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Estimating body fat in African American and white adolescent girls: a comparison of skinfold-thickness equations with a 4-compartment criterion model[1–3]

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ABSTRACT

Background: Although skinfold-thickness equations are widely used to estimate body fat, their accuracy in a biracial population of female adolescents has not been established.

Objective: We undertook this study to determine the agreement between 8 widely used skinfold-thickness equations and a 4-compartment criterion model in predicting the percentage body fat of 72 white and 40 African American girls aged 13.0 ± 1.9 y.

Design: The biceps, triceps, suprailiac, subscapular, thigh, calf, and abdominal skinfold thicknesses of the subjects were measured with skinfold calipers and the buttocks circumference with a metal tape. The percentage fat mass (%FM) predicted by using each skinfold-thickness equation was compared with the criterion value calculated by the 4-compartment model on the basis of measurements of body density, body water, and bone mineral content.

Results: When the racial groups were analyzed separately, the Bland-Altman analysis indicated that the quadratic equations agreed most closely with the 4-compartment model's measurement of %FM. Agreement of the other equations varied with body fatness.

Conclusions: The quadratic equation of Slaughter et al is recommended for population studies in female adolescents because of its accuracy and simplicity. However, an individual %FM can be over- or underestimated by ≈10% when this skinfold-thickness equation is used. *Am J Clin Nutr* 2000;72:348–54.

KEY WORDS Skinfold thickness, body fat, female adolescents, densitometry, isotope dilution, dual-energy X-ray absorptiometry, ethnicity, whites, African Americans, girls, race, prediction equations, blacks

INTRODUCTION

Obesity is a major health problem in the United States because of its association with increased risk of hypertension, coronary heart disease, diabetes, cancer, and many other health problems (1, 2). The third National Health and Nutrition Examination Survey (3) indicated that, on the basis of body mass index (BMI; in kg/m^2), ≈1 in 4 American children and adolescents is overweight, a condition that is increasing most rapidly among African American girls.

BMI is a general index of adiposity. More accurate estimates of the percentage body fat or fat mass (%FM) in healthy subjects can be made indirectly by numerous techniques, including underwater weighing, total-body electrical conductivity, bioelectrical impedance, isotope dilution, potassium-40 counting, and dual-energy X-ray absorptiometry (DXA). However, use of skinfold-thickness measurements to estimate %FM is particularly appealing in population studies because the procedure is relatively easy to perform, the measurements are noninvasive and do not involve radiation exposure, the measurement instrument (skinfold calipers) is inexpensive and does not require electrical power to operate, and, most important of all, the measurements can be done anywhere.

Over the years, many skinfold-thickness equations have been developed for predicting %FM. However, most of these equations were developed by using adult data (4–9) and only 2 equations were developed specifically for children and adolescents (10, 11). Furthermore, most of these equations were based on data collected from white subjects. In deriving these equations, the density of the fat-free mass (FFM) was routinely assumed to be constant. However, the density of FFM changes with age (12) and differs between African American and white subjects (13).

Hence, the validity of the various skinfold-thickness equations for use in predicting %FM in a biracial population of female adolescents has not been established or evaluated. The aim of this study was to evaluate the agreement between various widely used skinfold-thickness equations and the 4-compartment criterion model in predicting %FM in a biracial group of female adolescents.

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SUBJECTS AND METHODS

Subjects

A group of 72 white and 40 African American girls (**Table 1**) aged 9–17 y was recruited from schools in the greater Houston metropolitan area. All the subjects were healthy and nondiabetic at the time of the study. Breast and pubic hair development was determined by a physician according to the Tanner stages of classification (14). The Institutional Review Board for Human Research at Baylor College of Medicine approved the protocol. All subjects and their parents gave written, informed consent.

Anthropometric measurements

On admission to the Children's Nutrition Research Center, each subject's body weight was measured to the nearest 0.1 kg with an electronic scale (Scale-Tronix, Wheaton, IL) and height was measured to the nearest 0.1 cm with a stadiometer (Holtain Ltd, Crymmych, United Kingdom). A pair of Lange skinfold calipers (Cambridge Scientific Industries, Cambridge, MD) was used to measure the biceps, triceps, subscapular, suprailiac, thigh, calf, and abdominal skinfold thicknesses in triplicate (5). A metal tape was used to measure the circumference of the buttocks. One investigator, trained in skinfold-thickness measurements, made all the anthropometric measurements.

Skinfold-thickness equations

Eight skinfold-thickness equations for the prediction of %FM were evaluated, 3 logarithmic equations, 2 quadratic equations, and 3 linear equations, respectively.

Durnin and Wormersley (4):

$$\%FM = \left(\frac{4.95}{1.1509 - 0.0715 \times \log S_1} - 4.5\right) \times 100 \qquad (1)$$

Brook (10):

$$\%FM = \left(\frac{4.95}{1.2063 - 0.0999 \times \log S_1} - 4.5\right) \times 100 \qquad (2)$$

Durnin and Rahaman (5):

$$\%FM = \left(\frac{4.95}{1.1369 - 0.0598 \times \log S_1} - 4.5\right) \times 100 \qquad (3)$$

Slaughter et al (11):

$$\%FM = 1.33 \times S - 0.013 \times S_2 - 2.5 \qquad (4)$$

Jackson et al (6):

$$\%FM = ([4.95/(1.1455 - 0.00066 \times S^2 + 0.0000015 \times S_2{}^2 - 0.00006 \times \text{age} - 0.00060 \times B)] - 4.5) \times 100 \qquad (5)$$

Sloan et al (7):

$$\%FM = ([4.95/(1.0764 - 0.00081 \times \text{suprailiac} - 0.00088 \times \text{triceps})] - 4.5) \times 100 \qquad (6)$$

Wilmore and Behnke (8):

$$\%FM = ([4.95/(1.06234 - 0.00068 \times \text{subscapular} - 0.00039 \times \text{triceps} - 0.00025 \times \text{thigh})] - 4.5) \times 100 \qquad (7)$$

Katch and McArdle (9):

$$\%FM = ([4.95/(1.08347 + 0.0006 \times \text{triceps} - 0.00151 \times \text{subscapular} - 0.00097 \times \text{thigh})] - 4.5) \times 100 \qquad (8)$$

TABLE 1
Age, physical characteristics, anthropometric measurements, and body composition of the female adolescents

	Whites (n = 72)	African Americans (n = 40)	P[1]
Age (y)	12.7 ± 1.9[2]	13.6 ± 1.7	<0.02
Weight (kg)	48.0 ± 13.1	57.2 ± 14.3	<0.01
Height (m)	1.54 ± 0.11	1.59 ± 0.07	<0.01
BMI (kg/m^2)	20.0 ± 4.0	22.4 ± 5.1	<0.01
Skinfold thickness			
Biceps (mm)	10.4 ± 5.4	10.9 ± 5.7	0.65
Triceps (mm)	17.4 ± 7.4	19.7 ± 8.5	0.14
Suprailiac (mm)	12.1 ± 7.5	14.9 ± 6.8	0.05
Subscapular (mm)	10.4 ± 5.2	12.7 ± 5.6	<0.04
Thigh (mm)	16.8 ± 6.6	18.7 ± 8.6	0.19
Calf (mm)	12.5 ± 4.9	14.6 ± 5.3	<0.04
Abdomen (mm)	12.3 ± 6.7	15.2 ± 7.2	<0.04
Buttocks circumference (cm)	84.3 ± 10.5	90.4 ± 10.9	<0.01
Body composition			
D (kg/L)	1.0377 ± 0.0162	1.0366 ± 0.0163	0.73
BMC (kg)	1.54 ± 0.44	1.95 ± 0.43	<0.01
TBW (kg)	26.1 ± 5.8	30.5 ± 5.3	<0.01
FM (kg)[3]	11.8 ± 6.6	14.8 ± 8.5	<0.05
%FM (kg)[3]	23.3 ± 7.2	24.4 ± 7.8	0.45

[1] Student's *t* test.

[2] x ± SD.

[3] Fat mass (FM) and percentage body fat (%FM) by the 4-compartment model were based on measurements of body density (D), bone mineral content (BMC), and total body water (TBW).

where age is in years, B is buttocks circumference (cm), S is the sum of the biceps and subscapular skinfold thicknesses (mm), S_1 is the sum of the biceps, triceps, subscapular, and suprailiac skinfold thicknesses (mm), and S_2 is the sum of the triceps, suprailiac, abdominal, and thigh skinfold thicknesses (mm).

Body-composition measurements

The criterion %FM was obtained by using a 4-compartment model as follows (15):

$$\%\text{FM} = \left(\frac{2.747}{D} - 0.727 \times \frac{\text{TBW}}{W} + 1.146 \times \frac{\text{BMC}}{W} - 2.0503\right) \times 100 \quad (9)$$

where D is body density (kg/L) measured by underwater weighing (16) using the force cube transducer method (17) with correction for residual lung volume by nitrogen dilution (18), TBW is total body water (kg) and is assumed to be identical to ^{18}O dilution space, BMC is bone mineral content (kg) measured by DXA (Hologic QDR-2000W, software version 5.56; Hologic, Inc, Waltham, MA), and W is body weight (kg). Although the 4-compartment criterion model was developed from BMC measurements made by single-photon absorptiometry, the use of BMC measured by DXA in this study should have had a minimal effect on the accuracy of the criterion method because single-photon absorptiometry measurements and DXA measurements are highly correlated. For the TBW measurement, a baseline plasma sample was collected by venipuncture before each subject drank 1.25 g of 10% $H_2{}^{18}O$ (Isotec Inc, Miamisburg, OH)/kg body wt. Another plasma sample was collected 3 h after the subject drank the $H_2{}^{18}O$. The plasma samples were prepared for oxygen isotope ratio measurements by gas-isotope ratio mass spectrometry (19). TBW was calculated as follows:

$$\text{TBW (kg)} = \frac{d \times A \times E_\alpha}{\alpha \times E_d \times 10^3} \quad (10)$$

where d is the dose of $H_2{}^{18}O$ (g), A is the amount of laboratory water (g) used in the dose dilution, α is the amount of $H_2{}^{18}O$ (g) added to the laboratory water in the dose dilution, E_α is the rise in ^{18}O abundance (^{o}/oo) in the laboratory water after the addition of the isotopic water, and E_d is the rise in ^{18}O abundance (^{o}/oo) in the 3-h postdose plasma sample.

Statistical analysis

The Bland-Altman pairwise comparison (20) was used to compare %FM predicted by using the skinfold-thickness equations with %FM measured by the 4-compartment criterion method. Regression analysis was used to test the relation between the differences between the 2 methods and their average %FM. If the slope was not significant, the relative bias [mean difference (MD) between methods, or the accuracy] and the 95% limits of agreement (MD ± 2 SD of the difference) were computed. If the slope relating the differences and average %FM was significant, the 95% limits of agreement were estimated as 2 SEE around the regression line. Analysis of variance was used to evaluate the effect of age and Tanner stages of sexual maturation on the differences between the 2 methods. All statistical analyses were performed by using SPSS for WINDOWS (version 7.5.1; SPSS Inc, Chicago). A P value of 0.05 was used to define significance.

RESULTS

Mean values for age, physical characteristics, anthropometric measurements, and body composition of the 112 female adolescents are given in Table 1. On the basis of the BMI classification (21), ≈22% of these adolescents were considered overweight. The African American girls were older, heavier, taller, and had higher BMIs than the white girls. The skinfold-thickness measurements at the suprailium, subscapula, calf, and abdomen were thicker and the buttocks circumference was higher in the African American girls than in the white girls. In terms of body composition, no significant group difference was observed in body density. However, BMC, TBW, and absolute FM of the African American girls were higher than those of the white girls. Body fat normalized to body weight (%FM) was not significantly different between the 2 groups. After age was controlled for, the physical characteristics, skinfold thicknesses (suprailiac, subscapular, calf, and abdominal), buttocks circumference, BMC, and TBW remained significantly higher in the African American girls than in the white girls. The difference in absolute FM between the 2 racial groups, however, disappeared after we adjusted for age ($P = 0.12$).

The comparison of %FM for each of the 8 skinfold-thickness equations with the %FM based on the 4-compartment criterion method for the 72 white girls is shown in **Figure 1**. Of the 8 skinfold-thickness equations, only the quadratic equations of Slaughter et al (11) and Jackson et al (6) yielded relative biases and limits of agreement that were not dependent on body fatness. Of these 2 equations, the equation of Slaughter et al yielded the most accurate %FM (relative bias: 0.1%) but the equation of Jackson et al yielded the most precise estimate of %FM (SEE: 4.5%). Similar results were obtained with the data for the African American girls (**Figure 2**). The relative bias and limits of agreement (Figure 2) were also not dependent on body fatness when Brook's logarithmic equation (10) was used for the African American girls. However, the relative bias and limits of agreement were larger than those obtained with use of the quadratic equations. Although not shown in these figures, similar relative biases and 95% limits of agreement were obtained when the triceps and calf skinfold-thickness measurements, rather than the biceps and subscapular skinfold-thickness measurements, were used in the equation of Slaughter et al to predict %FM in our subjects.

DISCUSSION

The results of the third National Health and Nutrition Examination Survey (3) indicated that ≈22% of American children and adolescents were overweight when the 85th percentile of the BMI was used as the criterion. According to this sex- and race-specific BMI classification (21), 22% of the 112 girls who participated in our study were overweight, in good agreement with the national norm. It is interesting to note that the %FM of these 24 adolescent girls who were classified as overweight by BMI ranged between 16% and 42%. According to the %FM criteria (22), 2 of the 24 girls would have been classified as normal weight (%FM ≤ 25%), 6 as overweight (%FM > 25%), and 16 as obese (%FM ≥ 32%). When compared with the %FM criteria, BMI would have correctly classified only 13 of the 24 adolescent girls. The results further confirm the risk of falsely mislabeling a significant number of children when BMI is used to define childhood obesity (23) and the need for a simple and inexpensive procedure, such as skinfold-thickness measurements, to predict %FM.

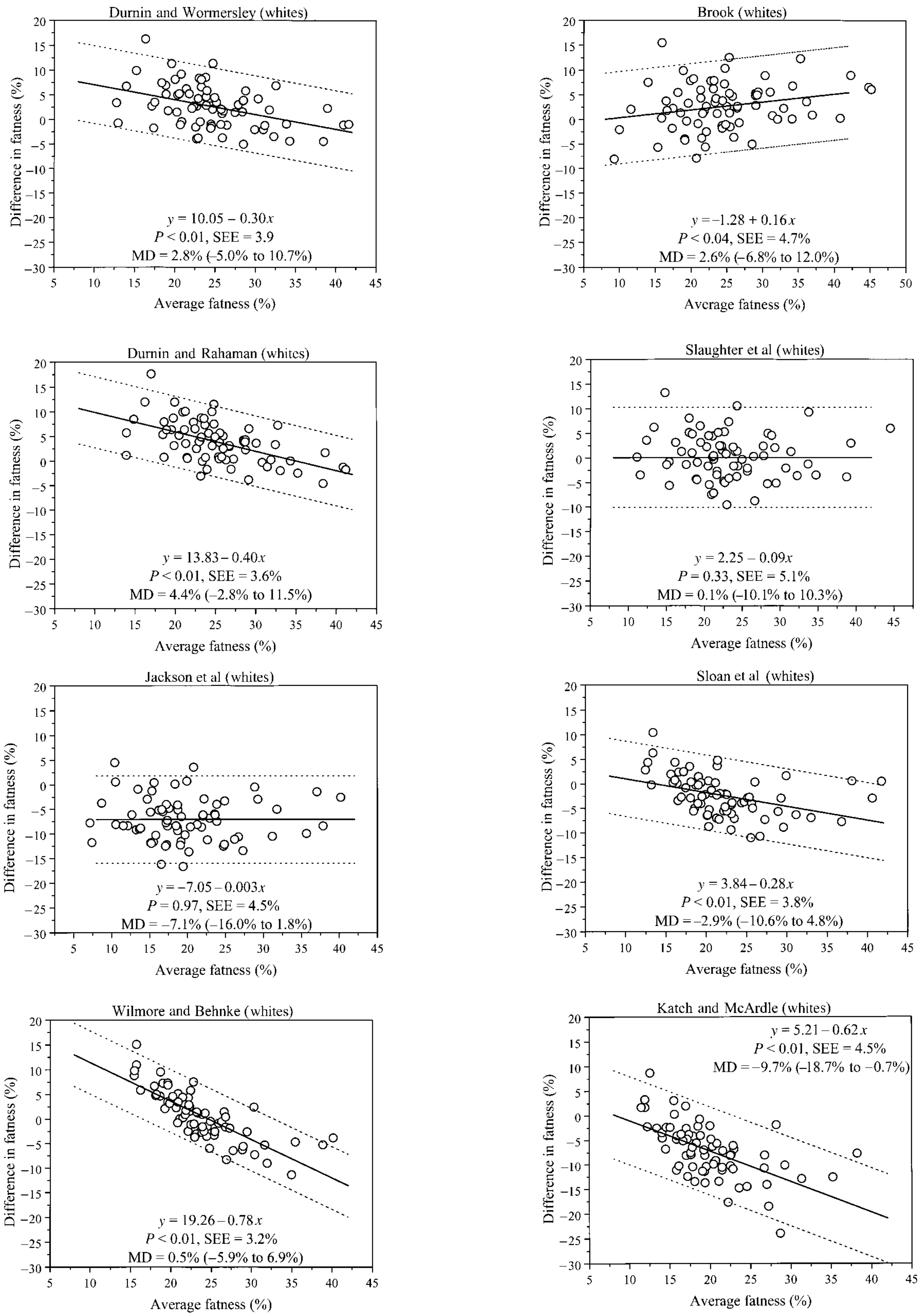

FIGURE 1. Comparison of predicted percentage fat mass between skinfold-thickness equations and the 4-compartment criterion method for the 72 white girls. The solid line represents the mean difference (MD) between methods. The dotted lines represent upper and lower limits of agreement, calculated as MD ± 2 SD of the differences when the slope is not significant or as MD ± 2 SEE around the regression line; open circles represent the individual differences. The equation in each panel represents the linear relation between the difference in fatness (y) and the average fatness (x), its significance (P), and SEE. The MD (and 95% limits of agreement) for an average body fatness of 24% are also shown.

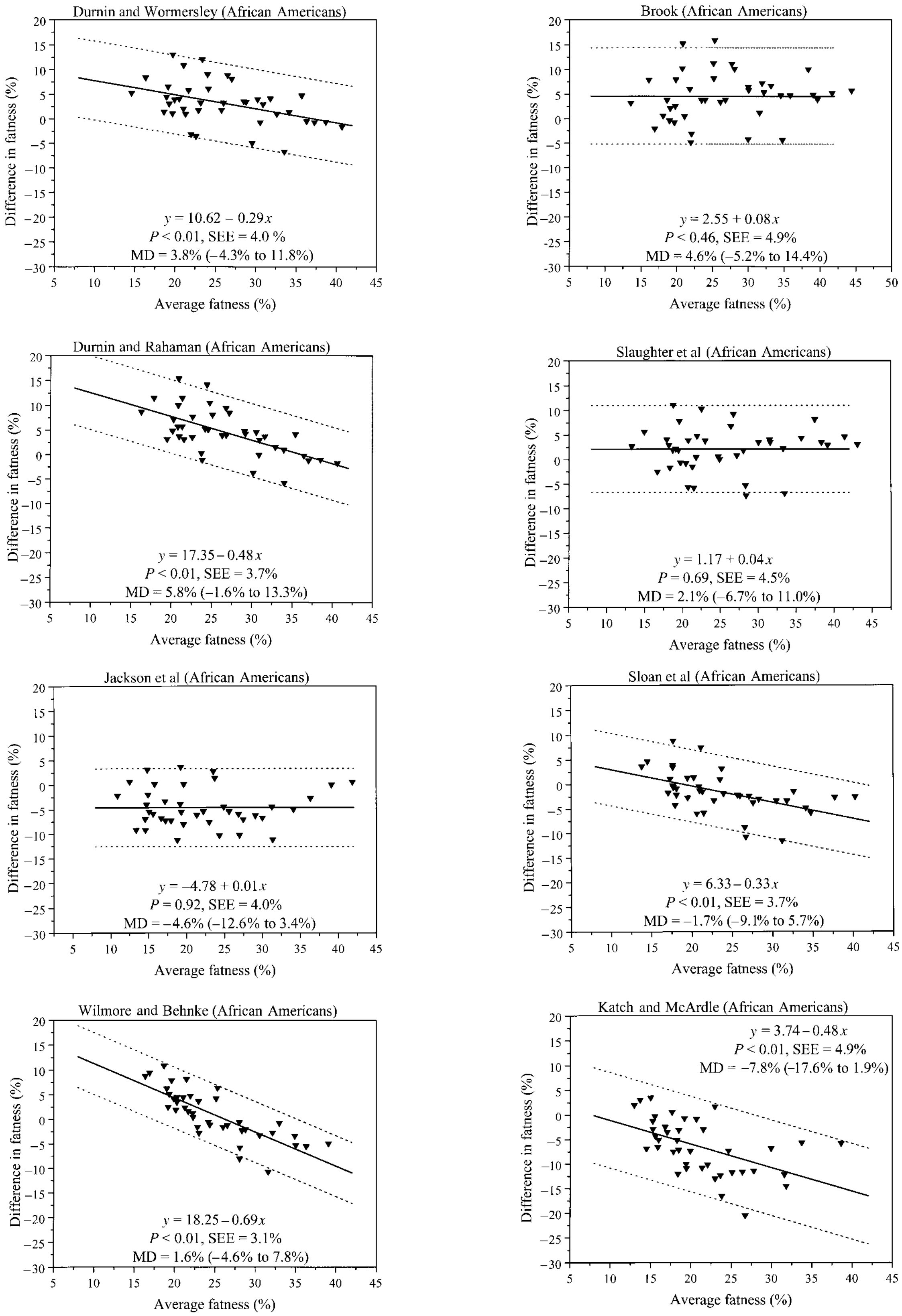

FIGURE 2. Comparison of predicted percentage fat mass between skinfold-thickness equations and the 4-compartment criterion method for the 40 African American girls. The solid line represents the mean difference (MD) between methods. The dotted lines represent upper and lower limits of agreement, calculated as MD ± 2 SD of the differences when the slope is not significant or as MD ± 2 SEE around the regression line; solid triangles represent the individual differences. The equation in each panel represents the linear relation between the difference in fatness (y) and the average fatness (x), its significance (P), and SEE. The MD (and 95% limits of agreement) for an average body fatness of 24% are also shown.

The original age- and sex-specific logarithmic equation of Durnin and Wormersley (Eq *1*) was based on skinfold-thickness and body density measurements of 209 males and 272 females aged between 16 and 72 y (4). As shown in Figures 1 and 2, further refinement of the original Durnin and Wormersley equation by inclusion of skinfold-thickness data involving 60 young men, 45 young women, 86 adolescent boys, and 38 adolescent girls (5) in the Durnin and Rahaman equation (Eq *3*) led to deterioration in the relative biases with minimal improvement in the 95% limits of agreement of the skinfold-thickness equation for predicting %FM in our biracial group of girls. Analysis of variance indicated that the difference in %FM between the criterion model and the Durnin and Wormersley model was affected by a significant interaction between race and age ($P < 0.05$). However, when the girls were segregated by race, neither age nor Tanner stages of breast or pubic hair development showed any significant effect on the difference in %FM between the criterion model and the Durnin and Wormersely model. These results suggested that age and sexual maturation might not be the only factors that would affect the accuracy and precision of the Durnin and Wormersley equation for predicting %FM.

Although Brook's logarithmic equation (Eq *2*) was developed specifically for children (10), its relative biases and 95% limits of agreement were not much better than those of the Durnin and Wormersley equation (4). The lack of improvement when Brook's pediatric equation was used to predict %FM is probably due to the inaccuracy associated with the fact that this equation was originally based on the very limited skinfold-thickness and TBW measurements of only 23 children. Although not included in the results, substitution of race-, sex-, and age-specific density values of FFM (12) in these logarithmic equations dramatically improved the relative bias [Durnin and Wormersley (MD ± SD): 2.7 ± 4.3% to –1.4 ± 4.7%; Brook: 2.7 ± 4.8% to −1.3 ± 5.4%; Durnin and Rahaman: 3.9 ± 4.3% to –0.1 ± 4.5%] in our white subjects but with deterioration in the limits of agreement.

The use of a single, adult, race-specific density for FFM (13) in our African American subjects led to deterioration in both the relative biases and the 95% limits of agreement among the logarithmic equations [Durnin and Wormersley (MD ± SD): 3.2 ± 4.4% to 4.8 ± 4.5%; Brook: 4.6 ± 4.9% to 6.2 ± 4.9%; Durnin and Rahaman: 4.6 ± 4.7% to 6.1 ± 4.9%]. With use of the %FM of our adolescent subjects measured with the 4-compartment model and assuming the density of FM to be 0.9 kg/L, the density of FFM of our white and African American subjects was calculated to be 1.0858 and 1.0876 kg/L, respectively. These values for density of FFM are substantially lower than the literature value of 1.10 kg/L (16) but similar to those reported for children and adolescents (12). These results therefore support the premise that race-, sex-, and age-specific densities of FFM are needed to improve the accuracy of skinfold-thickness equations for predicting %FM.

Among the quadratic skinfold-thickness equations (Figure 1), the equation of Slaughter et al (11) yielded the closest agreement in %FM (MD ± SD: 0.8 ± 5.0%) when compared with the 4-compartment criterion method. The equation of Slaughter et al was originally based on skinfold-thickness measurements of 310 African American and white children and youths aged between 8 and 29 y and a 4-compartment criterion method. Hence, it is reasonable to expect the equation of Slaughter et al to yield a %FM in better agreement with the %FM estimated by using the same 4-compartment method in our adolescent female subjects than the equation of Jackson et al (6).

The latter equation was originally based on the skinfold-thickness and buttocks-circumference measurements and body density of 249 white women. However, as shown in Figures 1 and 2, the equation of Jackson et al (6) yielded more precise %FM values (SEE: 4.0–4.5%) than did that of Slaughter et al. Although the equation of Jackson et al underestimated body fatness by 7.1% in the white girls and by 4.6% in the African American girls, these differences could be eliminated by adjusting the predicted %FM by these amounts because they were not dependent on body fatness. As stated in Results, the use of the triceps and calf skinfold-thickness measurements in the equation of Slaughter et al (11) yielded relative biases (whites: −0.3%; African Americans: 1.3%) and 95% limits of agreement (whites: −10.5% to 9.9%; African Americans: −7.9% to 10.5%) that were similar to those obtained by using the biceps and subscapular skinfold-thickness measurements (Figures 1 and 2). Obviously, the triceps and calf skinfold-thickness measurements are easier to obtain than are the biceps and subscapular skinfold-thickness measurements because the former measurements require minimal removal of clothing on the upper body, which is a sensitive area in adolescent girls.

As shown in Figures 1 and 2, none of the 3 linear skinfold-thickness equations—those of Sloan et al (7), Wilmore and Behnke (8), or Katch and McArdle (9)—yielded relative biases and 95% limits of agreement that were independent of body fatness. Although not shown in Results, we found that incorporation of the race-specific density of FFM (12, 13) into these linear equations did not improve the equations' relative biases or 95% limits of agreement in predicting %FM. On the contrary, introduction of race-specific densities of FFM into these linear equations appeared to exaggerate the differences in %FM predicted between these skinfold-thickness equations and the 4-compartment model [Sloan et al (MD ± SD): −2.1 ± 4.2% to –4.2 ± 5.5%; Wilmore and Behnke: 0.8 ± 5.0% to –1.2 ± 5.9%; and Katch and McArdle: −6.9 ± 5.5% to –9.1 ± 6.6%].

The fact that the density of FFM changes with maturation and differs between racial groups has been documented (12, 13). Our own calculations also indicated that the density of FFM of our adolescent subjects was lower than the assumed value of 1.10 kg/L. Furthermore, our results suggest that the density of FFM of the African American subjects in our study (1.0876 ± 0.0074 kg/L) might be higher than that of the white girls (1.0858 ± 0.0085 kg/L). One recent study showed that Asians had more subcutaneous fat and a different fat distribution than did whites (24). Therefore, it is unreasonable to expect that skinfold-thickness equations that were based on white adults would be applicable to children and adolescents of different races. Nonetheless, our results indicated that similar 95% limits of agreement were obtained when the skinfold-thickness equations were used in both white (Figure 1) and African American (Figure 2) girls. The relative bias, however, was consistently exaggerated in the African American girls when the skinfold-thickness equations of Durnin and Wormersley (4), Brook (10), Durnin and Rahaman (5), Slaughter et al (11), and Wilmore and Behnke (8) were used. Note that part of the error associated with using skinfold-thickness equations to predict %FM is attributable to errors associated with the measurements of body density, body water, and BMC in the 4-compartment criterion model.

The Bland-Altman pairwise comparison indicated that the quadratic equation of Jackson et al was the optimal equation to use to predict %FM in female adolescents on the basis of its superior precision (SEE: 4.0–4.5%). However, the quadratic equation of

Slaughter et al appeared to be a good alternative because of its accuracy, despite its slightly poorer precision (SEE: 4.5–5.1%). Furthermore, the equation of Slaughter et al, which uses the triceps and calf skinfold-thickness measurements, may be more practical to use because it relies on 2 skinfold-thickness measurements that are much easier to obtain from adolescent girls than are the biceps and subscapular skinfold-thickness measurements of the equation of Jackson et al, which uses 4 skinfold-thickness measurements and 1 buttocks circumference measurement.

According to the criteria of Lohman (25), the quadratic equation of Jackson et al, with an SEE that ranges between 4.0% and 4.5%, could be rated only from fairly good to fair, whereas that of Slaughter et al, with an SEE that ranges between 4.5% and 5.0%, could be rated only from fair to not recommended. However, the criteria of Lohman were based on a 76.5-kg man and a 60.0-kg woman with fat contents of 15% and 25%, respectively. As shown by the same author (26), a higher SEE is anticipated when greater variability is observed in the criterion measurement. Because the %FM obtained by using the 4-compartment model ranged between 8% and 42% in the 112 adolescent girls, it is reasonable to expect the SEE to be much higher when the skinfold-thickness equations were used to predict %FM in the biracial group of adolescent girls. Therefore, the SEE criteria proposed by Lohman (25) would not be applicable in our evaluation. Furthermore, the use of SEE alone as the criterion is not recommended because it would not be able to detect any significant relation between the differences and the average %FM as we showed using the Bland-Altman pairwise comparison method (20).

Our analyses indicated that further refinement of the quadratic equation of Slaughter et al is needed to improve the accuracy of predicting %FM in minority populations. Because fat patterning is affected by age, racial background, and physical activity status, inclusion of skinfold-thickness measurements and 4-compartment %FM data from large numbers of subjects at different stages of sexual maturation, representing different racial backgrounds, and with different physical activity statuses will help to fine-tune the equation. It is also possible that age-, sex-, race-, and fitness-specific equations will be needed to improve the accuracy and precision of the skinfold-thickness equations for predicting %FM. More importantly, the relatively high variability (10%) of %FM predicted by using skinfold-thickness equations must be taken into account in the evaluation of obesity or of the influence of any dietary, genetic, or environmental factors on obesity.

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