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Body Measurement Variability, Fatness, and Fat-Free Mass in Children 8, 11, and 14 Years of Age: Project HeartBeat!

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ABSTRACT Project HeartBeat! is a four year mixed-longitudinal study of the development of cardiovascular risk factors in White and African American children who at baseline comprised three age cohorts 8, 11, and 14 years. This paper focuses on the anthropometric variables which were chosen to reflect body fat and fat-free mass. Selected anthropometric dimensions are compared with those of samples from the combined National Health and Nutrition Examination Surveys I and II to explore the similarities of the samples in terms of central tendencies and variances. The measurements were then explored in terms of their ability to estimate the two compartment model of body composition: fat-free mass (FFM) and body fat (BF) from bioelectrical impedance (BIA). Project HeartBeat! children are slightly larger than NHANES children and have variances that are generally comparable to the national surveys. Over seven percent (7.7%) of children were overweight (BMI) and 25% had 'mild obesity' by %BF. Three different factor analytic methods (incomplete principal components, alpha and maximum likelihood) produced two latent variables from 17 anthropometric dimensions which together accounted for 76–83% of the variation: (1) A body mass factor (F1) which was weighted highly on six circumferences, weight and six skinfolds, and (2) a linear growth factor (F2) which was strongly associated with height, arm length, and sitting height. Triceps, subscapular and midaxillary skinfolds were consistently highly loaded on the body mass factor and their sum was highly correlated to %BF and fat mass (0.90–0.99). This suggests that this sum could be used to estimate fatness in children in studies where the BIA or other body composition techniques are unavailable. FFM and %BF were predicted from the anthropometric factors. Both factors contributed to the estimate of FFM (R^2 = 0.81–0.93), although F2 contributed proportionately more. The 'body mass' factor (F1) was the main predictor of %BF (R^2 = 0.86–0.93), though at some ages the linear factor (F2) was significantly and negatively related to %BF. This set of anthropometric dimensions, taken for the purpose of estimating body composition and summarized as two latent vectors by factor analysis, strongly reflects body fat and FFM in children and adolescents. Am. J. Hum. Biol. 11:69–78, 1999. © 1999 Wiley-Liss, Inc.

Project HeartBeat! is a mixed-longitudinal study of the development of cardiovascular risk factors in children who at baseline comprised three age cohorts of 8, 11, and 14 years and who were followed for a period of four years (Labarthe et al., 1997). The purpose of Project HeartBeat! is to document the developmental changes that occur in cardiovascular risk variables during late childhood and adolescence in two ethnic groups (African American and White). Autopsy studies of youths and young adults

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young adults show a large proportion of individuals already at these young ages with signs of atherosclerosis (Enos et al., 1953, Holman et al., 1958, Strong 1986; Newman et al., 1991). The percentages of affected children and young adults vary from study to study, but are substantial (45–77%). The data suggest that coronary risk factors develop early in life and that the identification of the factors associated with such high prevalences should be uncovered. A part of this puzzle is, of course, understanding cardiovascular risk variables in terms of their usual central tendencies and variances, and their associated changes with age during growth and maturation. Cardiovascular risk variables which were studied in Project HeartBeat! included blood pressures, blood lipids, body size, maturation, body fat and central body fat distribution, physical activity, physical fitness, alcohol use, dietary intake of fat, and behavioral variables such as smoking and anger expression. This paper focuses on the anthropometric variables, reflecting growth of body fat and fat-free mass. Selected anthropometric variables in Project HeartBeat! are compared with those of samples from the National Health and Nutrition Examination Surveys I and II (NHANES) first, to explore the similarities of the samples in terms of central tendencies and variations in the distributions of variables. The anthropometric dimensions were then explored in terms of their ability to estimate the two compartment model of body composition: Fat-free mass (FFM) and body fat (BF) (Lohman, 1995). If anthropometry truly reflects these compartments of body composition, latent variables of BF and FFM should be detectable in the universe of the measured dimensions. Latent variables can be detected by factor analysis of anthropometric variables which in turn can be used to predict FFM and BF as estimated with the bioelectrical impedance method. It was hypothesized that (1) two factors will emerge in the factor analysis of anthropometry, one reflecting BF and the other, FFM; (2) the respective factors will be correlated with high precision ($R^2 \geqslant 0.90$) to estimates of FFM and percent body fat (%BF) derived from bioelectric impedance; and (3) clusters of anthropometric variables highly correlated to %BF and fat mass (FM) will emerge as useful field measures of BF.

MATERIALS AND METHODS

Project HeartBeat! is a study of children who reside in two communities, The Woodlands and Conroe, Texas (Grunbaum et al., 1997; Tanner et al., 1997; Labarthe et al., 1997). The Woodlands is a planned community in Montgomery County, 30 miles north of Houston. Its population is 92% White, 4% Hispanic, 2% African American, and 2% "other." The town of Conroe is in the same county and school administrative district, 10 miles north of The Woodlands. Its ethnic makeup is 75% White, 13% African American and 12% "other." Most of the African American participants were selected from Conroe. Beginning in 1985, the University of Texas-Houston, School of Public Health Epidemiology Research Center, began a series of contacts and pilot studies in The Woodlands to consider the feasibility of a long-term project on the growth and maturation of cardiovascular risk factors (Sangi et al., 1992). Local advisory committees were formed consisting of leaders representing health departments, schools, churches, and several community agencies. Through these initial projects and committees as well as local media communications and the establishment of a field center, subjects were recruited to participate in the long-term study. Data collection began in the Fall of 1991.

The baseline sample size

At baseline, all children were initially required to be either 8, 11, or 14 years of age. Each of these cohorts of children was to be followed for four years with tri-annual examinations, thus comprising a mixed-longitudinal study design. Some children, however, fell outside of the ages at baseline due to extended recruitment. This was especially true for the African American children (Grunbaum et al., 1997). This resulted in the exclusion of 3 White and 56 African American children for analysis of the baseline sample (Table 1). However, all children in Table 1 would be included in any longitudinal use of the data. Ethnicity was designated by asking parents to indicate to which ethnic group they and their participant child belonged. Among children designated as "White," there was also a small proportion of Hispanic and Asian children. There are 277 White boys, 262 White girls, and 40 African American boys and 40 Afri-

TABLE 1. The numbers of children in the baseline sample, Project HeartBeat! by ethnic group, gender, and age cohort

	Cases retained				Cases deleted[1]			
Sex/Cohort	Age	White	African American	Total	Age	White	African American	Total
Males								
(1)	8.0–8.9	120	25	145	9.0–10.0	1	13	14
(2)	11.0–11.9	82	10	92	12.0–12.6	1	11	12
(3)	14.0–14.9	75	5	80	15.3–15.5	0	2	2
Totals		277	40	317		2	26	28
Females								
(1)	8.0–8.9	114	26	140	9.0–9.5	0	15	15
(2)	11.0–11.9	75	5	80	12.0–12.7	1	12	13
(3)	14.0–14.9	73	9	82	15.0–15.3	0	3	3
Totals		262	40	302		1	30	31

[1]Outside of age ranges of cohorts at baseline sampling (see text).

can American girls for a total of 619 children of the appropriate ages at baseline (Table 1).

Anthropometry and body composition variables

The chosen variables and procedures followed the recommendations of the Airlie Anthropometric Standardization Conference (Lohman, et al., 1988). Among other concerns, this conference suggested useful variables for cardiovascular research in adults and children. There were 16 anthropometric dimensions taken on each child: stature, weight, sitting height, upper arm length, three limb and three body circumferences: arm, maximum calf, thigh, waist, abdominal and hip, and six skinfolds: triceps, midaxillary, subscapular, abdominal, distal thigh, and lateral calf. Stature was measured with a wall mounted stadiometer, sitting height with a base-mounted anthropometer with the subject seated on a table, weight with a beam balance scale, circumferences with a steel tape measure, and skinfolds with a Holtain caliper. All variables were measured one time at each occasion except skinfolds, which were measured three times. For these repeated measures, the entire set of six skinfolds was taken once, and then repeated twice again in the same measuring session to prevent the observer from remembering previous values, and to minimize reduction of values due to fluid changes. The average of the three determinations for each skinfold is reported.

Two stages of quality control were effected: 1) quality assurance and 2) quality assessment. 'Quality assurance' has to do with procedures prior to data collection. This included systematic training of data collectors by WHM and CLA and their certification for anthropometric assessment as well as recertification on an 'as needed' basis throughout the four years of data collection. Certification was based on meeting pre-set criteria for technical errors of measurement as listed in the Project HeartBeat! training manual. The manual also included instructions on the calibration of equipment and procedures for measurement with illustrations (photographs) for each anthropometric variable. 'Quality assessment' refers to statistical procedures used to detect unusual or outlying measurement values. Both cross-sectional and longitudinal methods were used to detect unusual values which were then related to hard copy where possible and corrected, or set to blank if correction was not possible.

The following derived variables and indices are included: the body mass index ($wt(kg)/ht^2(m^2)$) is an indirect indicator of body fat (Himes and Dietz 1994; Malina and Katzmarzyk 1997). Arm muscle circumference was calculated according to the formula presented by Frisancho (1990) and is used in the calculation of FFM described below. FFM and %BF were estimated from measures of bioelectrical impedance. Bioelectrical impedance was measured using the R.J.L. Systems device (BIA 101-A). The subject was placed in a supine position on an examining table. Electrodes were applied following standard methods on the right hand and foot, and the subject was positioned so that hands were away from the body and legs were not touching. Subject identifying information was entered into a computer terminal along with the resistance and reactance from the impedance analyzer. The resistance was divided by the subject's height^2 to compute bioelectrical impedance (Heyward, 1991; Pollock and Wilmore, 1990).

Percentage body fat (%BF) and fat free mass (FFM) were calculated from a combination of anthropometry and bioelectrical impedance using the formulae of Guo et al. (1989). These equations have been cross-validated in three samples which included adolescents and young adults. The dimensions included in the estimates were lateral calf skinfold in both sexes, as well as the midaxillary skinfold and arm muscle circumference in males, and the triceps and subscapular skinfolds in females.

Data analysis

Descriptive statistics (means and standard deviations) are presented by sex and age cohort for anthropometric variables common to Project HeartBeat! and NHANES for combined African American and White children (Frisancho, 1990). Also presented are %BF and FFM. t-tests and F ratios of variance were used to test the null hypothesis that Project HeartBeat! and NHANES data do not differ significantly for measures of central tendency and variances, respectively.

The two component model of body composition consists of BF and FFM (Lohman, 1995). Anthropometric variables were chosen in this study to reflect in their informational structure these two components. Factor analysis is a statistical technique that explores the informational structure of a set of variables (Gorsuch, 1983). It might reasonably be expected, therefore, that a factor analysis of the full anthropometric data set would produce latent variables of the body composition model. The expectations are that: (1) two factors (reflecting respectively FFM and BF) should occur in each age and sex group; (2) %BF should be highly related to one and FFM to the other; and (3) prediction of %BF and FFM from the anthropometric factors should be possible with high precision ($R^2 \geqslant 0.90$). High anthropometric accuracy has been defined as an R of 0.95 or greater, where R is the reliability coefficient (Ulijaszek and Lourie 1994). This would be analogous to an R^2 of about 0.90 from a prediction equation.

Three types of factor analyses of the anthropometry were employed to demonstrate that the obtained factor structure is not dependent on the extraction process. In the first, the extraction procedure utilized was 'Incomplete Principal Components.' Determination of the number of factors to extract was based on simultaneously considering Guttman's lower bound for roots greater than or equal to unity, the percentage of total variance extracted, and subjective evaluation of scree plots of the percentage of variance explained for each of the successive factors (Gorsuch, 1983). Incomplete Principal Components Analyses were done within gender and age cohort. In all cohorts, two factors were extracted for the initial solution. Derived orthogonal solutions were obtained by subjecting each initial solution to the orthonormal transformation of Kaiser's varimax rotation. Since principal components extraction tends to produce somewhat inflated pattern coefficients, "salient" values for variables (greater than or equal to 0.70 in absolute value) are shown in bold in the tables.

Two additional factor analyses stratified by gender included the original anthropometric dimension and two marker variables, FFM and %BF from bioelectrical impedance. Two techniques that provide iterative scale-invariant solutions were used: Alpha and maximum-likelihood. These two techniques are distinct both philosophically and in the approach for determining the dimensionality of the variables (Gorsuch, 1983). Alpha factor analysis is a psychometric factor extraction procedure that maximizes the alpha generalizability of the common factors, and only factors with positive generalizability (factors associated with eigenvalues greater than unity) are retained for the analysis. In contrast, the maximum-likelihood method is a statistically oriented rank-reduction technique retaining only those factors that meet a significance test criterion. For both sexes, the Alpha factor method extracted two, and the maximum-likelihood method extracted seven factors. Orthogonally derived solutions were obtained by rotating to the varimax criterion.

Finally, selected anthropometric variables were correlated to %BF and FM after factor analysis had suggested their possible utility or because they are known correlates of BF from the literature: 1) sum of the triceps, subscapular, and midaxillary skin-

TABLE 2. Selected anthropometric variables at baseline measurement: Project HeartBeat!

	Males					
	8.0–8.99 yrs. (N = 145)		11.0–11.99 yrs. (N = 92)		14.0–14.99 yrs. (N = 80)	
	Mean	SD	Mean	SD	Mean	SD
Stature (cm)	131.2*	5.4	147.3	7.0	167.0	7.0
Weight (kg)	29.8*	5.9	41.9*	9.2	58.1	11.7
BMI (kg/m^2)	17.2*	2.7	19.2*	3.4	20.7	3.3
Arm circ. (cm)	20.1*	2.8	23.4*	3.3	26.4	3.4
Subscapular sk. (mm)	7.5*	4.1[2]	10.4*	6.4[2]	9.9	4.9[2]
Triceps sk. (mm)	10.8*	5.0	14.4*	6.6	12.5*	6.6
Body Fat (%)[3]	21.7	7.9	24.2	8.2	18.2	7.1
Fat Free mass (kg)[3]	22.9	3.3	31.3	5.2	46.5	7.2
	Females					
	(N = 139)		(N = 80)		(N = 82)	
	Mean	SD	Mean	SD	Mean	SD
Stature (cm)	130.4	6.5	147.1	7.5	162.5*	5.5
Weight (kg)	29.5*	7.3	40.0[1]	8.7[2]	59.1*	12.4
BMI (kg/m^2)	17.1*	3.0	18.3	2.9[2]	22.4*	4.4
Arm circ. (cm)	20.3	3.0	22.5[1]	2.6[2]	26.7*	4.0
Subscapular sk. (mm)	8.7*	4.6[2]	10.9	6.1[2]	14.5*	7.2
Triceps sk. (mm)	12.7	4.8	14.7	6.2	19.0*	7.2
Body Fat (%)[3]	24.6	7.8	25.6	8.7	27.6	6.5
Fat Free mass (kg)[3]	21.8	3.8	29.3	4.8	41.2	4.9

*Larger than NHANES I & II. } $P < 0.05$
[1]Smaller than NHANES I & II. }
[2]*Less* variable than NHANES I & II.
[3]%Body Fat and Fat-Free Mass could not be compared to NHANES I & II.

folds, 2) sum of the thigh and lateral calf skinfolds, 3) the BMI, and 4) abdominal circumference. Also explored were the percentages of overweight children using BMI criteria presented by Himes and Dietz (1994) to which the percentage of children with excess %BF (⩾32% in females and ⩾25% in males) as per the findings of Lohman (1995) and Williams et al. (1992) were compared.

RESULTS

Comparison with national data

Descriptive statistics for the body measurements are shown in Table 2. Superscripts denote instances in which Project HeartBeat! and NHANES data differ. With the exception of 11 year old girls, Project HeartBeat! children tend to be slightly taller than national reference children. These differences reach significance only for 8 year old boys and 14 year old girls. The differences are small (1–2 cm). Project HeartBeat! children are also somewhat heavier and have thicker skinfold thicknesses than their NHANES counterparts (1–2 kg, $P < 0.05$), with the exception of 11 year old females, who are slightly lighter (Table 2). This last observation appears related to the variance in this same age group which is significantly reduced in the Project HeartBeat! sample compared to NHANES ($P < 0.01$). From the percentile distribution (not shown), it was ascertained that in this age group there are fewer girls at or above the 75th percentile. The medians are nearly the same in the two samples (39.6 vs. 39.8 kg). Thus, there is a reduction in the variance of this age/sex group. In general, standard deviations for weight and other variables in Project HeartBeat! are equal to or greater than those of the NHANES, suggesting that the study has reasonably sampled the kind of variability typical for the U.S. in basic measures of growth.

Of the 619 children, 48 (7.7%) had a BMI that indicated 'overweight' by the criteria of Himes and Dietz (1994). However, there were 156 children (25%) whose %BF was at a level associated with increasing levels of lipids and blood pressures (Williams et al., 1992). Hence, the BMI and %Body Fat, as

*TABLE 3. Incomplete principal components analysis of anthropometrics, Project HeartBeat!: factor pattern coefficients, after varimax rotation**

	Ages 8.0–8.90				Ages 11.0–11.9				Ages 14.0–14.9			
	Males (n = 141)		Females (n = 136)		Males (n = 92)		Females (n = 78)		Males (n = 76)		Females (n = 76)	
Factor	1	2	1	2	1	2	1	2	1	2	1	2
Stature	.17	**.86**	.26	**.87**	.06	**.92**	.05	**.95**	.00	**.88**	–.07	**.90**
Sitting height	.31	**.82**	.34	**.77**	.17	**.90**	.13	**.91**	.05	**.86**	.09	**.86**
Upper arm length	.36	**.73**	.28	**.75**	.33	**.78**	.10	**.86**	.21	**.79**	.23	.68
Arm muscle circ.	–.42	.64	–.38	.66	–.61	.41	**–.74**	.27	–.65	.56	–.56	.30
Weight	**.77**	.59	**.74**	.64	**.74**	.65	.63	**.74**	.58	**.80**	**.83**	.52
Maximum calf circ.	**.79**	.48	**.72**	.61	**.73**	.54	.64	.67	.57	.69	**.81**	.38
Hip circumference	**.82**	.50	**.78**	.58	**.79**	.55	.55	**.74**	.60	.65	**.80**	.47
Arm circumference	**.85**	.41	**.73**	.58	**.83**	.46	**.80**	.48	.61	.64	**.90**	.26
Thigh circumference	**.86**	.42	**.80**	.55	.67	.32	.68	.68	**.70**	.62	**.83**	.42
Waist circumference	**.84**	.39	**.80**	.47	**.85**	.44	**.80**	.46	**.74**	.58	**.89**	.22
Abdominal circ.	**.87**	.37	**.84**	.44	**.86**	.43	**.81**	.50	.65	.48	**.88**	.25
Triceps skinfold	**.97**	.02	**.95**	.14	**.95**	.17	**.94**	.19	**.95**	.11	**.95**	.07
Distal thigh skinfold	**.91**	.03	**.84**	.11	**.89**	.07	**.77**	.31	**.89**	.09	**.76**	.05
Midaxillary skinfold	**.88**	.19	**.91**	.17	**.90**	.19	**.88**	.16	**.87**	.28	**.90**	.01
Subscapular skinfold	**.91**	.15	**.88**	.19	**.90**	.17	**.90**	.13	**.87**	.32	**.92**	.02
Abdominal skinfold	**.92**	.15	**.87**	.11	**.90**	.24	**.81**	.30	**.83**	.27	**.85**	.05
Lateral calf skinfold	**.87**	.01	**.79**	.19	**.81**	.16	**.72**	.29	**.84**	.07	**.79**	.02
%Variance accounted for	60.24	22.92	54.17	27.41	56.34	25.49	48.90	32.78	46.55	33.09	58.38	18.31

*Entries in **bold** are loading coefficients ≥0.70 to emphasize pattern.

estimated from bioelectrical impedance, gave significantly different estimates of 'overweight.' More boys (n = 317) were overweight (10%) or had a higher %BF (28.7%) than girls (n = 302) (5.3% and 21.5%, respectively).

Factor analysis

Table 3 presents Incomplete Principal Components analysis of the anthropometry in 8, 11, and 14 year olds, respectively. The varimax rotated factors show two main factors in each age and gender. The first (1) accounts for 47–60% of the multivariate variance and is highly correlated to skinfold measurements and circumferences, suggesting that it represents 'body mass.' The second (2) accounts for 18–33% of the variation and is highly associated with stature, sitting height and upper arm length, suggesting an affiliation with linear growth. Together these two factors account for the bulk of the multivariate variance (76–83%). Weight and the circumferences tend to be weighted on both factors except in 14 year old girls; however, skinfolds are strongly related *only* to the first factor. Of the circumferences, abdominal and waist circumferences have stronger weightings on the first factor (mass) than with the second (linearity), and this distinction increases with age, especially in girls.

The correlations among factor scores of the corresponding factors ('body mass' with 'body mass,' 'linearity' with 'linearity') across the three types of factor solutions (Incomplete Principal Components, Alpha, and Maximum-Likelihood) were high (0.89–0.99) showing that similar patterns emerge irrespective of the factor method (data not shown). Correlations of %BF or FM with the first factor range from 0.94–0.97. Correlations of the BMI with this factor are lower (0.78–0.88). Correlations of FFM with the second factor range from 0.77–0.93. The maximum-likelihood solution provides more than two factors, in fact a total of seven factors. However, only the first four exhibit strong pattern coefficients with specific variables. The first two factors are, as stated before, a body mass and a linear factor. Factor #3 is highly correlated with abdominal circumference in boys but accounts for only 2.4% of the variance. In girls Factor #3 is strongly related to the lateral calf and distal thigh skinfolds, and to a lesser degree with hip, thigh, and calf circumferences. It accounts for 9% of the variance. The third factors in each sex thus appear to relate to regional differences in BF. The fourth factor in both genders relates only to arm muscle

TABLE 4. Equations predicting Fat-Free Mass (FFM) and percent Body Fat (%BF) from two anthropometric factors (F1, F2)†

Sex/age group	Prediction equation $C + b_1 \pm Se_{b1}$ (F1) + $b_2 \pm Se_{b2}$ (F2)	R^2	n
Males			
8.0–8.99	FFM = 22.9 + 0.90 ± 0.11* + 2.78 ± 0.11*	0.83	141
11.0–11.99	FFM = 31.3 + 1.48 ± 0.21* + 4.56 ± 0.21*	0.85	92
14.0–14.99	FFM = 46.4 + 0.56 ± 0.23[1] + 6.86 ± 0.23*	0.93	76
Females			
8.0–8.99	FFM = 21.7 + 1.21 ± 0.11* + 3.08 ± 0.11*	0.87	136
11.0–11.99	FFM = 29.2 + 0.62 ± 0.19* + 4.57 ± 0.19*	0.88	78
14.0–14.99	FFM = 41.2 + 1.98 ± 0.24* + 3.90 ± 0.24*	0.81	76
Males			
8.0–8.99	%BF = 21.5 + 6.90 ± 0.23* − 1.05 ± 0.23*	0.87	141
11.0–11.99	%BF = 24.2 + 7.72 ± 0.30* − 0.15 ± 0.30^{ns}	0.88	92
14.0–14.99	%BF = 18.0 + 6.61 ± 0.27* − 0.06 ± 0.27^{ns}	0.89	76
Females			
8.0–8.99	%BF = 24.2 + 7.12 ± 0.25* + 0.19 ± 0.25^{ns}	0.86	136
11.0–11.99	%BF = 25.3 + 8.29 ± 0.29* + 0.56 ± 0.29^{ns}	0.92	78
14.0–14.99	%BF = 27.7 + 6.25 ± 0.20* − 0.42 ± 0.20**	0.93	76

†NS, not significant.
*$P < 0.01$.
**$P < 0.05$.

circumference and accounts for 2.4% and 5% of the variance in boys and girls, respectively.

Regression equations within gender and age cohort predict FFM and %BF from the linear combinations of the two incomplete principal components (Table 4). FFM is strongly related to the linear factor (F2) and significantly related to the body mass factor (F1) as well as in all cohorts. For FFM, R^2 are highest at puberty ($R^2 = 0.88$ in 11 year old females and $R^2 = 0.93$ in 14 year old males). %BF is strongly related to the body mass factor (F1), and in two of the cohorts (8 year old males and 14 year old females), it is significantly and negatively related to the linear factor (F2). For %BF, R^2 are highest among 14 year olds of both sexes ($R^2 = 0.89$ and 0.93 in males and females respectively). Thus, both factors contribute to the estimates of FFM, whereas it is mainly the first factor that contributes to %BF.

Correlations of %BF and FM with selected anthropometric indicators show that the sum of three skinfolds (triceps, midaxillary, and subscapular) has higher correlations (0.90–0.99) than the BMI (0.82–0.93), sum of lower extremity skinfolds (0.79–0.88) or abdominal circumference (0.71–0.94). The sum of the triceps, midaxillary, and subscapular skinfolds appears to be a useful field measure of BF in children and adolescents of these age groups.

DISCUSSION

Observation of means and variances of selected anthropometric variables in Table 2 suggests that the present sample is very similar to national reference data in measures of central tendency and variability. The majority of children who are non-African American are of White ancestry. There are only a few Hispanics and Asians. Unfortunately, due to difficulties in sampling the African American children, which took place over a more extended period than among the White children, fewer of these met the age criterion for inclusion in a cross-sectional analysis of baseline measurements. The NHANES data presented for combined ethnicities by Frisancho (1990) contains approximately 20% African American children. Whereas the total number of African American children in the present study is a similar proportion (about 20%) in the baseline cohorts presented here, African American children comprise only about 13% of the sample. This sample of African American children was too small to present separately so that all children were combined. This means that the anthropometry in Project HeartBeat! with a 13% African American sample, is compared to Frisancho (1990) with a 20% African American sample. Since African American children are somewhat taller than White children, this might bias the sample to appearing 'shorter' or the NHANES data as appearing 'taller.' It is unclear as to how other biases might appear, as for example BF. The Project HeartBeat! sample does not appear to be markedly different from NHANES in stature or the other measurements. The children are slightly taller, definitely heavier, and have marginally larger skinfolds than NHANES children. It would appear that these are expected differences given probable secular changes (the last data of the NHANES would have been collected in the early 1980s).

The first hypothesis tested in this study was that two latent variables would be evident from a factor analysis of 17 anthropometric variables and that these two factors would reflect the two compartments (BF and FFM) in the body composition model. The data are consistent with accepting this hypothesis. Two factors did emerge from the analysis and each appeared correlated strongly with either %BF or FFM as derived from a combination of bioelectrical impedance and anthropometry. Jackson and Pollock (1976) also identified an association of %BF and FFM with two anthropometric factors of body mass and linearity in adults. Unlike Jackson and Pollock (1976), who used hydrostatic weight to estimate FFM, %BF and FFM are not entirely independent of some of the anthropometric variables. The lateral calf skinfold in both genders, the triceps and subscapsular skinfolds in females, and arm muscle circumference and the midaxillary skinfold in males were included in the formulae which estimate these parameters of body composition. For that matter, stature combined with electrical resistance as resistance/stature^2 is used to estimate bioelectrical impedance in the first place. Nevertheless, the data relating bioelectrical impedance to %BF suggest that resistance/stature^2 will enter first in regression predictions of hydrostatic weight, when other anthropometrics such as weight, circumferences, and skinfolds are also potential predictors (Roche et al., 1986). The correlation of resistance/stature^2 with body fat is of the order 0.80–0.90 (Roche, personal communication). It is assumed, therefore, that the strong appearance of %BF and FFM on the fat and lean factors, respectively, are largely because they reflect true and 'best' estimates of these components of body composition.

Another caveat is in order. The factors extracted from any factor analysis are dependent on the number and kinds of variables entered (Mueller, 1984). In this study, the anthropometric variables were selected to reflect body composition and linear growth. Hence, it is not surprising that a strong association is found between the resulting factors and some indicators of BF and FFM. The maximum-likelihood factor analysis revealed a third factor: abdominal circumference in boys and lower limb fat in girls. This factor accounted for very small percentages of variance, 2.4% and 9% in boys and girls, respectively, so that it is probably best not to make too much of it. Nevertheless, it is tempting to see these variables as potentially important in revealing individual differences in central BF in boys and lower BF in girls. Principal component analyses of subcutaneous fat variables show a small but consistent 'second' component of variance, after a general, first "fat component," which reveals information regarding individual differences in central vs peripheral fat distribution (Hammond, 1955; Wohlleb and Mueller, 1981; Baumgartner et al., 1986). The fourth factor from the maximum-likelihood method was related only to arm muscle circumference and explained very small proportions of variance (2–5%). It did not relate strongly to FFM. It is probably an artifact of computing arm muscle circumference from a combination of arm circumference and the triceps skinfold, variables also present in the factor structure.

The second hypothesis tested in this study is that the respective factors will be predictive of %BF and FFM with high precision ($R^2 \geqslant 0.90$). This hypothesis was only partially upheld. The R^2s from the prediction equations in Table 4 range from 0.81–0.93. They are generally higher for %BF (0.86–0.93) than for FFM (0.81–0.93). Therefore, the precision is not high enough to suggest that the factors are functionally equivalent to their respective compartments of body composition. This is especially so, as the estimates of the body composition components are likely to be biased upward by the inclusion of some of the anthropometry in their calculation. The lack of functional equivalence may be because of the peculiar set of anthropometrics included in the data set, some of which reflect adipose stores (skinfolds) and others which include both fat and lean tissues (e.g., calf circumference). This would lessen the specificity of the fat factor and require that elements from both factors be included in prediction of FFM, which is the case (Table 4).

The third hypothesis was that clusters of anthropometric variables would emerge that could serve as surrogate measures of %BF or FFM in field studies in which BIA is not included. One such cluster did indeed emerge. The sum of the triceps, subscapular, and midaxillary skinfolds was highly correlated to %BF and FM, much more so than lower extremity skinfolds, the BMI or abdominal circumference. The BMI is more related to FM than %BF, a finding in other studies as well (Roche et al., 1981). The triceps, subscapular, and midaxillary skinfolds are also strongly and consistently weighted on the 'body mass' factor across ages and sexes (Table 3). Factor loadings equal or exceed 0.85 for these variables. These are among the very skinfolds shown by Guo et al. (1989) to be the 'best' estimators of BF from anthropometry and bioelectrical impedance measures among adolescents and young adults. These results lend support to the use of these three skinfolds as a sum for grading individuals for body fatness. No such "simple" indicator of FFM emerged in the analysis. Indeed, the prediction of FFM from anthropometric factors involved both factors, 'body mass' (F1), and 'linearity' (F2) (Table 4).

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