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Predicting body composition from anthropometry in pre-adolescent children

CV Dezenberg[1], TR Nagy[1], BA Gower[1], R Johnson[2] and MI Goran*[1]

[1]*Division of Physiology and Metabolism, Department of Nutrition Sciences, School of Health Related Professions and Obesity Research Center, University of Alabama at Birmingham, Birmingham, AL and* [2]*Department of Nutritional Sciences, University of Vermont, Burlington, VT, USA*

The objectives of this paper were to: a) evaluate the accuracy and precision of previously published pediatric body composition prediction equations and b) develop additional prediction equations from a large, heterogeneous group of Caucasian ($n = 133$) and African-American ($n = 69$) children. The combined cohort of 202 children included a wide range of ages (4.0 – 10.9 y), weights (14.0 – 70.8 kg), fat mass (FM: 1.2 – 28.5 kg) and percent body fat (% body fat: 6.2 – 49.6%). Skinfold measurements were obtained using a Lange caliper and body fat was measured with a Lunar DPX-L densitometer. The previously published equations of Slaughter *et al* and Goran *et al* did not accurately predict body fat. The entire cohort was randomly divided into two sub-groups for purposes of deriving and cross-validating a new prediction equation. In stepwise regression analysis in the development group ($n = 135$), weight, triceps skinfold, gender, ethnicity and abdominal skinfold estimated FM measured by dual energy x-ray absorptiometry (DEXA) with a model R^2 of 0.95. The new prediction equation was cross-validated in the control group ($n = 67$) and each ethnic and gender subgroup. We conclude that a) the equations of Slaughter *et al* and Goran *et al* did not accurately predict FM in a heterogeneous group of children and b) a new anthropometric prediction equation is proposed that may provide accurate estimates of FM in both Caucasian and African-American children aged 4 – 10 y with a wide range of FM and body composition.

Keywords: anthropometry; skinfold thickness; body composition; adipose tissue; child

Introduction

The assessment of body composition in childhood can be performed with several sophisticated techniques,[1–5] but in many circumstances it is more desirable to utilize widely available and simple techniques such as anthropometry. This would allow quick determination of body composition without the need for specialized laboratories, radiation exposure or expensive equipment. There have been several attempts to relate skinfold thicknesses to body fat,[3–7] but there are inherent difficulties relating these across a wide range of ages, ethnic groups and degree of obesity, in children. This is partly related to differences in hydration and fat-free mass (FFM) density due to differences in age and maturation.[8,9]

One of the major limitations of comparing body composition techniques is the lack of a gold standard. In children, the closest to a gold standard body composition technique would probably be the 4-compartment model or dual energy X-ray absorptiometry (DEXA). Using body density, body water and bone mineral measurements to estimate body composition in 66 prepubescent children, from a 4-compartment model, Slaughter *et al*[10] derived body fat prediction equations from anthropometry based on ethnicity, gender and maturation. In young children, the 4-compartment model may be impractical because of the difficulty in performing hydrostatic weighing in younger subjects (although more recent technology using air rather than water displacement may solve this problem) and therefore DEXA has been proposed as an accurate comparison technique.[11] The use of DEXA in young children is supported by previous studies which have cross-validated the technique against carcass analysis in a pig model.[11] In a previous study, we were unable to cross-validate the Slaughter *et al* equations against DEXA measurements in young children and therefore derived some alternative prediction equations for Caucasian children with a fat mass (FM) of 20 kg or less.[5] These equations have not been cross-validated or tested in other subgroups of the population. It is the intent of this paper to evaluate the precision and accuracy of the equations of Slaughter *et al*[10] and Goran *et al*[5] in predicting FM in children of different ethnic groups and genders, across a wide range of body fat and to determine the accuracy of anthropometry in general for predicting FM in children.

*Correspondence: Dr Michael I Goran, Division of Physiology and Metabolism, Department of Nutrition Sciences, University of Alabama, Birmingham, AL 35294, USA.
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Methods

Subjects

Through newspaper and radio advertisements and word of mouth, 104 children aged 4–10 y were recruited from the Birmingham, Alabama area. The sample included 69 African-American children studied during the fall and winter of 1995/1996 and 35 Caucasian children studied throughout the winter and spring of 1996. Children were excluded if they were aged <4 y or >10 y, taking medications known or suspected to affect body composition (for example, methylphenidate, growth hormone, prednisone) or diagnosed with any major illness since birth. The study was approved by the Institutional Review Board at The University of Alabama at Birmingham, AL, USA.

Additional subjects included 73 children (69 Caucasian and four of Native American descent) with a total of 98 observations from the Vermont cohort originally used to derive the prediction equations of Goran *et al*.[5] These additional subjects were studied using similar equipment and techniques to the Alabama cohort. They were added to the study population to insure that the prediction equations derived were valid across a large range of FM.

Measurements

Existing prediction equations 1. Slaughter et al. Slaughter *et al* derived prediction equations for percent body fat (% body fat) based on body density from underwater weighing, body water from deuterium oxide dilution and bone mineral from photon absorptiometry in 310 subjects aged 8–29 y.[10] This group included 66 prepubescent children (Tanner stages 1 and 2; 50 boys and 16 girls). The equations utilizing tricep and subscapular measurements in prepubescent children predicted percent body fat with a model $R^2 = 0.80$. The equations are as follows (Note: Slaughter equations predict % body fat):

$$1.21*(\text{triceps} + \text{subscapular}) - 0.008*(\text{triceps} + \text{subscapular})2 - 1.7 \text{ for white males;}$$

$$1.21*(\text{triceps} + \text{subscapular}) - 0.008*(\text{triceps} + \text{subscapular})2 - 3.2 \text{ for black males}$$

and

$$1.33*(\text{triceps} + \text{subscapular}) - 0.013*(\text{triceps} + \text{subscapular})2 - 2.5 \text{ for all females}$$

If the sum of the triceps and subscapular measurements are >35, however, the following equations are suggested:

$$0.783*(\text{triceps} + \text{subscapular}) + 1.6 \text{ for; all males}$$

and

$$0.546*(\text{triceps} + \text{subscapular}) + 9.7 \text{ for all females.}$$

Existing prediction equations 2. Goran et al. With DEXA measures as a criteria, Goran *et al*[5] derived an equation with a model $R^2 = 0.88$ to predict FM in children (4–10 y) using weight and two skinfold measurements. The prediction equation (FM = 0.23*subscapular + 0.18*weight + 0.13*tricep − 3.0 kg) was derived from 98 observations in 73 prepubescent children. Because repeat measures were performed in 25 of the children after a period of one year and significant changes were observed (by paired *t*-test) in body weight (3.2 kg), FM (2.1 kg), height (0.085 m) and skinfold thicknesses (for example, tricep 4.5 mm), these measurements were included in the analysis as independent observations. All of the children were Caucasian except for four girls who were of Native American descent.

Anthropometric and body composition measurements

In the Alabama cohort, anthropometric measurements were obtained for each child upon entry into the study, using the same equipment at the same location with a single trained examiner. Subjects were wearing a hospital gown and no shoes at the time of testing. Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer, weight was measured to the nearest 0.1 kg using an electronic scale (Toledo Scale, Worthington, OH) and the body mass index (BMI) was calculated from these. Hip and waist circumferences were measured to the nearest 0.1 cm. Using a Lange skinfold caliper (Cambridge Scientific Industries, Inc., Cambridge, MD) and the procedures of Lohman *et al*,[12] the following skinfold thickness measurements were taken: chest, abdomen, subscapular, suprailiac, tricep, calf and thigh. These were measured to the nearest mm, with the average of three measurements at each site being used for analysis. Similar equipment and techniques were used for the cohort studied in Vermont.

In both cohorts, body composition was measured by DEXA using a Lunar DPX-L densitometer (Madison, WI) in the pediatric medium mode (software versions 1.5d and 1.5e, which utilize the same mathematical calculations). Subjects were scanned in light clothing while lying supine and maintaining a steady position with their arms at their sides. Fat mass, as determined by DEXA, was adjusted by the previously established regression equation (actual FM = (DEXA FM × 0.87) + 0.19 kg) to standardize the measurements on the Lunar DPX-L to chemical pig carcass analysis in the pediatric weight range.[11] Henceforth, FM refers to this adjusted DEXA FM measurement.

Statistics

Physical characteristics of the two cohorts were compared for the effects of laboratory, ethnicity and gender through ANOVA. Fat mass measured by DEXA was compared to predicted FM, as determined by the previously published anthropometric equations of Slaughter *et al*[10] and Goran *et al*,[5] using regression analysis (measured *vs* predicted) and paired comparison *t*-tests. We used FM as the main dependent variable, rather than % body fat, because FM is the simple univariate variable that is actually measured, whereas % body fat is derived from dividing fat mass by body weight (this derivation introduces unnecessary complexity into the model prediction process). The prediction equations were considered to cross-validate if the regression between the measured and predicted FM was not statistically different from the line of identity (that is, slope = 1, intercept = 0), and the paired *t*-test was not significant (FM mean difference not significantly different from 0).

The cohorts were combined in order to increase the population size, increase ethnic diversity and span a wide range of FM and body composition. Two-thirds of this new group were randomly assigned to a development group from which the new equation was derived. The remaining one-third of the group was used for cross-validation. Stepwise regression analysis was used to derive the predictors of FM in the development group ($n = 135$). The independent variables considered in the model were laboratory, gender, ethnicity, age, height, weight, BMI, hip circumference, waist circumference and seven skinfolds (tricep, subscapular, suprailiac, chest, abdomen, calf and thigh). The regression equation was then tested for accuracy in the control group ($n = 67$) by examining the regression between the measured and predicted FM and by paired comparison *t*-test as described above. In addition, a plot of measured-predicted *vs* measured FM was conducted to examine possible bias in the prediction equation.

All statistics were computed using SAS for Windows version 6.10 (Carey, NC). The level of statistical significance was set at a probability of $P = 0.05$ for all tests. Data are cited as mean ± standard error unless otherwise stated.

Results

The descriptive characteristics of the two cohorts with regard to age, weight and FM are shown in Table 1. The Vermont children were younger (6.6 ± 1.4 y) than the children studied in Alabama (7.7 ± 1.6 y) and this was reflected in the lower body weight (24.1 ± 5.9 kg) compared to the Alabama children (33.0 ± 12.1 kg). There was also a greater degree of obesity in the Alabama cohort (28% mean body fat) than the Vermont cohort (20% mean body fat). Thus, there is diversity in age, size and body composition among the two cohorts.

Cross-validation testing of existing FM prediction equations is shown in Table 2. The Slaughter *et al* equations did not accurately predict FM in boys or girls of the Alabama cohort, so both cohorts were combined in order to increase the sample size and to provide for a larger range of FM and body composition (that is, % body fat). With this combined cohort, the Slaughter *et al* equations were still unable to be cross-validated, as there were significant differences in the slopes and intercepts of the regression equations of measured FM *vs* predicted FM (Table 2). The equation of Goran *et al* was also not cross-validated, even after limiting the Alabama cohort to children with characteristics similar to the Vermont cohort from which the equation was developed (that is, Caucasian children with 20 kg FM).

In the entire cohort, FM was highly correlated with all anthropometric measures including body weight ($\boldsymbol{r} = 0.94$), BMI ($\boldsymbol{r} = 0.90$), triceps skinfold ($\boldsymbol{r} = 0.88$), waist circumference ($\boldsymbol{r} = 0.88$) and all other skinfold measures ($\boldsymbol{r} = 0.71 - 0.88$). These correlations were similar across gender and ethnic groups. The relationship between FM and body weight (the single best predictor of FM) is shown in Figure 1.

Combining the two cohorts provided a large population ($n = 202$) with a wider range of sizes and body compositions than would be possible from either cohort independently. This combined cohort was randomly distributed between a development group ($n = 135$) from which the new equation was derived, and a control group ($n = 67$) that was used for cross-validation purposes. These two groups were well-matched with regard to body weight (28.2 ± 10.8 y and 29.7 ± 10.1 kg), FM (6.9 ± 5.6 kg and 7.2 ± 5.2 kg) and were balanced for ethnic and gender composition. The development group was

Table 1 Physical characteristics of the Vermont and Alabama cohorts. Reported as range (minimum-maximum) and mean ± s.d. By ANOVA, there were no significant effects of laboratory, gender or ethnicity on age, but there were significant effects of laboratory and gender on weight and of laboratory, gender, and ethnicity on fat mass (FM)

	n	*Age (y)*	*Weight (kg)*	*DEXA fat (kg)*
Vermont cohort				
Total	98	4.0 – 9.9 (6.6 ± 1.4)	16.2 – 51.0 (24.1 ± 5.9)	1.2 ± 20.0 (4.8 ± 3.0)
White boys	49	4.0 – 9.9 (6.6 ± 1.4)	16.6 – 43.2 (23.8 ± 5.5)	1.2 – 12.1 (4.0 ± 2.4)
White girls	49	4.1 – 9.2 (6.5 ± 1.4)	16.2 – 51.0 (24.4 ± 6.3)	1.6 – 20.0 (5.5 ± 3.3)
Alabama cohort				
Total	104	4.2 – 10.9 (7.7 ± 1.6)	14.0 – 70.8 (33.0 ± 12.1)	2.0 – 28.5 (9.2 ± 6.3)
White boys	16	6.0 – 10.9 (8.0 ± 1.0)	20.3 – 41.9 (28.2 ± 6.1)	2.5 – 14.5 (6.2 ± 3.6)
White girls	19	5.2 – 9.8 (8.3 ± 1.2)	18.5 – 70.8 (42.5 ± 14.0)	3.8 – 28.5 (13.3 ± 6.8)
Black boys	31	4.2 – 10.0 (7.3 ± 1.6)	16.9 – 59.7 (29.6 ± 10.0)	2.0 – 27.3 (6.8 ± 5.6)
Black girls	38	4.2 – 10.0 (7.4 ± 1.8)	14.0 – 62.6 (33.1 ± 11.8)	2.5 – 25.6 (10.2 ± 6.1)

DEXA = dual energy x-ray absorptiometry.

Table 2 Cross-validation of previously published fat mass (FM) prediction equations DEXA FM *vs* predicted FM

	n	R^2	*Slope (kg)*	*Intercept*	*Measured-Predicted (kg)*
Slaughter *et al* equations					
Alabama cohort	104	0.92	0.80 ± 0.02*	2.43 ± 0.27**	−0.79 ± 0.23***
Boys	47	0.91	0.83 ± 0.04*	2.12 ± 0.30**	−1.21 ± 0.26***
Girls	57	0.90	0.78 ± 0.03*	2.81 ± 0.47**	−0.44 ± 0.36
Alabama + Vermont cohorts	202	0.90	0.84 ± 0.02*	1.40 ± 0.18**	0.35 ± 0.14***
Boys	96	0.85	0.83 ± 0.04*	1.16 ± 0.24**	−0.28 ± 0.18
Girls	106	0.91	0.83 ± 0.02*	1.83 ± 0.27**	−0.42 ± 0.21***
Goran *et al* equations					
Alabama cohort	104	0.91	1.17 ± 0.04*	0.31 ± 0.33	1.61 ± 0.20***
Boys	47	0.95	1.37 ± 0.04*	−0.78 ± 0.29**	1.21 ± 0.25***
Girls	57	0.89	1.10 ± 0.05	0.97 ± 0.57	1.94 ± 0.30***
Caucasian, FM < 20 kg	32	0.91	0.92 ± 0.05	1.44 ± 0.48**	0.78 ± 0.27***
Boys	16	0.86	1.49 ± 0.15*	−1.03 ± 0.82	1.36 ± 0.44***
Girls	16	0.97	0.88 ± 0.04*	1.46 ± 0.45**	0.20 ± 0.25

*Slope significantly different from 1.0; **intercept significantly different from 0.0; ***mean difference significantly different from 0.0 by paired *t*-test.

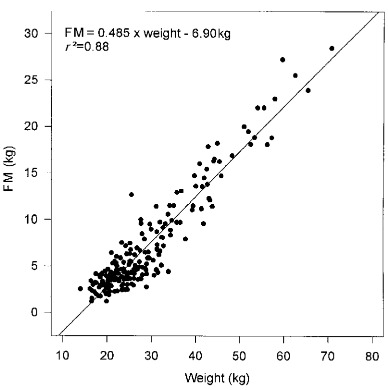

Figure 1 Relation between fat mass (FM) measured by dual energy x-ray absorptiometry (DEXA) and body weight, in the combined cohort ($n = 202$). Solid line is the regression line.

slightly younger than the control group (6.9 ± 1.6 y *vs* 7.6 ± 1.6 y, $P < 0.01$). Using the randomly assigned development group, the potential predictors of FM were entered into a stepwise prediction model and a new equation utilizing weight, tricep skinfold, gender, ethnicity and abdomen skinfold was defined (Table 3). For FM, 90% of the variance was accounted for by weight, 4% was explained by triceps skinfold and an additional 1% of the unique variance was explained by ethnicity, gender and abdomen skinfold.

Cross-validation of this new FM prediction equation was performed in the randomly assigned control group (Table 4). Through regression analysis of the measured *vs* predicted FM, all five steps of the derived equation were found to have regression equations that were not statistically different from the line of identity. By paired *t*-test, there were significant mean differences in Caucasian boys and African-American boys and girls for the first step, Caucasian boys and African-American girls for the second step, and Caucasian girls and African-American girls for the third step. Upon inclusion of gender and ethnicity in the equation by the fourth step, the equation cross-validated and remained valid in the fifth step. The graph of the measured FM *vs* the FM predicted by step 5 of the new prediction equation for the control group is shown in Figure 2. There was no significant correlation between measured minus predicted FM and measured FM, indicating that the prediction equation errors were randomly distributed and free of bias (see Figure 3).

Discussion

The main findings of this paper are: 1) using DEXA as a criterion, neither the Slaughter *et al*[10] equations nor the Goran *et al*[5] equation are valid in a heterogeneous population of children; 2) the main predictors of FM in the combined cohorts in this analysis were body weight, two skinfold measures (triceps and abdomen), ethnicity and gender with a model $R^2 = 0.95$; and 3) the new simple clinical prediction equation for FM in

Table 3 Stepwise regression analysis for the determination of fat mass (FM) as measured by dual energy x-ray absorptiometry (DEXA)

Step and variable	*Regression equation for FM (kg)*[a]	*Model* R^2	*Model SEE (kg)*
1. Weight	0.491*weight − 6.918	0.90	0.44
2. Tricep	0.334*weight + 0.285*tricep − 6.249	0.94	0.34
3. Gender	0.342*weight + 0.256*tricep + 0.837*gender − 7.388	0.95	0.46
4. Ethnicity	0.332*weight + 0.263*tricep + 0.760*gender + 0.704*ethnicity − 8.004	0.95	0.50
5. Abdomen	0.308*weight + 0.230*tricep + 0.641*gender + 0.857*ethnicity + 0.053*abdomen − 7.62	0.95	0.51

[a]Weight is in kg, triceps and calf skinfold thickness are in mm, gender is 1 for male and 2 for female, ethnicity is 1 for Caucasian and 2 for African-American. Additional variables not selected in the model were: age, height, body mass index (BMI), hip circumference, waist circumference and the following skinfolds: subscapular, suprailiac, thigh, calf, and chest.

Table 4 Cross-validation of fat mass (FM) prediction equation in Table 3

		R^2	*Slope**	*Intercept (kg)***	*Measured-predicted (kg)*
Step 1	Total control group	0.86	0.97 ± 0.05	−0.21 ± 0.44	−0.15 ± 0.13
	Caucasian boys	0.76	0.96 ± 0.13	−0.28 ± 0.89	−0.73 ± 0.24***
	Caucasian girls	0.92	0.93 ± 0.06	0.15 ± 0.60	0.13 ± 0.19
	African-American boys	0.76	0.85 ± 0.13	0.07 ± 1.04	−0.84 ± 0.35***
	African-American girls	0.84	1.35 ± 0.19	−2.97 ± 1.99	0.89 ± 0.25***
Step 2	Total control group	0.91	0.96 ± 0.04	−0.02 ± 0.34	−0.11 ± 0.10
	Caucasian boys	0.89	0.90 ± 0.08	−0.04 ± 0.56	−0.59 ± 0.17***
	Caucasian girls	0.92	0.93 ± 0.06	−0.09 ± 0.63	−0.17 ± 0.19
	African-American boys	0.90	0.96 ± 0.08	0.09 ± 0.63	−0.04 ± 0.21
	African-American girls	0.96	1.07 ± 0.08	0.20 ± 0.80	0.78 ± 0.18***
Step 3	Total control group	0.91	0.96 ± 0.04	0.04 ± 0.33	−0.09 ± 0.10
	Caucasian boys	0.89	0.93 ± 0.08	0.20 ± 0.55	−0.17 ± 0.17
	Caucasian girls	0.92	0.95 ± 0.06	−0.55 ± 0.64	−0.51 ± 0.18***
	African-American boys	0.89	0.97 ± 0.09	0.40 ± 0.64	0.35 ± 0.22
	African-American girls	0.95	1.12 ± 0.08	−0.63 ± 0.88	0.45 ± 0.18***
Step 4	Total control group	0.92	0.97 ± 0.04	−0.10 ± 0.32	−0.11 ± 0.09
	Caucasian boys	0.89	0.94 ± 0.08	0.31 ± 0.54	−0.01 ± 0.17
	Caucasian girls	0.92	0.96 ± 0.06	−0.40 ± 0.64	−0.26 ± 0.18
	African-American boys	0.90	0.98 ± 0.09	−0.20 ± 0.67	−0.15 ± 0.22
	African-American girls	0.95	1.12 ± 0.08	−1.12 ± 0.90	0.03 ± 0.18
Step 5	Total control group	0.92	0.97 ± 0.03	−0.09 ± 0.31	−0.11 ± 0.09
	Caucasian boys	0.89	0.92 ± 0.08	0.40 ± 0.52	0.01 ± 0.16
	Caucasian girls	0.92	0.96 ± 0.06	−0.38 ± 0.63	−0.26 ± 0.18
	African-American boys	0.91	0.97 ± 0.08	−0.18 ± 0.61	−0.23 ± 0.20
	African-American girls	0.96	1.12 ± 0.08	−1.03 ± 0.86	0.08 ± 0.18

*All slopes not significantly different from 1.0; **All intercepts not significantly different from 0.0; ***Mean differences significantly different from 0.0 by paired *t*-test.

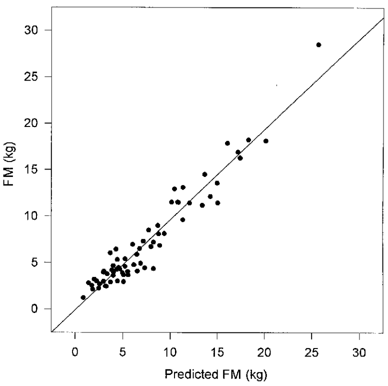

Figure 2 Relation between fat mass (FM) measured by dual energy x-ray absorptiometry (DEXA) and the predicted FM in the randomly assigned control group (n = 67). The predicted FM was estimated with step 5 of the equation presented inTable 4. Solid line is the regression line.

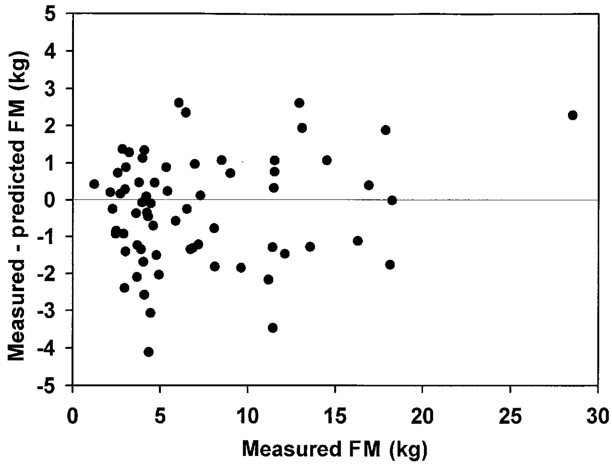

Figure 3 Relation between measured minus predicted fat mass (FM) *vs* measured FM in the randomly assigned control group (n = 67). There was no significant correlation (r = 0.19; P = 0.13). The predicted FM was estimated with step 4 of the equation presented inTable 4).

children has potential use for large scale studies and clinical evaluation.

Slaughter *et al*[10] provided a major contribution to body composition measurement techniques in children. In our analysis, there was a strong association between FM predicted by the Slaughter *et al*[10] equations and FM measured by DEXA for the Alabama cohort (R^2 = 0.92, SEE = 0.27 kg) and the combined Alabama and Vermont cohort (R^2 = 0.90, SEE = 0.18 kg). Compared to FM determined by DEXA however, the equations were found to consistently under-predict FM in the low range and over-predict FM for the mid to higher range of FM studied. The prediction equation of Goran *et al*,[5] who used similar techniques and equipment compared to that used for the Alabama cohort, was not found to cross validate in the Alabama cohort. That the equation was not valid for the heterogeneous group of African-American and Caucasian children helps emphasize that prediction equations are generally only valid when applied to similar groups. However, even when limited to Caucasian children with a FM 20 kg, the equation of Goran *et al* was not cross-validated, but this may be because of the low sample size for each subgroup (16 boys and 16 girls).

Table 3 reports the five steps of the newly derived prediction equation. The fourth and fifth steps cross-validated with the control group. Specifically, weight was a strong predictor of FM, but because of ethnicity and gender effects it was only valid in the subgroup of Caucasian girls. Similarly, although the addition of triceps in the second step increased the accuracy of predicting FM, the equation was not valid by paired *t*-test for the sub-groups of Caucasian boys and African-American girls. The equation was corrected for the effects of gender and ethnicity, with their inclusion in the equation in the third and fourth steps. The equation remained valid with the addition of the second skinfold (abdomen) in the fifth step, but the R^2 was only minimally improved (0.002). Since the fourth and fifth steps are valid, and there was very little improvement in precision in the fifth step, the fourth step may be used to accurately predict FM. This would obviate the need to measure abdominal skinfold thickness, which is technically more difficult and less commonly measured than other skinfolds, such as the triceps. Thus, FM can potentially be determined with only two direct measurements: weight and triceps skinfold thickness.

There are a few limitations of this study that should be considered. First, this study was limited to Caucasian and African-American children (plus the inclusion of four Mohawk girls), so the equations tested may not be valid for other ethnic groups. Second, the children ranged from 4–10.9 y and while presumed to be prepubescent (Tanner stages 1 and 2), not all were specifically Tanner staged. Third, combining cohorts from different laboratories can potentially introduce error into the measurements, whether secondary to technique or equipment. However, we feel this is outweighed by the advantages of creating an equation from a large diverse group of children that is less likely to be lab-specific.

An additional limitation was that the DEXA data for FM was transformed by applying correction factors derived from a validation study with pig carcasses.[11] The correction factors are specific for the equipment, software and scan mode used, but were derived from a narrower range of weights and lower mean than the group to which they were applied (range 15.8–35.6 kg, mean 25.5 ± 7.0 kg in pigs; range 14.0–70.8 kg, mean 29.7 ± 10.4 kg in the children). Also, this correction assumes that pig and human fat are similar in amount, composition and detection by DEXA. Despite these limitations however, our approach to estimating FM in children has the advantage of being standardized relative to a known and defined standard (that is, pig carcass analysis). In general our findings would be similar if we had used actual measured FM rather than adjusting it relative to the carcass data, although in some cases, the specific parameter estimates may be different. For example, the comparison of FM using existing equations against DEXA measures were similar whether we used actual measures of FM rather than adjusted FM. In fact, if anything, there was a greater discrepancy between estimates of FM by the previous equations of Goran *et al* (6.18 ± 4.43 kg) or Slaughter *et al* (6.68 ± 6.15 kg) as compared to the measured FM (7.87 ± 6.28 kg), rather than the adjusted FM (7.03 ± 5.47 kg) Thus, the adjustment of the DEXA data did not explain the lack of cross-validation of previous equations. In addition, for the purposes of clarification and comparison, the simple regression of unadjusted FM with body weight and the step 4 regression equation from Table 3 are shown below (see legend to Table 3 for description of variables):

$$\text{FM (kg)} = 0.56\text{*body weight} - 8.17\ (R^2 = 0.90);$$

$$\text{FM (kg)} = 0.38\text{*body weight} + (0.30\text{*triceps}) + (0.87\text{*gender}) + (0.81\text{*ethnicity}) - 9.42\ (R^2 = 0.95);$$

Other general limitations of using anthropometry to predict fatness in children include issues related to inter-laboratory and inter-rater variability, inability to directly correlate FM measurement techniques to actual FM and inherent ethnic and gender differences over different ages and FM ranges. However, the cross-validation of the newly-derived FM prediction equation supports the use of anthropometric prediction equations for large groups. This has implications for the use of simple techniques (that is, anthropometry) for estimating body composition in large population studies. Note that the prediction equations presented are for FM. Separate prediction equations for FFM are unnecessary since the FFM can be estimated by subtracting FM from total body mass and % body fat can be calculated from the division of FM by total body mass.

Conclusion

In summary, we were not able to cross-validate the equations of Slaughter *et al* or Goran *et al* in a heterogeneous group of African-American and Caucasian children. With an extended range to approximately 30 kg of body fat, a new prediction equation was derived and cross-validated for the combined cohort, which proved valid for each ethnic and gender subgroup. This new equation, estimating FM measured by DEXA with a model R^2 of 0.95, utilizes weight, triceps skinfold, gender, ethnicity and abdominal skinfold (although the abdominal skinfold is not essential). With the emergence of new methods and techniques for measuring body composition, it is important to continue to refine prediction equations. This will help make the accurate assessment of body composition in children more universally available since anthropometry can be obtained with portable equipment that is far less expensive and requires less training than other techniques. In turn, the accurate assessment of body composition in children is useful for detecting and monitoring growth aberrations, for either natural history or response to interventions, that can be associated with significant morbidity and mortality.

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