming water mass is not different in blacks and whites, M/FFM must be nearly twice as high in blacks to produce the increased \(D_{FFM}\) (1.113 g/ml).
hypothesized by Schutte et al. These calculations further support the present findings that $D_{FFM}$ in black men is not significantly different from the $D_{FFM}$ in white men.

It has been hypothesized that a greater proportion of skeletal muscle mass in blacks may also contribute to an increased $D_{FFM}$ (18, 32, 44). However, this theory is contradicted by the present study as well as that of Visser et al. (43). The FFM, total protein, and water mass were not different between our two control groups of B and W. Because skeletal muscle is primarily water (~74%), its density is slightly ~1.1 g/ml (~1.066 g/ml for fat-free muscle). Therefore, if the FFM were composed of a higher proportion of skeletal muscle in blacks, then $D_{FFM}$ would, in fact, be reduced. This rationale is supported by the present findings in the muscular B-RT. It has been suggested that the skeletal muscle of black men may have a higher concentration of protein (44), resulting in a higher $D_{FFM}$. If the protein concentration of muscle is elevated in blacks, $P/FFM$ should be elevated as well. However, $P/FFM$ was not higher for B compared with W in the present study, and a moderate effect size (Cohen’s delta = 0.58) suggests that it was actually lower. These findings are consistent with those of Visser et al., who found $P/FFM$ to be lower in blacks compared with whites and suggest that skeletal muscle is not more concentrated in black compared with white men. The hypothesis that skeletal muscle has a higher protein concentration leading to a denser muscle in blacks requires further investigation with more direct measures of protein.

**Effect of resistance training status on $D_{FFM}$**. Until recently, the $D_{FFM}$ in resistance trainers was unknown. It was suggested that the $D_{FFM}$ is reduced in resistance-trained men because of a proportionately larger contribution of muscle than bone to the FFM (48). Alternatively, because the density is inherently greater (2.982 g/ml) and weight training increases bone mineralization (39), others suggested that the $D_{FFM}$ in resistance-trained men is >1.1 g/ml (26). Although recent studies confirmed that the $D_{FFM}$ is <1.1 g/ml in white male resistance trainers (29, 47), the $D_{FFM}$ in black resistance trainers had not been determined. Because the $D_{FFM}$ in black men was controversial (36, 43, 45), it was difficult to predict $D_{FFM}$ in black resistance trainers. The present study suggests that male B-RT have a $D_{FFM} < 1.1$ g/ml.

These findings are similar to observations in white resistance trainers (29, 46) and other muscular male athletes involved in resistance training (33). Modlesky et al. (29) observed a significantly lower $D_{FFM}$ in white resistance trainers compared with controls (1.089 vs. 1.099 g/ml) based on higher W/FFM (74.8% FFM) and reduced M/FFM and P/FFM. The result was $\%Fat_{D,Siri}$ overestimated $\%Fat_{D,W,M}$ by ~4% fat. These findings have been confirmed by Withers et al. (47), who reported a low $D_{FFM}$ (1.094 g/ml) in three male bodybuilders (Meso = 8.6), resulting in $\%Fat_D$ overestimating $\%Fat_{D,W,M}$ by 2.1% fat. Similarly, Prior et al. (33) observed a $D_{FFM}$ of 1.092 g/ml in muscular football players (black and white); however, some other resistance-trained athletes did not display a lower $D_{FFM}$ (e.g., female gymnasts). These findings tend to support the theory that participation in resistance training results in a dilutional effect on the FFM and skeletal muscle in men; consequently, muscular male weight trainers may have a reduced $D_{FFM}$, leading to an overestimation of $\%Fat_D$ when a $D_{FFM}$ of 1.1 g/ml is assumed. Yet, whether the $D_{FFM}$ is reduced in all resistance-trained athletes of both genders (participating in various sports) is not entirely clear.

Although the $D_{FFM}$ observed in B-RT (1.091 g/ml) was similar to the $D_{FFM}$ previously observed in white weight trainers (29), it was higher by 0.003 g/ml. Consequently, the deviation from 1.1 g/ml was less and the overestimation of $\%Fat_{D,Siri}$ was slightly smaller (3.6 vs. 4.1% fat). These subtle differences are likely linked to the type of densitometer used (30, 34) and the assumptions regarding body water measurement from deuterium oxide. Bone mineral estimates from the densitometer used in the present study (Lunar DPX-L) are known to be ~11% higher than estimates from the densitometer (Hologic QDR 1,000 W) used in the study of white weight trainers (29). Furthermore, body water measurements from dilution were reduced by 4% body mass to account for hydrogen exchange with protein and carbohydrate, whereas a 2% correction was applied in the study of white weight trainers. If the same densitometer and corrections employed by Modlesky et al. (29) were used in the present study, $D_{FFM}$ in the resistance trainers would equal 1.089 g/ml, which is identical to the results observed in white weight trainers. Another difference in the present study compared with the study of whites (29) was a small age discrepancy (7 yr) between B-RT and B. However, age does not appear to affect $D_{FFM}$ in men (43), particularly as all subjects were young adults. The observation that the difference in $D_{FFM}$ between W and B-RT was the same as that observed between white controls and white weight trainers in the Modlesky et al. study illustrates the small effect of densitometer type, hydrogen exchange correction factor, and slight age differential on estimates of $D_{FFM}$.

The reason for the lower $D_{FFM}$ in B-RT than assumed is primarily related to W/FFM and secondarily to lower M/FFM and P/FFM compared with controls. The higher W/FFM and lower M/FFM are plausible considering that muscle is predominantly water and weight training may induce a proportionately greater accrual of muscle than bone mineral. Skeletal muscle and cross-sectional areas can increase 15–40% with weight training compared with mineral (30). It has been observed that weight training increases total body water (4). Other potential contributors to an increased W/FFM associated with training include increased extracellular fluid volume (46) and increased water stored with glycogen (31). However, because these measurements were not obtained, their influence is not known.
Implications of using a two-component model. The major practical implications from the present study are that densitometry via %FatD-Siri can give a reasonably accurate estimate of %fat in black men (mean difference = 0.8% fat, SEE = 1.8%) and that the use of a race-specific equation is not justified. This is consistent with other recent studies in the literature (9, 43). Cote and Adams (9) found no difference between %FatD-Siri and %FatD,W,M in black women. Visser et al. (43) also reported no significant difference between mean %FatD,Siri and %FatD,W,M in blacks (0.2%) or whites (1%). We observed that %fat is overestimated by 2.7% when the race-specific equation proposed by Schutte et al. (36) is employed. In black weight trainers with high musculoskeletal development (and a lower DFFM), neither the Siri (38) nor Schutte et al. (36) equation accurately estimate %FatD, with overestimations of 3.6 ± 4.5 and 6.2 ± 4.3% fat, respectively.

Because the lower DFFM in B-RT subjects is reflected in their measured total Db, the relation between measured Db and total body fatness will be different in individuals who do not weight train and different from values assumed by Siri (38). The two-component model (on which densitometry is based) may, therefore, result in inaccuracies that would ultimately lead to inappropriate recommendations to reduce body weight and fat. The SEE (4.4%) for %FatD-Schutte and %FatD,Siri in B-RT compared with the criterion was above the level suggested by Lohman (23) for acceptance (<3%). Based on the Bland-Altman plots, the key difference between estimates from the two equations is the systematic error associated with the %FatD,Schutte estimates (which appears to be greatest at the lower levels of %fat). This is because B-RT had a greater discrepancy between %FatD and %FatD,W,M (because of their lower than normal DFFM) and lower %FatD,W,M than the control groups. Based on the results of this study as well as those of Visser et al. (43), the use of the Schutte et al. (36) equation in the estimation of %fat from Db is not recommended. The Siri equation (38) is more suitable for blacks who do not resistance train (and have average musculoskeletal development) but may not be valid for other population groups (e.g., Asian).

The use of a race-specific %fat equation [as proposed by Schutte et al. (36)] is based on the unsubstantiated theory that black men have a higher DFFM. Furthermore, race-specific equations have been frequently employed in the literature to validate other measures of body composition in blacks (6, 20). However, the methods used by Schutte et al. were insufficient to test the validity of the DFFM in blacks as mentioned previously. Estimates of %fat from body water do not account for variations in M/FFM and P/FFM, which can result in substantial error. Because their sample sizes were small and the findings conflict with recent studies, which have utilized a four-component model, it is difficult to justify the use of the Schutte et al. equation or other equations specific to blacks.

The concept of employing race-specific equations to estimate %FatD in black men continues to persist in the literature, however. A recent investigation by Wagner and Heyward (45) suggests the DFFM in black men is 1.1057 g/ml, and the authors recommended a new %fat equation based on this value (44, 45). The proposed DFFM and %fat equation were based on body composition estimates from a four-component model in a sample of 30 black men. Their recommendations may have been premature for two reasons. First, because the study of black men did not include a control group of white men for reference purposes (13, 14), a systematic error in the measurement of DFFM cannot be discounted. Second, when all recent studies (9, 32, 43, 45) are considered, the concept that DFFM is higher in blacks compared with whites (and >1.1 g/ml) is not consistently supported.

Alternatively, it has been hypothesized that an index of musculoskeletal development may improve estimates of %FatD. The theory was based on observations of an inverse relationship between DFFM and musculoskeletal development (r = -0.64) in muscular weight trainers and controls with average musculoskeletal development. In the present study, DFFM was also significantly related (r = -0.44) to Meso ratings in the total subject pool (n = 45).

Using musculoskeletal development as a criteria to improve estimates of %FatD (and a two-component model) is not without its pitfalls, however. Prior et al. (33) indicated that DFFM was poorly related to musculoskeletal development in a large group (n = 172) of male and female athletes and nonathletes. Football players, who engage heavily in weight training, had a lower DFFM (1.092 g/ml), and thus %FatD overestimated %FatD,W,M by 3.5%. However, DFFM was poorly related to musculoskeletal development (r = -0.14) in a large group of athletes of different sports and genders (as well as nonathletes), suggesting that the relationship between Meso and DFFM is not strong across a heterogenous population. The deviations in the DFFM of athletes are complex and not simply a reflection of differences in musculoskeletal development (assessed via an anthropometric measurement). Deviations in DFFM among different types of athletes may be linked to their varied training regimens, and thus changes in the chemical constituents of the FFM due to resistance training may be different from when they are combined with other physical activities. Further research is needed to determine whether different types of training have unique effects on the constituents of the FFM and, consequently, DFFM.

An alternative equation (%FatD = 521/Db - 478) based on the low DFFM (1.089 g/ml) observed in white resistance trainers has been proposed to provide better estimates of %fat in resistance trainers (29). Although systematic error of %FatD in relation to %FatD,W,M was greatly reduced (mean %fat = 10.3 vs. 10.4% for %fatD,W,M) when the proposed equation was used compared with traditional equations, large variability between the two estimates remained (SEE = 4.4% fat). These results suggest that the %fat in resistance trainers cannot be accurately estimated from Db alone.

In conclusion, the present study suggests that DFFM in B is not different from that in W or from 1.1 g/ml.
Thus %fat is more accurately estimated when $D_b$ is used in conjunction with the Siri equation (38) rather than a race-specific equation developed by Schutte et al. (36). Furthermore, B-RT with high musculoskeletal development, like their white counterparts, appear to have a $D_{FFM} < 1.1$ g/ml, due primarily to higher W/FFM and secondarily to lower M/FFM and P/FFM. The result is an overestimation of %fat from $D_b$ and the Siri equation (38). The %fat overestimation is exacerbated when $D_b$ is used in conjunction with the race-specific equation.

REFERENCES


