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## Assessing the Body Composition of 6–17-Year-Old Black and White Girls in Field Studies

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**ABSTRACT** The purpose of the study was to develop ethnic-specific equations for fat-free mass (FFM) from selected anthropometric dimensions and bioelectrical impedance measures of resistance ( $R$ ) and reactance ( $X_c$ ) for use in the NHLBI Growth and Health Study. Using dual-energy X-ray absorptiometry measures of body composition as the dependent variable and field measures of body composition by anthropometry and bioelectrical impedance as the explanatory variables, ethnic-specific prediction equations were developed on a sample of girls representing a wide range of ages and BMI. The equations were cross-validated using (1) the Prediction of Sum of Squares (PRESS) statistic and (2) an independent sample of 20 girls of each race from a study conducted at the National Institute of Child Health and Human Development (NICHD). Subjects were 65 White and 61 Black girls 6–17 years of age. The best race-specific equations for FFM each explained 99% and 97% of the variance in the White and Black girls, respectively. Root mean square errors (RMSE) ranged from 1.14 to 1.95 kg. The equation for Black girls used Stature<sup>2</sup>/Resistance ( $R$ ), weight, and reactance ( $X_c$ ) as predictor variables; the equation for White girls used Stature<sup>2</sup>/ $R$ , weight, and triceps skinfold thickness. The results indicate that (1) equations to predict FFM in girls should be ethnic-specific and that (2) accurate values for TBF and %BF can be calculated from the predicted FFM. *Am. J. Hum. Biol.* 13:249–254, 2001. © 2001 Wiley-Liss, Inc.

Laboratory measurements of total body composition require expensive equipment and procedures that must be used in a fixed location, making them impractical for large-scale epidemiological studies. The development of equations that predict body composition values from easily and accurately measured variables provides an alternative method that is practical in such studies. Although the computed values are less precise than laboratory measures, the ability to estimate body composition in large epidemiological samples may justify the lesser precision.

The National Heart, Lung, and Blood Institute's National Growth and Health Study (NGHS) is a 10-year cohort study of changes in weight, body mass, and adiposity during adolescence and its effects on major cardiovascular disease risk factors in Black and White girls (NHLBI Growth and Health Study Research Group, 1992). Clinical centers at three sites (University of California, Berkeley; Children's Hospital Medical Center, Cincinnati, OH (CHMC); and Westat,

Inc enrolled 2,379 girls. The CHMC clinic conducted an ancillary project (Guo et al., 1993) of the NGHS to develop prediction equations for body composition from the field measures used in NGHS, using measures of fat-free mass (FFM) from dual energy x-ray absorptiometry (DXA) as the laboratory standard. The ancillary study comprised a representative sample of Black and White girls, subsequently referred to as the CHMC validation sample. The field measures used in NGHS were made following the same protocol. In addition, the children in the CHMC validation sample had DXA measures of FFM, total body fat (TBF),

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and percent body fat (%BF) by the Hologic QDR 1000/W. This paper presents the prediction equations for estimates of body composition in the NGHS population using bioelectrical impedance and anthropometry. The equations were cross-validated using an independent sample. The final equations are applicable for use by other investigators studying body composition in young girls.

## MATERIALS AND METHODS

### *Validation and cross-validation samples*

The CHMC study sample consisted of 126 girls, 6 to 17 years of age, including 65 White girls and 61 Black girls, enrolled to encompass a wide distribution of body mass indices. Participants were recruited from ongoing CHMC study populations and from the children of CHMC staff. The protocol for the CHMC validation study was approved by the Institutional Review Board of the Children's Hospital Medical Center, Cincinnati, Ohio. An independent cross-validation sample of 20 White girls and 20 Black girls was provided from a separate study conducted at the National Institute of Child Health and Human Development (NICHD) by Yanovski et al. (1996). Signed informed consent was obtained on all participants in both samples.

### *Clinical procedures*

The CHMC validation study made the same field measures, using the same instruments, and the same certified staff as NGHS (NHLBI Growth and Health Study Research Group, 1992). Anthropometric dimensions included stature; the weight, triceps, subscapular, and suprailiac skinfolds, and upper arm, waist, upper thigh and maximum below the waist circumferences. Measurements were made with the girls clothed in t-shirts, socks, and underpants. The measures were made in order so that all variables were measured once before a second measure was taken. Stature was measured with a portable stadiometer. Weight was measured to the nearest 0.1 kilogram (kg) using electronic Health-o-meter Scales (Creative Health Products, Plymouth, MI). Skinfold thicknesses were measured to the nearest 1.0 mm using Holtain calipers (Pfister Imports, NJ). Circumferences were measured to the nearest 0.5 cm. Two measurements were taken of each variable, with a third measurement taken if the first two differed by more than 0.5 cm (stature and cir-

cumferences), 0.3 kg (weight), or 1.0 mm (skinfolds). Bioelectrical impedance was measured using a BIA 101 body composition analyzer (RJL Systems, Detroit, MI). Resistance ( $R$ ) and reactance ( $X_c$ ) were measured to the nearest ohm on the right side of the body using a tetrapolar placement of electrodes (Lukaski, 1987). Stature ( $S$ ) and weight ( $W$ ) were used to calculate the body mass index ( $BMI = kg/m^2$ ). Measures of resistance ( $R$ ) and stature ( $S$ ) were used to calculate the ratio  $S^2/R$ . Age was used as a potential predictor in the models as social age. A similar protocol was used for collecting the anthropometric, bioelectric impedance and body composition data in the NICHD cross-validation sample.

In the CHMC validation sample total body composition was measured using a Hologic QDR-1000/W total body scanner. The Hologic QDR-2000 was used for the girls in the NICHD cross-validation sample. Total DXA tissue mass (body weight) is the sum of DXA soft tissue plus bone mineral content. %BF was calculated as DXA whole-body fat tissue divided by total DXA tissue mass times 100. The precision of DXA analysis of body composition, as determined by the coefficient of variation, ranged from 0.5% to 1.0% (Guo and Chumlea, 1996).

### *Statistical analysis*

Means and standard deviations were calculated for age, the anthropometric variables, DXA measures of %BF and FFM,  $S^2/R$ , and reactance for each ethnic group. Ethnic differences were evaluated using the  $t$ -test. The statistical methods for developing prediction equations for body composition values have been described elsewhere (Guo and Chumlea, 1996). Briefly, an all-possible subsets of regression analysis (APSR) was used to develop the set of possible prediction equations. The response variable in the prediction equation was FFM. Potential predictor variables included age,  $S^2/R$  ( $cm^2/ohms$ ),  $X_c$ ,  $W$ , BMI, skinfold thickness measures at suprailiac, subscapular, and triceps sites and circumferences at arm and abdomen. The Cp statistic, which is a measure for the appropriate number of independent variables for a statistical model, was used to select number of predictor variables to be included in the final equations (Mallows, 1973). These equations were examined further for the significance of the regression coefficients ( $P < 0.05$ ) us-

ing multiple regression analysis. The predicted values for FFM were then used to calculate values for total body fat and %BF for each individual.

#### Cross-validation

The accuracy of the prediction equations developed in the CHMC validation sample was evaluated by cross-validation. First, the selected prediction equations were cross-validated using the Prediction of Sum of Squares (PRESS) procedure (Guo and Chumlea, 1996; Myers, 1986). In addition, the agreement between the measure of FFM by DXA and the estimate of FFM from the prediction equation was evaluated using the method of Bland and Altman (1986). Finally, the independent sample of girls in the NICHD longitudinal study was used to cross-validate the corresponding CHMC prediction equations. The pure error was used to evaluate the cross-validation results from the independent sample. The pure error is defined as follows:

$$\text{Pure Error} = \sqrt{\frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{n}}$$

The values for TBF and %BF were calculated using predicted FFM values from the equation for each individual as  $\text{TBF} = \text{weight} - \text{FFM}$  and  $\text{\%BF} = \text{TBF}/\text{weight} \times 100$ . The accuracy of the estimated TBF and %BF compared to DXA results was evaluated using pure errors. SAS version 6.12 was used for the statistical analyses (SAS Institute Inc., 1989).

## RESULTS

Means and standard deviations are presented for the anthropometry, body composition, and impedance variables in Table 1 for the girls in the CHMC validation sample. Mean ages of the Black and White girls did not differ significantly, but Black girls had significantly greater mean values for arm circumference, triceps skinfold thickness, BMI, and DXA%BF than corresponding mean values for the White girls. There were no statistically significant racial differences in mean values for  $S$ ,  $S^2/R$ ,  $X_c$ , and DXAFFM.

The NICHD cross-validation sample of girls was younger than the CHMC validation sample and had smaller means for  $S$ ,

TABLE 1. Univariate statistics for the anthropometric, body composition, and impedance variables in the CHMC validation sample by ethnicity

Variables	Black (N = 61)		White (N = 65)	
	Mean	SD	Mean	SD
Age, year	11.2	2.7	11.2	2.4
Stature, cm	147.4	14.9	146.2	13.7
Weight, kg	49.0	21.1	43.2	16.4
Arm circ, cm	25.5	6.2	24.1	4.5
Abdominal circ, cm	84.4	16.3	81.0	13.0
Suprailiac, mm	14.7	11.0	14.2	9.0
Subscapular, mm	16.6	11.5	14.9	9.9
Triceps, mm	17.3	9.4	16.0	6.9
BMI, kg/m <sup>2</sup>	21.7 <sup>a</sup>	6.4	19.6	4.5
$S^2/R$ , cm <sup>2</sup> /ohm <sup>b</sup>	34.7	10.2	33.6	9.8
Reactance, ohm	68.2	9.0	68.0	7.8

<sup>a</sup>Ethnic difference by *t*-test,  $0.01 < P < 0.05$ .

<sup>b</sup> $S^2/R$  = stature squared divided by resistance.

$W$ , arm circumference, TBF, %BF, FFM,  $S^2/R$ , and  $X_c$ . The girls in the NICHD cross-validation sample also had smaller mean values for abdominal circumference, and the triceps, suprailiac, and subscapular skinfolds than did the girls in the CHMC validation sample (Table 2).

#### Development of prediction equations

The prediction equations for FFM are summarized in Table 3. The "best" equations were selected based upon the smallest value for Cp. The predictor variables for FFM differed between Black and White girls. For Black girls, the best equation had three predictor variables, weight,  $S^2/R$ , and reactance. The equation explained 99% of the variance in FFM and had a RMSE of 1.95 kg. The corresponding FFM equations for White girls included weight,  $S^2/R$ , and triceps skinfold thickness. This equation explained 99% of the variance and had a RMSE of 1.14 kg. When comparing the goodness of fit between the equations for the Black and White girls, the coefficient of variations (CV) indicated a slightly better fit for the White girls than for the Black girls (Table 3). Bland-Altman plots (not shown) indicated good agreement between the two methods (DXA and the prediction equations) for girls of each race. Although the above prediction equation for White girls was the best equation, a second equation ( $\text{FFM} = -6.41 + 0.56 \text{Ht}^2/R + 0.34 \text{Wt} + 0.06 X_c$ ) used the same variables as did the equation for FFM in Black girls and did not require measurement of skinfolds. This

TABLE 2. Univariate statistics for the anthropometric, body composition, and impedance variables for girls in the NICHD cross-validation sample by ethnicity

Variables	Black (N = 20)		White (N = 20)	
	Mean	SD	Mean	SD
Age, year	9.2	0.5	9.3	0.6
Stature, cm	134.1	4.2	137.2	6.8
Weight, kg	31.4	4.4	32.2	4.9
Arm circ, cm	21.3	2.1	20.6	2.2
Abdominal circ, cm	59.2	4.5	57.7	4.1
Suprailliac, mm	11.7	5.0	10.6	5.8
Subscapular, mm	9.2	4.6	7.7	2.4
Triceps, mm	12.3	4.0	11.4	4.2
BMI, kg/m <sup>2</sup>	17.4	1.9	17.0	1.4
%BF, %	24.5	6.5	21.3	5.9
FFM, kg	23.0	1.9	24.5	3.1
TBF, kg	8.0	3.3	7.1	2.8
S <sup>2</sup> /R, cm <sup>2</sup> /ohm	25.7	2.8	26.5	3.2
Reactance, ohm	75.0	8.9	74.1	7.9

equation explained slightly less (0.001) of the variance.

#### Cross-validation

Cross-validation of the prediction equations for FFM for the girls using data from the participants in the NICHD sample yielded pure errors of 1.2 kg for Black girls and 1.5 kg for White girls (Table 4). These pure errors correspond to CVs of 5% and 6%. Estimates of TBF and %BF were derived and the corresponding pure errors are presented in Table 5. The pure errors for TBF and %BF were smaller for Whites than Blacks in the validation sample. In the cross-validation sample, however, the pure errors were slightly smaller for Black girls than for White girls.

#### DISCUSSION

A number of studies have presented equations that predict body composition from impedance and selected anthropometric measurements in children (Deurenberg et al., 1989, 1990; Guo et al., 1989; Conlisk et al., 1992; Houtkooper et al., 1992). Most such studies used body composition measures estimated from underwater weighing as the response variables. The present study used DXA measures of body composition as the response variable. Brunton et al. (1993) and Rose et al. (1998) compared estimates of lean body mass by DXA (Hologic QDR 1000/W) to chemical analysis in piglets and the Zucker rat, respectively. Brunton et al. (1993) reported good agreement between the methods in piglets >6 kg. The difference was statistically significant, but only 1.3%. Rose et

al. (1998) reported there was no significant difference between DXA estimates of lean body mass and chemical analysis. In both studies, analyses by the method of Bland and Altman indicated good agreement. Thus, DXA is accurate. Moreover, it does not require high levels of compliance by the subject as does underwater weighing (Morrison et al., 1994; Gutin et al., 1996), making it an appropriate technique to produce reliable body composition measures for children (Mazess et al., 1990; Lohman et al., 1992; Gutin et al., 1996). A reliability study conducted at Fels, in which repeated measurements were taken at 1 hr apart for participants 18–30 years of age, indicated that the technical errors for DXA was 0.9 kg for FFM and 1% for %BF (Guo and Chumlea, 1996). Kalkwarf and colleagues (personal communication) compared the Hologic 1000 and 2000 DXA machines, using 54 females, aged 3–83 years. The mean lean body mass by the two methods was 35.4 kg and the mean difference between machines (Hologic 1000-2000) was 0.358 kg, or approximately 1%. Both machines used the regular total body software, as was used in this study.

The sample in the present study, 61 Black girls and 65 White girls, is relatively small, but within the range of subjects used in previous studies (Deurenberg et al., 1989; Conlisk et al., 1992; Houtkooper et al., 1992; Ellis, 1996; Goran et al., 1996; Yanovski et al., 1996; Okasora et al., 1999). The accuracy of the equations should be preserved when applied to the NGHS for several reasons. The sample size required in order to develop prediction equations depends on several factors, including the number of predictor variables relative to sample size and the relationships between the predictor variables and the response variable. The number of predictor variables in these equations for each ethnic group was three, giving over 20 observations for each predictor. Thus, the models were not overparametrized. The most significant single predictor of FFM based upon the partial *F* values was *S*<sup>2</sup>/*R*. A close association between *S*<sup>2</sup>/*R* and FFM is to be expected because impedance is affected by the amount of body water in the FFM (Deurenberg et al., 1989; Houtkooper et al., 1992). Weight is correlated with FFM so that the inclusion of weight with positive regression coefficients is also to be expected. These predictor variables, *S*<sup>2</sup>/*R* and weight, are biologically pro-



TABLE 3. Best prediction equations for FFM from DXA for Black and White girls, by ethnicity

Black Girls (n = 61)				
R <sup>2</sup>	RMSE	Mean	CV	
0.99	1.95 kg	34.16 kg	4.7%	
Variable	Parameter estimates			VIF <sup>a</sup>
Intercept		-8.78	3.13	
S <sup>2</sup> /R (cm <sup>2</sup> /ohm)		0.78	0.06	5.03
Reactance (ohm)		0.10	0.03	1.50
Weight (kg)		0.18	0.02	4.17
White Girls (n = 65)				
R <sup>2</sup>	RMSE	Mean	CV	
0.99	1.14 kg	31.46 kg	3.6%	
Variable	Parameter estimates			VIF
Intercept		1.07	0.62	
S <sup>2</sup> /R (cm <sup>2</sup> /ohm)		0.37	0.04	9.6
Triceps skfld (mm)		-0.17	0.04	3.6
Weight (kg)		0.47	0.03	15.4

<sup>a</sup>VIF (variance inflation factor) indicates the increase in the error sum of squares due to the inclusion of this variable.

TABLE 4. Cross-validation for the developed prediction equations for FFM for Black and White girls

	Black girls (n = 20)	White girls (n = 20)
Mean FFM (kg)	24.5	23.0
Pure error (kg)	1.2	1.5
CV (%)	5	6

portional to the response variables, total body water, and FFM. Such strong relationships between the predictor and response variables ease concerns regarding the use of relatively small samples. Reactance is an impedance measure and is the resistance to the tissue membrane. Triceps skinfold thickness is a measure of subcutaneous fat. In White girls, the triceps skinfold is negatively related to FFM, indicating that the larger the triceps skinfold the less FFM and the more fat the participant has. Finally, the subjects used to develop these equations encompassed a wide range of body weights and ages (with age not entering the equations) similar to those seen in the NGHS cohort to which these equations are to be applied. The predictor variables in the selected equations (S<sup>2</sup>/R and weight, plus reactance in Black girls and the triceps skinfold thickness in White girls) can be obtained at low cost with high reliability. The measures are acceptable to children and do not require them to change clothes or to disrobe (Guo and Chumlea, 1996).

The regression estimates for the predictor variables in the prediction equations were different between Black and White girls, which indicates the need for ethnic-specific

prediction equations to predict body composition in NGHS participants. The present equations for Whites girls had a smaller RMSE than did those for the Black girls.

The developed equations can be used to calculate TBF and %BF for each individual. Using the predicted FFM from these equations, TBF and %BF were estimated with pure errors of 0.9 kg and 2.8% for Black girls and of 1.3 kg and 3.7% for White girls. The values for TBF and %BF were calculated from the predicted FFM and body weight for each individual in the validation sample and cross-validation sample. These estimated TBF and %BF values were compared with the observed values from DXA, and the average of the squares of the discrepancy was calculated. In general, the equations yielded small pure errors ranging from 0.9 to 1.9 kg for TBF and from 2.5% to 3.7% for %BF. Despite the reasonable performance of these equations, they appear to be related to body fatness, suggesting that total body water predicts FFM differently in obese and non-obese girls.

The results thus indicate that (1) equations to predict FFM in Black and White girls should be ethnic-specific and that (2) %BF can be calculated in the NGHS cohort from the predicted FFM with good accuracy. Although these equations are intended for use with NGHS, the good agreement between predicted and measured %BF in the cross-validation sample indicates that the equations could be used in other samples of Black and White girls in the age range covered here.

TABLE 5. Pure errors for estimating percentage body fat using FFM from prediction equations for Black and White girls

	Validation sample (PRESS)				Cross-validation sample			
	%BF pure errors	CV (%)	TBF (kg) pure errors	CV (%)	%BF pure errors	CV (%)	TBF (kg) pure errors	CV (%)
Black Girls	3.4	13	1.9	13	2.8	13	0.9	13
White Girls	2.5	10	1.1	10	3.7	15	1.3	16

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