Estimating Body Fat from Anthropometry and Isotopic Dilution: A Four-Country Comparison

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Abstract

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Objective: The goal was to assess the ability of BMI to predict body fat (BF) among youths in four countries and identify the degree to which additional anthropometric measures improve this prediction. BMI is widely recommended as an indicator of overweight. However, whether BMI adequately estimates BF and has the same meaning in different ethnic groups and youths has been questioned.

Research Methods and Procedures: Data come from 456 Filipino, Chinese, Russian, and black South African youths, 6 to 16 years old. Percentage BF and fat mass index (FMI) were estimated by the deuterium dilution method. Skinfold thicknesses (triceps, subscapular, and suprailiac) and weight and height measures were collected. Percentage BF was regressed first on BMI and age and then with the addition of the skinfold measures. Linear models were run separately by country and sex. The models were repeated with FMI as the outcome.

Results: The R^2 values from the percentage BF models ranged from 0.13 to 0.69 in the first models to 0.38 to 0.81 in the full models. The values were lowest among Russian males ≥ 13 years and Russian females ≥ 13 years of age in the reduced and full models, respectively, and were highest among Chinese females. Using FMI as the outcome did not meaningfully change the results.

Discussion: The ability of BMI to adequately predict BF and the additional predictivity of anthropometric measures varied widely across the samples, making its uniform use as a proxy for BF in youths from different countries questionable.

Key words: percentage body fat, deuterium dilution, BMI, developing countries, fat mass index

Introduction

Obesity is an established risk factor for cardiovascular disease, type 2 diabetes, and other chronic health problems (1–3). The prevalence of obesity is increasing among youths and adults both in developed (4–7) and in developing countries undergoing the nutrition transition (8–13). For children, the studies documenting these important trends often rely on weight-for-height indices to define overweight or obesity, despite the fact that excess body fat (BF)[1] is the specific factor associated with increased disease risk. Epidemiological studies of obesity could benefit from a simple and appropriate indicator for adiposity for use in different age and ethnic groups.

Adiposity may be estimated through in vivo body composition methods such as underwater weighing, deuterium oxide dilution, and radioactive potassium counting (14). However, these methods are expensive and/or invasive and, thus, not well suited to large epidemiological studies. In addition, the assumptions underlying these methods are population- and age-specific and may not be equally valid for different age and ethnic groups (14,15). In contrast, anthropometry is inexpensive, practical, and easy to use in large population-based field studies, and age- and sex-specific reference data are available.

The most common anthropometric indicator of BF is BMI (kilograms per meter squared). Although the World

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[1] Nonstandard abbreviations: BF, body fat; WHO, World Health Organization; FM, fat mass; FMI, fat mass index; FFM, fat-free mass; TBW, total body water; SF, skinfold; FFMI, fat-free mass index; MSE, mean squared error; PFM, percentage fat mass.

Health Organization (WHO) and the Centers for Disease Control and Prevention both recommend BMI as a fatness indicator across populations (4,16–18), recent findings have challenged the assumption that BMI has the same meaning in all ethnic groups (19).

A recent meta-analysis of the relationship between BMI and percentage BF among Chinese, Ethiopians, Indonesians, Polynesians, Thais, American blacks, and American whites revealed that people of different ethnic groups had significantly different BMIs at the same levels of BF, age, and gender (20). Differences in the relationship between BMI and percentage BF have also been shown in populations from Singapore (21), Japan (22), and Hong Kong (23) when compared with American whites. Within the U.S., the National Heart, Lung, and Blood Institute Growth and Health Study found that the BMI for lean 9-year-old black children was ~3% higher than that for lean white children of the same age (24). Possible reasons for ethnic differences in the relationship between BMI and percentage BF include differences in fat-free body density, the distribution of subcutaneous fat, and limb length relative to trunk size (14,25).

These findings suggest that estimates of BF from anthropometric indicators may produce systematic errors across different ethnic groups (26). Thus, there has been an urgent call for further research in diverse populations, especially those from developing countries (20), to help clarify ethnic differences in body composition and to develop measures of BF that allow us to accommodate these differences.

Our study addresses this gap by exploring the ability of a variety of anthropometric indicators to predict body fatness in youths from four different countries: the Philippines, China, South Africa, and Russia. Two different indicators of body fatness are explored as standards against which the anthropometric measures are compared. These are percentage BF and fat mass (FM) index (FMI) (FM per height squared), both estimated using the deuterium oxide dilution method. FMI is included in addition to percentage BF because percentage BF, commonly considered to be the standard of body fatness, has been criticized for ignoring between-subject variation in fat-free mass (FFM) (26). Differences in percentage BF between two individuals could reflect either similarities in FFM and true differences in FM or could reflect similarities in FM and differences in FFM (26). This has led to the suggestion that FM and FFM, both derived from total body water (TBW) through the same deuterium dilution method used to calculate percentage BF, be normalized for height by dividing them by height squared and used as distinct indices of body composition (26).

Research Methods and Procedures

Subjects

Subjects 6 to 16 years of age were recruited from local schools in Metropolitan Cebu, Philippines ($n = 87$); Beijing, China ($n = 91$); Moscow, Russia ($n = 192$); and Johannesburg, South Africa, where all the subjects recruited were black ($n = 86$). Sample sizes reflect exclusions due to age >17 years (3 in Cebu), age < 6 years (1 in Russia), implausible values of percentage BF (<3) (2 in Russia and 1 in South Africa), missing percentage BF measures (16 in Cebu, 10 in China, and 7 in South Africa), missing subscapular skinfold (SF) measures (1 in Russia), and measurements that caused violations in the assumptions of normality and linearity necessary for unbiased use of linear regression, as will be discussed further later (4 in Cebu, 4 in China, 2 in South Africa, and 5 in Russia). The four country locations were chosen to help derive estimating equations of percentage BF for use in four ongoing longitudinal studies: the Cebu Longitudinal Health and Nutrition Survey, the Chinese Health and Nutrition Survey, the Birth to Ten study in South Africa, and the Russian Longitudinal Monitoring Survey. These larger studies have been described in detail elsewhere (27–30). Parental consent was obtained for all recruits, and the study protocols were approved locally and by the University of North Carolina at Chapel Hill School of Public Health Institutional Review Board.

Data Collection

On a specified day, subjects reported to a designated classroom on arrival at school, after breakfast. Control saliva samples were immediately collected in special tubes (Salivette, Starstedt, Newton, NC) by having children chew on a cotton pellet for 45 to 60 seconds. Each child then received a 30-g dose of deuterium oxide (99% atom percent excess; Cambridge Isotope Laboratories, Andover, MA), followed by a tap water rinse. During the equilibration period, children remained in the specified classroom, with investigators present, reading or performing light activities. There was no food intake during the equilibration period, and water intake was measured and considered in the calculations. Additional saliva samples were collected at 3.0 and 3.5 hours after administration of the deuterium oxide. The saliva samples were placed in tubes, then frozen and shipped to the Johns Hopkins Center for Human Nutrition (Baltimore, Maryland) for analysis. Data collection at all four sites was completed by personnel who received training guided by the same techniques and training manuals.

During the wait between the administration of the deuterium oxide and the collection of the final saliva samples, anthropometric measures were taken by highly trained personnel using standard techniques. Weight was measured to the nearest 0.1 kg, and height was measured to the nearest 0.1 cm. Triceps, suprailiac, and subscapular SFs were measured to the nearest 0.1 mm. BMI was calculated for each individual as kilograms per meter squared (2). Children wore light clothing and were barefoot or wore socks.

Laboratory Analysis

Saliva samples were analyzed for isotopic enrichment by infrared spectroscopy, as described elsewhere (31). Water was extracted by vacuum sublimation and condensed in a dry ice-methanol trap. Deuterium absorbance was measured in duplicate at 2500 cm^{-1} in a fixed filter, single-beam infrared analyzer (Miran, Foxboro Analytical Co., South Norwal, CT). Interassay coefficient of variability was <3%. The deuterium dilution space was calculated as (D/C)/wt, where D is the isotope dose, C is the tracer concentration in saliva at equilibrium, and wt is body weight (kilograms). TBW was calucated from the deuterium dilution space assuming that this space corresponds to 104% of TBW. Results from the samples taken at 3 and 3.5 hours were averaged.

Calculation of Percentage BF, FMI, and FFM Index (FFMI)

Percentage BF was estimated based on the assumption that the water content of FFM (fat-free hydration) is 76%:

$$\%BF = [(\text{weight} - \text{TBW}/0.76)/\text{weight}] \times 100$$

where weight is body weight in kilograms and TBW is in kilograms. FFM was estimated as suggested by Wells (26):

$$\text{FFM} = \text{TBW}/\text{FFM hydration}$$

FM was then estimated as follows:

$$\text{FM} = \text{body weight} - \text{FFM}$$

FM and FFM were then each divided by height squared to produce the FMI and the FFMI, respectively.

Statistical Analysis

Multilinear regression estimating models were tested separately for each country and were stratified by sex. Percentage BF and FMI were separately regressed on different combinations of anthropometric measures to identify the best predictors. Due to the wide age range in the Russian sample, models using the Russian data were further stratified by age (two strata of <13 and ≥13 years of age). Age 13 was chosen as the cut point in creating these strata because it coincides approximately with puberty and because it makes the two Russian groups comparable in age with the groups from the other countries. Three sets of model specifications were tested for each outcome (percentage BF and FMI). Model 1 included only BMI and age as predictors because these are often the only variables available in large studies and because BMI is recommended by the WHO and the Centers for Disease Control and Prevention to define overweight. Model 2 retained BMI and age and added triceps SF thickness. Triceps is the most commonly measured SF and represents limb fat. Model 3 retained BMI, age, and triceps SF and added suprailiac and subscapular SFs, which measure subcutaneous trunk fat. We also tested a fourth model using the sum of SFs as a predictor, but this specification did not improve the model fit in any of the samples, and in some cases lowered the R^2 values. Thus, only Models 1 to 3 are presented.

For each model specified above, several regression diagnostics were performed. Cook and Weisberg tests for heteroscedasticity indicated no violations. The normality of the residuals from each model was tested using the Wilkes-Shapiro test, and subjects whose measurements caused violations were excluded. After exclusions made due to normality violations of the residuals, subjects with absolute values of Studentized residuals > 3 and whose exclusions caused increases of more than three percentage points in the R^2 values for the model under scrutiny were additionally excluded. Lowess smoothers were used to examine the assumption of linearity between the independent variables and the outcomes of interest. Subjects whose measurements resulted in gross violations of the linearity assumption were excluded. Subjects who were excluded due to violations with regard to any one model were excluded from all analyses to ensure comparability among the models. These criteria resulted in the exclusion of four subjects from Cebu, four from China, two from South Africa, and five from Russia, as mentioned earlier. All analyses were performed in Stata for Windows (Release 6.0, Stata Corporation, College Station, TX).

Results

Descriptive Statistics

Means (±SD) for the anthropometric variables and for age are presented in Table 1. Among males, Russians < 13 years of age had the highest mean percentage BF (30.4%), whereas South Africans had the lowest (19.4%). Among females, Russians ≥ 13 years of age had the highest mean percentage BF (36.0%), whereas Chinese youths had the lowest (19.0%). FMI followed the same pattern. Among males, mean BMI was highest in the sample of Russians ≥ 13 years of age (19.4) and lowest in the South African sample (16.3). Among females, mean BMI was highest in the Cebu sample (20.6) and lowest in the sample of Russians < 13 years of age (16.7).

Percentage BF, FMI, BMI, and FFMI with data from all countries combined were plotted against age among girls in Figure 1 and among boys in Figure 2. Because only three children contributed measurements at 6 years of age, they were excluded from the figures; thus, the figures reflect data from ages 7 through 16 years. Also, it should be noted that although the data are pooled, different countries contributed data to the graph at different ages. The age ranges of the subjects, again, were 13 to 16 years in Cebu, 8 to 11 years in China, 4 to 16 years in Russia, and 10 to 12 years in South Africa. Despite these age differences, the same indi-

Table 1. Mean (SD) age in years, percentage BF, FMI, BMI, and SF thicknesses (millimeters)

	Cebu		China		South Africa		Russia			
							Males		Females	
Variable	**Males (n = 37)**	**Females (n = 50)**	**Males (n = 46)**	**Females (n = 45)**	**Males (n = 38)**	**Females (n = 48)**	**<13 yrs (n = 70)**	**≥13 yrs (n = 25)**	**<13 yrs (n = 53)**	**≥13 yrs (n = 44)**
Percentage BF	19.8 (7.39)	31.7 (6.07)	19.9 (6.55)	19.0 (8.06)	19.4 (8.61)	23.5 (9.08)	30.4 (8.27)	26.9 (6.53)	34.3 (6.73)	36.0 (5.72)
FMI	3.9 (1.79)	6.6 (1.98)	3.4 (1.53)	3.4 (1.90)	3.3 (1.72)	4.2 (2.46)	5.4 (2.15)	5.3 (1.66)	5.9 (2.04)	7.1 (1.76)
BMI	19.3 (2.12)	20.6 (3.09)	16.8 (2.19)	17.1 (2.51)	16.3 (1.79)	16.9 (3.02)	17.1 (2.41)	19.4 (2.20)	16.7 (2.80)	19.5 (2.32)
Age	15.6 (0.44)	15.4 (0.53)	10.1 (0.75)	9.9 (0.77)	11.2 (0.59)	10.9 (0.42)	9.5 (1.69)	14.8 (0.88)	9.8 (1.83)	14.3 (0.93)
Triceps SF	9.6 (3.72)	16.1 (2.97)	14.1 (4.43)	11.5 (4.98)	7.3 (2.39)	9.5 (5.81)	9.4 (4.66)	8.1 (2.81)	11.5 (5.58)	14.9 (4.28)
Subscapular SF	8.9 (2.22)	12.6 (2.74)	10.2 (4.49)	9.3 (5.88)	7.6 (2.13)	9.6 (5.51)	7.9 (4.95)	8.2 (1.86)	8.5 (5.57)	11.1 (4.16)
Suprailiac SF	9.5 (2.58)	11.4 (2.39)	9.3 (4.58)	9.6 (7.77)	6.9 (2.61)	8.6 (6.41)	8.7 (5.36)	9.9 (4.23)	10.3 (7.04)	15.6 (5.48)

viduals contributed to each of the four graphs (percentage BF, BMI, FMI, and FFMI) at each age in both sexes; thus, sex-specific comparisons made among the graphs by age are valid. Among girls, the graphs of percentage BF and FMI reveal similar shapes, with body fatness beginning high at 7 years of age, falling steadily until 9 years of age, then rising to its peak between 12 and 13 years of age before falling again briefly through 14 years of age, and then rising again. The graph of BMI, however, shows a fairly consistent increase across age. The graph of FFMI also shows a steady increase with age, except for one dip between 11 and 12 years. Among boys, the graphs of percentage BF and FMI show body fatness beginning high at 7 years of age. Fatness then decreases until 11 years of age, jumps up at 12 years of age, and then falls, with one small rise on the way, to its lowest level at 16 years of age. Again, the graphs of BMI and FFMI show a different shape with adiposity generally rising with age, aside from a few dips during early adolescence. Although the graphs reveal sex differences between females and males, the graphs from both sexes are similar in that they make the shortcomings of BMI apparent: the graphs of BMI do not track with the graphs of percentage BF. As Wells (26) has pointed out, BMI is correlated with both FM and FFM and, thus, can act as a proxy for both but cannot distinguish between the two. For example, among both boys and girls, the graphs in Figures 1 and 2 show that the rise in BMI between 7 and 9 years of age reflects a rise in FFM, whereas FM and percentage BF actually dropped in both sexes at the same ages.

Regressions of Percentage BF and FMI on Anthropometric Measures

The R^2 values and mean squared error (MSE) terms from the regressions both of percentage BF and of FMI are shown in Table 2. The percentage of variation in percentage BF explained by the independent variables was highest among Chinese females (with R^2 values ranging from 0.69 to 0.81 from Models 1 to 3, respectively) and was lowest among Cebu females, Russian males $\geq$ 13 years of age, and Russian females in both age strata. The R^2 values for these groups ranged from 0.13 among Russian males $\geq$ 13 years of age in Model 1 to 0.42 among Russian females $<$ 13 years of age in Model 3. FMI was predicted with considerably larger R^2 values (e.g., a range of increase in R^2 values of 14 to 45 percentage points in Model 1) and much smaller MSE terms than percentage BF for all groups. That is, the anthropometric measures explained more of the variation in FMI than in percentage BF.

The regression coefficients from the regressions of percentage BF are shown in Table 3. BMI was positively associated with percentage BF in all groups and was statistically significant ($p < 0.05$) in all groups except among Russian males $\geq$ 13 years of age in Model 1. In Model 2, triceps SF was positively associated with percentage BF in

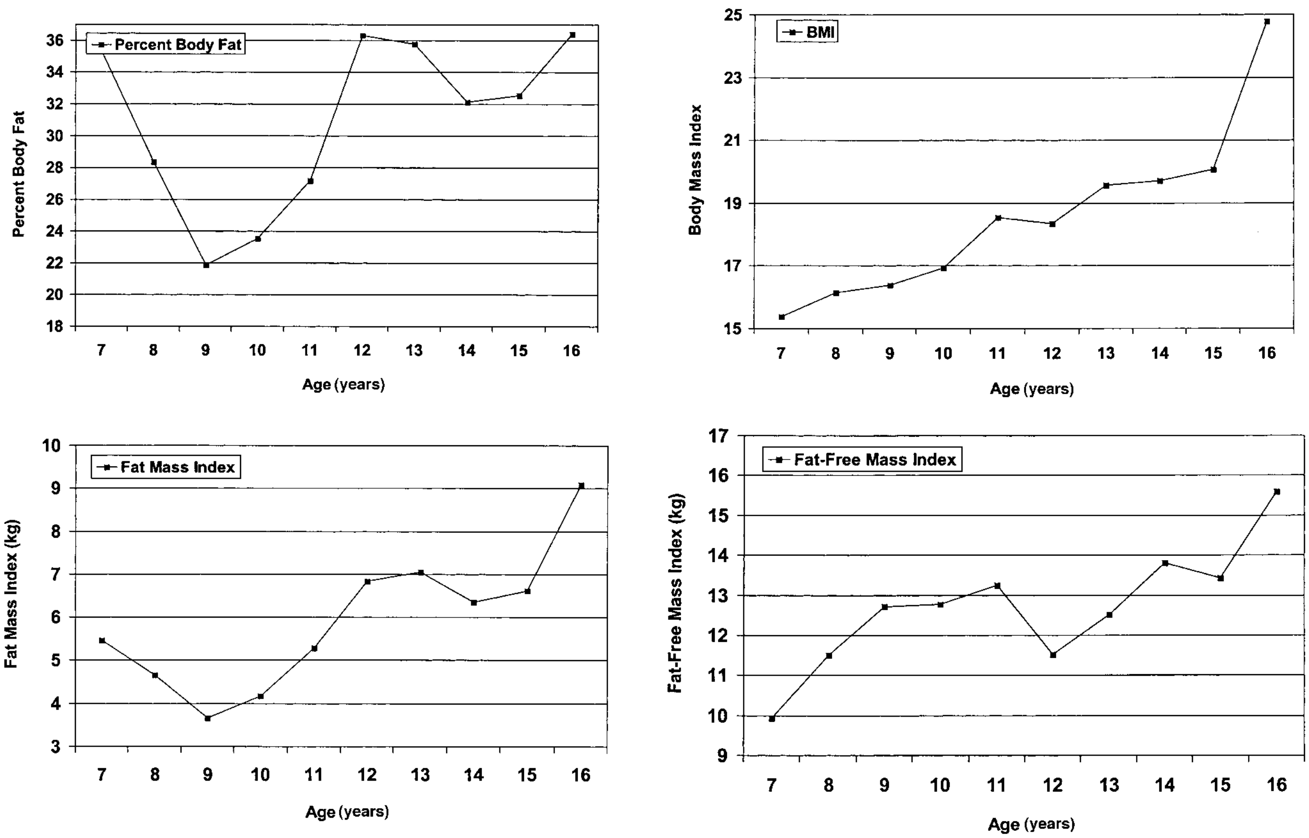

Figure 1: Percentage BF, BMI, FMI, and FFMI by age among girls in the combined populations from Cebu, China, South Africa, and Russia.

all groups and was statistically significant among both males and females in Cebu and South Africa, among Chinese females, and among Russian males ≥ 13 years of age. The direction of the association between BMI and percentage BF switched from positive to negative among Russian males ≥ 13 years of age in Model 2, but the association was not significant. Referring back to Table 2, the gains in the R^2 values with the addition of the triceps SF in Model 2 ranged from 0 percentage points among Chinese males to 25 percentage points among Russian males ≥ 13 years of age. The direction of the association of the subscapular and suprailiac SFs with percentage BF in Model 3 was inconsistent across the populations, across the sexes, and within the sexes. The subscapular SF was statistically significant only among Chinese children, and the suprailiac SF was not statistically significant in any of the groups. With the addition of the trunkal SFs in Model 3, the association between BMI and percentage BF switched from a positive to a negative relationship among Cebu males, but the association was not significant. Again referring back to Table 2, the rise in the R^2 values in Model 3 compared with Model 2 ranged from 0 percentage points among Cebu females and South African males to 7 percentage points among Chinese males.

The relationship between the independent variables and FMI was virtually the same in all the groups as it was with percentage BF as the outcome. Thus, the coefficients from the models of FMI are not included in Table 3. When considering all the models in all the groups, there were only two differences in the direction of associations between independent variables and the outcome when using FMI as the outcome instead of percentage BF; in each case, the associations were not significant. There were more differences with regard to the significance of the different anthropometric measures, but wherever a particular measurement was significant using only one of the outcomes, there was near-significance using the other outcome.

Discussion

When judged by the percentage of variation in percentage BF accounted for by anthropometric measures, BMI was not a satisfactory proxy for percentage BF even among Chinese children, for whom the R^2 values in the models tested were highest. Even with the addition of SFs, the highest R^2 value reached for Chinese females in Model 3 was not as high as that reached in regressions of percentage BF on a combination of weight and SF thicknesses in the Pathways mul-

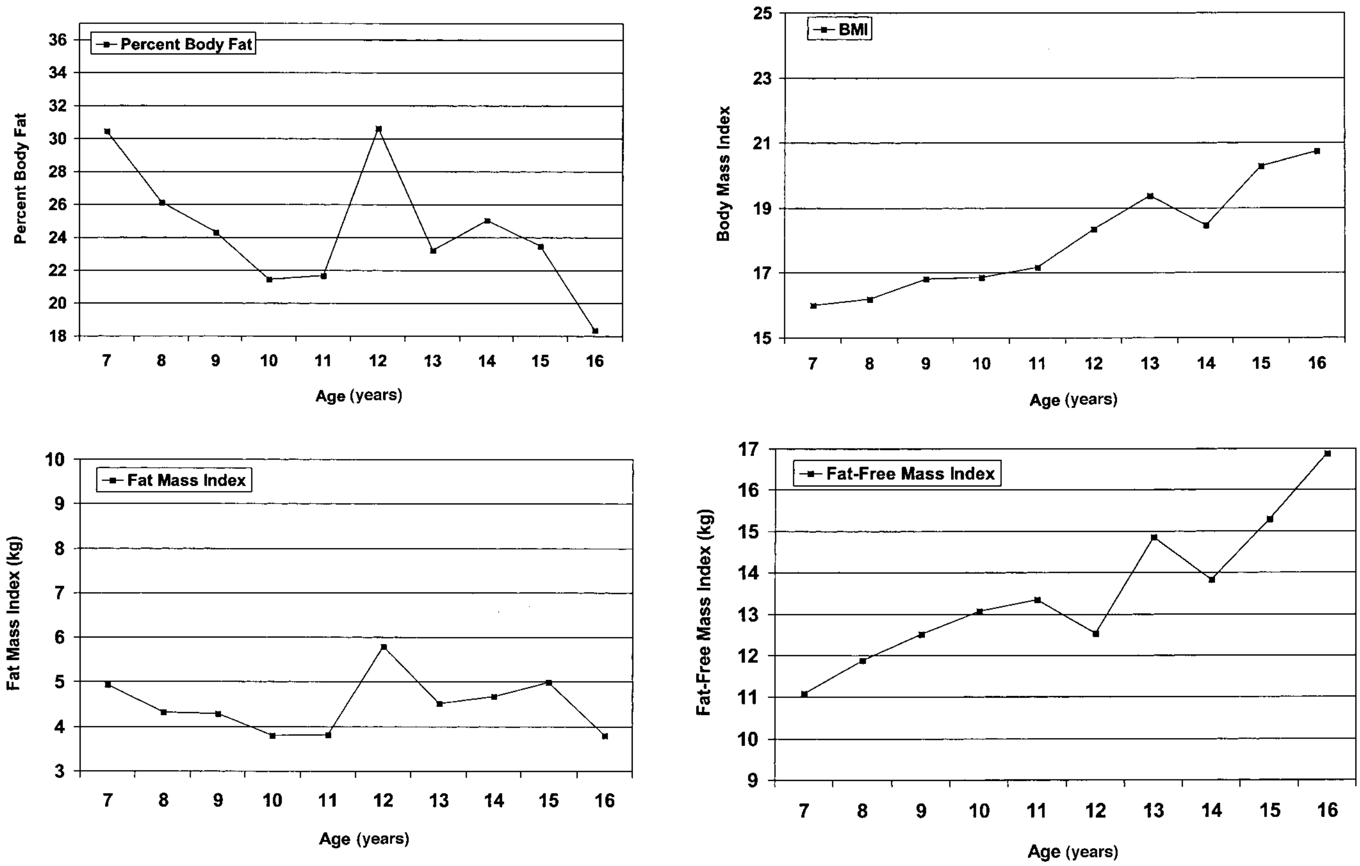

Figure 2: Percentage BF, BMI, FMI, and FFMI by age among boys in the combined populations from Cebu, China, South Africa, and Russia.

tisite study of obesity in Native American children (31). This indicates that BMI and other anthropometric proxies for percentage BF should be used with caution among children from diverse ethnic groups. There are several possible explanations for our findings.

In any study where anthropometric measures are performed and laboratory samples are collected, measurement error and sample handling must be considered. Measurement error was minimized by having trained personnel perform all measurements using standard procedures. Although it is possible that there were slight differences among the sites in measurement technique, any errors likely would be systematic within sites. Proper storage and shipping of the saliva samples were ensured.

Because it was considered to be unethical to require young children to fast for the duration of time needed for deuterium dosage and saliva collection (over 3 hours), children were allowed a light breakfast before saliva collection. Although specific dietary intake data were not collected, we estimate that food caused only a relatively small increase in TBW during the period of study. Food intake causes an expansion in TBW due to metabolic water being produced by the metabolism of food-derived energy. Under the conditions of light physical activity during the study and assuming an average respiratory quotient of 0.85, the rate of expansion of the body water pool during the equilibration period would have been ~0.04% per hour. Such a small measurement error would neither introduce major biases into our results nor explain the differences across countries found in our study. Although food intake also may have affected weight, it is unlikely that the weight of a light breakfast differed significantly by site. Thus, any error introduced would be systematic and would not affect the validity of our conclusions drawn from comparisons between the groups. Similarly, because it was not considered appropriate to weigh adolescents without clothing, all subjects wore light clothing consisting of a t-shirt, shorts, and socks. Again, because it is unlikely that the weight of such clothes differed meaningfully by sight, the validity of our comparisons is not compromised. However, the small sample sizes available in this study may have affected the fit of the models.

The assumptions underlying the isotopic dilution method for estimating BF must also be considered. This method requires an assumption of the water content of fat-free body mass. This hydration fraction is known to decrease progressively with age to the adult value of 73%. We used a hydration fraction of 76% for the age range of the subjects

Table 2. R^2 values and MSE terms from regressions of percentage BF and FMI in three sequential models

	Model 1 (age, BMI)				Model 2 (triceps SF added)				Model 3 (subscapular and suprailiac SFs added)			
	Percentage BF		FMI		Percentage BF		FMI		Percentage BF		FMI	
Population	R^2	**MSE**	R^2	**MSE**	R^2	**MSE**	R^2	**MSE**	R^2	**MSE**	R^2	**MSE**
Cebu												
Males	0.36	6.09	0.55	1.24	0.48	5.56	0.65	1.10	0.51	5.56	0.67	1.11
Females	0.28	5.26	0.73	1.05	0.39	4.91	0.76	1.00	0.39	4.91	0.77	1.01
China												
Males	0.65	3.98	0.81	0.68	0.65	3.99	0.81	0.68	0.72	3.64	0.86	0.61
Females	0.69	4.61	0.83	0.81	0.77	4.00	0.87	0.70	0.81	3.75	0.90	0.63
South Africa												
Males	0.56	5.86	0.71	0.96	0.63	5.44	0.77	0.87	0.63	5.60	0.77	0.90
Females	0.56	6.17	0.83	1.04	0.62	5.80	0.88	0.89	0.64	5.76	0.90	0.84
Russia												
Males < 13	0.52	5.82	0.79	1.01	0.54	5.74	0.80	0.98	0.55	5.74	0.81	0.96
Females < 13	0.37	5.43	0.81	0.90	0.38	5.47	0.81	0.90	0.42	5.38	0.83	0.87
Males ≥ 13	0.13	6.37	0.45	1.29	0.38	5.48	0.62	1.09	0.41	5.62	0.64	1.12
Females ≥ 13	0.31	4.87	0.71	0.98	0.36	4.75	0.73	0.95	0.38	4.81	0.73	0.96

in our study based on research by Boileau et al. (32), who reported factors of 75.6% in white and African-American prepubescent children (mean age 9.8 years) and 75.5% in pubescent children (mean age 12.8 years). Their data indicate that the hydration of fat-free body mass does not show larger differences with age until the postadolescent period and does not reach the adult value of 73% until age 22 years or later. A hydration fraction of 76% for youths has been used by other researchers as well (31). Although the use of a single hydration coefficient for all the ages included in our study may introduce some error, the magnitude of this error would be too small to explain the observed between-site differences in percentage BF. For example, in an extreme scenario in which the adult FFM hydration fraction (73%) was used in combination with prepubertal tissue density (1.050), there would be a 4% error in BF estimates. Age and sex-specific ethnic differences in hydration of the FFM are rather minor (14,25,33).

Based on the evidence from Figure 1, BMI does not distinguish between FM and FFM. Although BMI and FFM increase steadily with age, FM does not. This indicates that at some ages, the increase in BMI reflects increases in FFM rather than FM and, thus, is a poor explanatory factor for the variability in percentage BF.

One potential reason for the incongruities between BMI and the other estimates of adiposity is the failure to correct for level of maturation. In a study exploring the relationship of BMI to percentage FM (PFM) in German youths, Shaefer et al. (34) found that correction for pubertal stage significantly improved the prediction of PFM from BMI. For instance, in boys, the total explained variance of PFM was increased from 29% to 66% when pubertal stage defined by the Tanner method (35) was included in a model regressing PFM on BMI. In our data, the coefficients for BMI were significant in all three models of percentage BF for Russian males < 13 years of age but were not significant in any of the models for Russian males ≥ 13 years of age, differences that may reflect the effects of puberty. Precise measures of maturation were available only for the Cebu boys, for whom pubertal stage data were collected. Surprisingly, inclusion of maturation corrections did not produce a more precise prediction equation in this case. Maturation stage was not measured among Cebu girls or in the other three samples, leaving open the possibility that maturation might matter in these other groups.

BMI and SFs explained more variation, and with lower MSE values, in FMI than in percentage BF. In Figure 1, we see that trends in FMI and percentage BF are quite comparable and include large dips with age, whereas BMI increased steadily with age. Thus, the improvement of the fit of the models when using FMI as the outcome rather than percentage BF is most likely the result of both BMI and FMI being adjusted for height in the same manner. Thus, although BMI has the same problem with regard to its relationship with FMI that it does with percentage BF—namely that it cannot distinguish fat from FFM—it does a

Table 3. Regressions of percentage BF in three sequential models

Population	Model 1 (age, BMI)		Model 2 (triceps SF added)		Model 3 (subscapular and suprailiac SFs added)	
	Males coefficient (SD)	Females coefficient (SD)	Males coefficient (SD)	Females coefficient (SD)	Males coefficient (SD)	Females coefficient (SD)
Cebu						
BMI	2.13 (0.49)*	1.04 (0.24)*	0.47 (0.74)	0.54 (0.29)	−0.14 (0.89)	0.75 (0.43)
Age	−3.54 (2.37)	0.66 (1.43)	−2.27 (2.21)	1.33 (1.36)	−2.95 (2.29)	1.52 (1.42)
Triceps			1.16 (0.41)*	0.84 (0.30)*	0.68 (0.55)	0.98 (0.36)*
Subscapular					0.26 (0.80)	−0.36 (0.65)
Suprailiac					1.07 (0.80)	−0.05 (0.48)
China						
BMI	2.56 (0.29)*	2.68 (0.28)*	2.41 (0.33)*	1.30 (0.43)*	1.52 (0.45)*	0.93 (0.55)
Age	−3.31 (0.84)*	−2.63 (0.91)*	−3.55 (0.88)*	−2.73 (0.79)*	−3.76 (0.82)*	−2.89 (0.77)*
Triceps			0.16 (0.17)	0.84 (0.22)*	0.08 (0.16)	0.97 (0.31)*
Subscapular					0.50 (0.25)*	0.81 (0.30)*
Suprailiac					0.14 (0.27)	−0.56 (0.28)
South Africa						
BMI	3.50 (0.57)*	2.20 (0.30)*	2.09 (0.77)*	1.17 (0.49)*	1.97 (0.89)*	1.00 (0.57)
Age	0.79 (1.74)	1.25 (2.19)	0.52 (1.61)	1.11 (2.06)	0.63 (1.70)	2.10 (2.13)
Triceps			1.45 (0.57)*	0.66 (0.25)*	1.44 (0.70)*	0.18 (0.41)
Subscapular					0.22 (0.70)	−0.37 (0.58)
Suprailiac					−0.06 (0.61)	0.84 (0.56)
Russia $<$ 13 years of age						
BMI	2.63 (0.31)*	1.51 (0.30)*	1.98 (0.49)*	1.27 (0.54)*	1.64 (0.55)*	1.25 (0.64)
Age	−0.86 (0.45)	−0.14 (0.46)	−0.88 (0.44)	−0.14 (0.47)	−0.95 (0.44)*	−0.14 (0.46)
Triceps			0.43 (0.25)	0.14 (0.26)	0.22 (0.29)	0.39 (0.36)
Subscapular					0.08 (0.31)	0.45 (0.34)
Suprailiac					0.31 (0.29)	−0.54 (0.31)
Russia $\geq$ 13 years of age						
BMI	0.99 (0.61)	1.39 (0.32)*	−0.39 (0.70)	0.85 (0.45)	−0.33 (0.98)	0.84 (0.49)
Age	0.56 (1.52)	−0.75 (0.81)	2.68 (1.49)	−0.61 (0.79)	2.90 (1.70)	−0.52 (0.81)
Triceps			1.64 (0.55)*	0.41 (0.24)	1.49 (0.73)	0.55 (0.28)
Subscapular					−0.89 (1.22)	0.12 (0.27)
Suprailiac					0.43 (0.54)	−0.23 (0.22)

* $p < 0.05$.

better job of explaining the variability of FMI by virtue of their shared manner of controlling for body size.

Differences in the significance and direction of the anthropometric predictors of percentage BF between the populations and sexes suggest differences in BF distribution. For example, although SF thicknesses were important predictors of percentage BF in Chinese males and females, they were not significant predictors of percentage BF in Russian male and females $<$ 13 years of age, and the R^2 values for the Russian groups $<$ 13 years of age were low. This could indicate, for example, that Russian children $<$ 13 years of age had more subcutaneous fat that cannot be measured through SFs, whereas the Chinese children had more limb and trunk fat that was easily measured.

This paper contributes to the existing literature in several ways. It responds to the growing need for body composition research in diverse ethnic groups, it explores whether FMI might be more easily predicted by anthropometric measures than percentage BF, and it determines whether combining SF measures with BMI can improve the prediction of percentage BF over the use of BMI alone within the study population.

The conclusions drawn from this research reflect the complex nature of body composition research. First, changes in BMI represent changes in FFM in addition to changes in FM. In children undergoing dramatic changes in body composition, BMI is a poor proxy for adiposity. BMI is a better indicator of adiposity in adults, in whom dramatic changes in FFM are not common (in the absence of major disease), and weight changes mainly reflect shifts in FM. Second, future studies that relate anthropometric indicators to more direct measures of BF need to explore further the influence of maturation levels. Third, the ability of BMI and SF measures to predict adiposity differs substantially among children of different ethnic groups, which may reflect differences in fat distribution. Thus, tailored estimating equations that take into account such differences should be used when studying body composition in youths from different ethnic groups.

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