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US pediatric population-level associations of DXA-measured percentage of body fat with four BMI metrics with cutoffs

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Abstract

Objective—Four body mass index (BMI) metrics—BMI, BMI z-score, BMI percentile, and BMI %—are commonly used as proxy measures for children's adiposity. We sought to determine a BMI metric that is most strongly associated with measured percentage of body fat (%BF) in the US pediatric population stratified by sex, age and race/ethnicity, and to determine cutoffs that maximize the association for each BMI metric.

Subjects, Design and Methods—%BF was measured by DXA among N=6120 US boys and girls aged 8.0 to 17.9 years old from NHANES 1999-2004. We fit piece-wise linear regression models with cutoffs to %BF data using each BMI metric as the predictor stratified by sex, race/ethnicity and age. The slopes were modeled differently before and after the cutoffs which were determined based on grid searches.

Results—BMI z-score was in general most strongly associated with %BF for both boys and girls. The associations of the four BMI metrics were lowest for boys aged 12-13.9 years and girls aged 16-17.9 years, and strongest for Mexican-American boys and for non-Hispanic black girls. Overall, the associations were stronger for girls than for boys. In boys, BMI had the lowest association with %BF (R^2=0.39) for all ages combined. The fold changes in slopes before and after cutoffs were greatest in general for BMI percentiles regardless of age, sex and race/ethnicity. BMI z-score cutoffs were 0.4 for both boys and girls for all ages combined. Except for BMI, the slopes after the cutoffs were in general greater than those before.

Conclusions—All BMI metrics were strongly associated with %BF when stratified by age and race/ethnicity except that BMI was the least associated with %BF in boys for all ages combined.

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Overall, BMI z-score was superior for evaluation of %BF, and its cutoff of 0.4 can also serve as a threshold for careful monitoring of weight status.

Keywords

Pediatric obesity; percentage of body fat; BMI metrics; growth

INTRODUCTION

Excessive body fat is a serious public health concern not only for the adult population but also for the pediatric population[1]. Pediatric obesity is associated with a number of comorbidities including type II diabetes[2], hyperlipidemia[3], hypertension[4] and thus elevated risk of cardio-vascular diseases[5, 6]. Furthermore, pediatric obesity, and its associated comorbidity, can be carried into adulthood[7, 8]. Therefore, the assessment of excess body fat in childhood is critically important. To this end, advanced techniques such as dual energy X-ray absorptiometry (DXA) are utilized in pediatric samples to more accurately measure body fat[9-11]. However, body mass index (BMI; kg/m^2), weight in kilograms (kg) divided by the square of height in meters (m), is a widely used anthropometric proxy measure of adiposity because it is much easier to measure and thus more practical in clinical or research settings. For example, the American Academy of Pediatrics emphasizes BMI screening and use in routine clinical practice[12] as well as in schools[13]. In children, however, in order to take growth into account pediatric adiposity is more often measured by the following age-sex-adjusted measures derived from BMI: BMI z-score, BMI percentile, and BMI%[14]. BMI% is defined as100×log-$_e$(BMI/age-sex-adjusted median BMI), and thus it is a relative age-sex-adjusted BMI. Herein, these four measures are referred to as BMI metrics following the terminology used by Field et al[15]. The BMI metrics include BMI itself.

Pediatric obesity is defined based on the age-sex-adjusted BMI percentile which is derived from the Centers for Disease Control and Prevention (CDC) 2000 growth charts[16] while adult obesity is defined based on BMI[17]. For example, pediatric overweight and obesity are defined as 85 ≤ BMI percentile < 95 and BMI percentile ≥ 95, respectively in the United States (US). However, a study has shown that of the BMI metrics, BMI percentile is least associated with DXA-measured percentage of body fat (%BF) among the BMI metrics in children aged 5-18.7 years[15]. On the other hand, Pietrobelli et al validated the use of BMI for prediction of DXA-measured %BF fat in a relatively small sample of Italian children aged 5-19 years old[18]. Mei et al further supported the validity of BMI stratified by age in predicting underweight and overweight in children aged 2-19 years old using skinfold thickness data from the third National Health and Nutrition Examination Survey (NHANES III; conducted during 1988-1994) data in addition to DXA-measured %BF data from three independent studies[19]. Furthermore, a study of a small sample of Italian prekindergarten children aged 29-68 months suggested that BMI and BMI% are more relevant for representing changes in adiposity over nine months[20] than the other metrics. Nonetheless, Freedman and Sherry argued that although BMI is a good indicator of excess body fat among obese children it may also represent fat-free mass in relatively thin children[21]. In addition, BMI may have limited validity for racial/ethnic minorities with different body compositions[22].

In view of these conflicting findings, it is still unknown which BMI metric is most strongly associated with measured body fat at the pediatric population level when age and race/ethnicity are taken into account[23]. Furthermore, it has not been determined what cutoffs would change the relationship between each BMI metric and %BF. In this paper, therefore, we sought to identify a BMI metric that would be most strongly associated with DXA-measured %BF when stratified by sex, age and race/ethnicity, and to determine the cutoffs before and after which the degrees of the associations differ for each metric. This identification can provide more precise, low-cost assessment that would be useful for the routine clinical and research evaluation of pediatric adiposity. To this end, we used subjects aged 8.0-17.9 years old from the US National Health and Nutrition Examination Survey (NHANES) 1999-2004 surveys combined to evaluate a large, nationally representative study sample with body fat measured by DXA.

METHODS AND PROCEDURES

NHANES uses interview and physical examination data to assess the health and nutritional status of adults and children in the United States [24]. Based on a multi-stage complex survey design to increase representativeness of the US population, it examines a nationally representative cross-sectional sample of about 5,000 persons each year, and obesity is one of main health risk factors that the current NHANES is designed to study. Subjects for the present study are those aged 96-215 months old *at examination* in the NHANES 1999-2004 survey across three biannual waves: 1999-2000, 2001-2002, and 2003-2004.

Measurement of body fat mass by DXA

Throughout the survey periods, NHANES used the Hologic QDR-4500A fan-beam densitometer with Hologic software version 8.26:a3* (Hologic, Inc., Bedford, MA) to measure *in vivo* regional body fat distribution. The minimum age required for the DXA measurement was 8 years or 96 months old. The DXA scanner measures regional body fat mass first, and then computes total body fat mass as the sum of regional body fat masses. Pregnant females (based on self-report) and subjects heavier than 300lbs (136kg) or taller than 6’5” (195cm) were excluded from the DXA scanning according to the NHANES criteria. The QDR-4500A densitometer algorithm, however, overestimated lean mass by 5±1% [25]. For this reason, NHANES decreased DXA lean mass by 5% and added an equivalent kilogram weight to the fat mass without affecting the total mass [26].

Imputation for incomplete regional body fat measures

According to the NHANES overall imputation indicator variable ‘DXITOT’ [26], approximately 11% of the subjects aged 96-215 years months in the NHANES 1999-2004 had an incomplete total body fat measurement because at least one regional body fat measure was incomplete due to invalid DXA scanning. Reasons for incompleteness include the presence of certain non-removable objects (e.g., prostheses), excess X-ray noise and positional problems[27]. The National Center for Health Statistics (NCHS) imputed incomplete regional body fat measures applying a sequential regression multivariate imputation method[28, 29] to generate five imputed datasets[26]. However, imputation was not applied to pregnant women[26] or subjects with amputated body part(s), albeit scanned by DXA.

Anthropometric measurements and BMI metrics

A standard NHANES protocol[30] detailed procedures for anthropometric measurements including height and weight. In brief, unassisted standing height was measured as a maximum vertical size by a fixed stadiometer that utilized a computer for reading. Weight was measured in a standing position using a digital weight scale. We used the Centers for Disease Control and Prevention (CDC) algorithm, which generated CDC 2000 growth charts,[16] to compute BMI, sex-age-adjusted BMI z-score, and BMI percentile. We also modified the algorithm to compute BMI%.

Statistical Analysis

Study Sample and stratification—There was a total of N=6,262 subject aged 96-215 months old in the NHANES 1999-2004 study population. We excluded subjects who had incomplete BMI, had highly variable imputed DXA measurements, or were not imputed for incomplete DXA measurements. These exclusions (N=142) resulted in a total sample of N=6,120 subjects (3,708 boys and 2,412 girls) who had complete information, observed or imputed, on all variables that were used for the present study. In order to control for potential growth or pubertal effects on the %BF, we stratified the sample into the following five age groups for boys and girls with 2 year, or 24 month, intervals: 8-9.9; 10-11.9; 12-13.9; 14-15.9; and 16-17.9 years corresponding to 96-119; 120-143; 144-167; 167-191; and 192-215 months at the NHANES examinations.

We considered the following four race/ethnic groups based on the NHANES variable name ‘RIDRETH1’: non-Hispanic Whites, non-Hispanic Blacks, Mexican-Americans, and Other. The “Other” group is a combination of other Hispanics and multi-racial groups; the combination was necessary due to relatively small sample sizes compared to the other three race/ethnic groups.

Statistical methods—For all statistical analyses we took into account the sampling strata, primary sampling unit, and the individual sampling weights which we computed for the combined three waves of survey data adhering to the analytic guidelines suggested by the NHANES [31]. We used SAS PROC SURVEYFREQ, SURVEYMEANS and SURVEYREG with SAS v9.3 (SAS Institute Inc., Cary, NC, USA) for descriptive and inferential statistical analyses, respectively. In addition, statistical analyses were applied to each of five imputed data sets, yielding five sets of results from which final results were obtained based on a pooling method proposed by Rubin [32] applying SAS PROC MIANALYZE. For descriptive statistics, we reported weighted percentages, and means and standard errors of the mean (SEM). For inferential statistics, we report estimated regression coefficients, their standard errors (SE) and R^2 for assessment of goodness-of-fit of regression models. Graphical presentations and locally weighted scatterplot smoothing (*lowess*) fit[33] were performed using S-plus v8.1.1 (TIBCO Software Inc., Palo Alto, CA, USA).

Prediction model—To determine the association between each BMI metric and DXA-measured %BF, we fitted the DXA-measured %BF with a piecewise linear regression model in the following form for each sex-age stratum and also for each sex-race/ethnicity stratum: %BF = b0 + b1×(X – cutoff) if X < cutoff and %BF = b0 + b2×(X – cutoff) if X >= cutoff, where the independent variable X represents a BMI metric: BMI, BMI z-score, BMI percentile, or BMI%. (Since estimation of cutoff in this model is not straightforward, we relied on a grid search described below.) In this modeling, the cutoff is the point of change in relationship between a BMI metric and %BF. Specifically, the intercept b0 represents a predicted or estimated value of %BF at X=cutoff; b1 represents the slope before the cutoff; and b2 represents the slope after the cutoff. Stated differently, the slopes are modeled to differ before and after the cutoff and the two regression lines are restricted to meet at the cutoff. This modeling strategy was guided by the inspection of scatter plot of %BF versus BMI metrics followed by fits of *lowess* curves stratified by age and sex (**Figure 1**), and was uniformly applied to all BMI metrics for the purpose of comparison.

Determination of cutoffs and maximal association—We determined a cutoff based on a grid search over a range of X values in such a way that the cutoff was associated with the maximum R^2. Specifically, the ranges of X values were: from 15 to 45 by an increment of 1 for BMI; from −1.0 to 1.5 by an increment of 0.1 for BMI z-scores; from 70 to 95 by an increment of 1 for BMI percentile; and from −15 to 50 by an increment of 1 for BMI%. These ranges were determined based on inspection of *lowess fit* curves (**Figure 1**). We fit the model above for each value of X using SAS PROC SURVEYREG to obtained the maximum R^2 and identify its associated cutoff for each BMI metric in each age and race/ethnicity stratum as well as for all ages in boys and girls. We used the maximum R^2 as the measure for assessment of the association between each BMI metric and DXA-measured %BF.

RESULTS

Subject Characteristics

Descriptive statistics for the study sample by sex and age are presented in **Table 1**. Among boys, BMI significantly increased over age whereas all the other BMI metrics stayed constant. Despite the fact that both weight and absolute fat mass increased steadily and significantly over time, the relative %BF substantially decreased after 168 months. Among girls, BMI continually increased significantly over age whereas all the other BMI metrics formed a concave curve over age. However, unlike in boys, both absolute fat mass and %BF significantly increased over age and weight as well. The increase in height over time was steady and significant for both boys and girls reflecting the age range of the study sample. Percentage of body fat was significantly larger for girls than for boys for any age interval ($p<0.001$) and also for all ages combined ($p<0.001$).

Descriptive statistics for the study sample by sex and race/ethnicity are presented in **Table 2**. The weighted percentages of race/ethnicity groups were as follows: 61.7% for non-Hispanic Whites; 14.9% for non-Hispanic Blacks; 11.1% for Mexican-Americans; and 12.4% for other race/ethnicity. The weighted percentages were not proportional to the sample sizes of the corresponding race/ethnic groups, particularly because Mexican-Americans and non-Hispanic Blacks were oversampled. There was no significant difference in the percentages of the race/ethnicity groups between boys and girls based on the Rao-Scott Chi-square test (p=0.534). Among boys, despite the fact that neither age nor weight differed significantly across race/ethnicity, all BMI metrics and the other variables were significantly different. In particular, Mexican-Americans had the highest BMI metrics, absolute fat mass in kg, and %BF. Among girls, however, all subject characteristics were significantly different across the race/ethnicity groups (**Table 2**); Non-Hispanic Blacks in particular were heaviest, if not the tallest, and had all the highest BMI metrics, absolute fat mass in kg, and %BF.

Associations between BMI metrics and %BF stratified by age

Maximal Associations—Table 3 summarizes the results from the fit of the piecewise linear regressions of BMI metrics on %BFs for each sex-age stratum and for all ages combined as well. First, for all ages, the R^2 of the regression fits with the corresponding estimated cutoff points was highest for BMI z-score (R^2=0.66) in boys and for BMI z-scores and BMI% (R^2=0.70) in girls. Nevertheless, the R^2 across the four BMI metrics were generally comparable in boys and girls except that R^2 (=0.39) for BMI in boys was much lower than those for the other metrics. Despite this observation, when stratified by age, the R^2's for BMI in boys were close to or even higher (ages 8-13.9 years) than those of the other metrics.

Comparisons of R^2 between boys and girls showed that across all BMI metrics R^2's were greater in boys than in girls for ages 8-11.9 and 16-17.9 years, whereas they were smaller in boys than in girls for the other age rage, 12-15.9 years (**Table 3**). The R^2's of all BMI metrics were lowest for the age stratum of 12-13.9 years in boys and they were the lowest for the highest age stratum 16-17.9 years in girls.

Prediction equations with cutoffs—Estimated prediction equations of the four BMI metrics with their corresponding cutoffs are also presented in **Table 3** across sex-age strata. Variations of cutoffs were most pronounced for BMI% for boys and girls. However, in boys aged 14-15.9 years, the directions of the slopes before and after the cutoffs, b1 and b2 respectively, switched from negative to positive for fits with BMI, BMI z-scores and BMI%, even if the b2's were not statistically significant. In contrast, in girls, all slopes before and after the cutoffs were positive, even if not all statistically significant, regardless of the BMI metric and age.

Among boys, %BF appeared to decrease with advancing age for the same BMI and this relationship approximately held for the other BMI metrics (**Figure 1(A)** and **Figure 2(A)**). For example, boys aged 8-9.9 years old had the highest estimated %BF, and those with 16-17.9 years old had the lowest %BF for the entire BMI range. In contrast, among girls, there was no consistent relationship between estimated %BF and age for a given BMI metric (**Figure 1(B)** and **Figure 2(B)**). Overall, variations in the predicted lines over age appeared to be smaller for girls for any given BMI metric than for boys (**Figure 2**). However, the variation in the predicted lines based on BMI was most pronounced for both boys and girls.

In other words, %BF estimates for a given value of BMI depended more on age than those for a given value of any other BMI metric did.

Associations between BMI metrics and %BF stratified by Race/Ethnicity

Maximal Associations—Table 4 summarizes the results from the fit of the piecewise linear regressions of BMI metrics on %BFs for each sex-race/ethnicity stratum. Among boys, regardless of race/ethnicity, the fits based on BMI were the worst with R^2's less than 0.5, and the fits based on BMI z-scores resulted in the highest R^2's. Among girls, however, the fits were comparable across the BMI metrics with R^2's of 0.67 or greater. Across race/ethnicity, Mexican-American boys and non-Hispanic Black girls had the highest R^2's regardless of BMI metric.

Prediction equations with cutoffs—Estimated prediction equations of the four BMI metrics with their corresponding cutoffs are also presented in **Table 4** across sex-race/ethnicity. Variations in cutoffs across race/ethnicity were the most pronounced for BMI among boys and for BMI% among girls. However, the estimated %BF increased with all BMI metrics before and after the cutoffs regardless of sex. For any given BMI metric within a range between its 5th and 95th quantiles, non-Hispanic Blacks had the lowest estimated %BF for boys and girls (**Figure 3**).

DISCUSSION

Associations between the four BMI metrics and the DXA-measured %BF in this US population-based pediatric sample largely depended on sex, age and race/ethnicity. In general, BMI z-scores tended to have strongest associations with %BF with higher R^2 than the other metrics, if not substantially so. The associations were stronger in general for girls. Although associations of the four BMI metrics with the measured %BF varied with age, their R^2's were comparable for a given age range for each sex. However, the associations of the four metrics were all lowest for age 12-13.9 and 16-17.9 years for boys and girls, respectively. Therefore, the associations between all BMI metrics and %BF were dependent upon age in the growing stage, presumably reflecting hormonal or metabolic changes during pubertal stages. The associations were strongest for non-Hispanic Blacks among girls and for Mexican-Americans among boys. The estimated %BF was significantly higher for girls, decreased with advancing age in boys but not in girls, and was the lowest among non-Hispanic Blacks for any given BMI metric regardless of sex. For each sex, subjects' age appeared to be a more important factor to be considered in evaluation of %BF than their race/ethnicity; the variability of the predicted lines was smaller across race/ethnicity based on visual inspection of **Figures 2** and **3**.

Although R^2's for all ages were in general within the ranges of the R^2's across the age strata regardless of sex, R^2 for BMI was exceptionally low at 0.39 for boys (**Table 3**) and remained low at less than 0.5 across race/ethnicity groups (**Table 4**). The prediction line for all ages was also saliently different, albeit close to that for ages 14-15.9 years, from those for the other age strata (**Figure 2(A)**). Thus, the evaluation of %BF based on BMI must be made considering age[34]. Furthermore, the prediction lines for the non-Hispanic Whites were also somewhat different from those of the other race/ethnicity groups (**Figure 3(A)**). For instance, unlike the other BMI metrics, BMI significantly increased with increasing age while %BF significantly decreased after 16 years (**Table 1**) in boys. Nevertheless, these findings did not apply to girls emphasizing that the dynamic weight-%BF relationship over age was clearly different between boys and girls; however, the relationship appeared to be more stable, or less dependent upon age, in girls than in boys (**Figures 1** and **2**).

The estimated cutoffs were the points of change before and after which the degrees of association between BMI metrics and %BF are different. In general, except for BMI, the estimated slopes were greater before the corresponding cutoffs than after if both slopes before and after were significant regardless of sex, age and race/ethnicity. Therefore, the estimated cutoffs can be used for a threshold for faster increases in %BF per unit changes in each respective BMI metric except BMI. For example, fold changes in slopes between before and after the cutoffs (i.e., b2/b1) for BMI percentile ranged from 11-25 for boys and 6-11 for girls over the five age strata.

Given that the estimated cutoffs for BMI percentiles varied approximately between the 80-th and 90-th percentiles for boys and girls (**Tables 3 and 4**), the relationship between BMI percentile and %BF is more pronounced among overweight or obese children since the slopes were much steeper after the cutoff. Therefore, the BMI percentile criteria for overweight and obese children seemed to be well supported in that %BF was excessive compared to their normal-weight counterparts; this finding was also supported by Flegal et al[35] who also used the NHANES 1999-2004 data. BMI z-score cutoffs were at 0.4 for all ages combined for both boys and girls, and their corresponding fold changes were 9.7 and 3.0, respectively. In contrast, however, fold changes in slopes may be meaningless for BMI % since the cutoffs were relatively extreme for BMI%, especially among girls.

The finding that the slopes for BMI, unlike those for the other BMI metrics, were generally *lower* after the cutoffs seems to suggest that the relationships among the four BMI metrics are not necessarily linear even though they are highly correlated with each other. However, it is noteworthy that the computation of BMI was not adjusted for age while the computations of all the other BMI metrics were. Despite these complicated relationships, %BF can reliably be estimated based on any BMI metric for each age group.

The present study has limitations that should be considered in interpreting the findings. First, although the cutoffs and R^2 may vary across race/ethnicity for a given age range, we did not further breakdown the data (e.g., by race/ethnicity within age group) due to the potentially small sample size in each age-race/ethnicity combination especially for the “Other” race/ethnicity group. Second, the prediction equation models could have been formulated differently if determinations of cutoffs had not been of interest. However, when we fit with quadratic terms (X^2) and inverse terms (1/X), these fits did not yield R^2 as high as, even if very close to, those reported here. Finally, any covariates such as dietary pattern and physical activity levels that might influence weight and body fat were not taken into account. For example, it is unknown if the findings are due to different levels of muscle mass development or to changes in hormones and metabolism mediated by diet and physical activity rather than due to the demographic factors per se.

In conclusion, when assessing the relationship between %BF and the four BMI metrics among growing children aged 8.0-17.9 years old, the assessment should consider race/ethnicity in addition to age and sex even if BMI z-scores, BMI percentile and BMI% are already age-sex adjusted. This caution should be more carefully applied to assessing the BMI-%BF relationship especially for boys. Although associations with %BF are comparable across the four BMI metrics when age or race/ethnicity is taken into account, BMI z-score appears to be superior to the other metrics for both boys and girls. Furthermore, although the BMI percentile cutoffs are associated with greatest fold changes in slopes, a BMI z-score cutoff 0.4 can serve as a clinical action point for more careful monitoring of children's body fat, particularly when it is necessary to follow up body weight changes over time.

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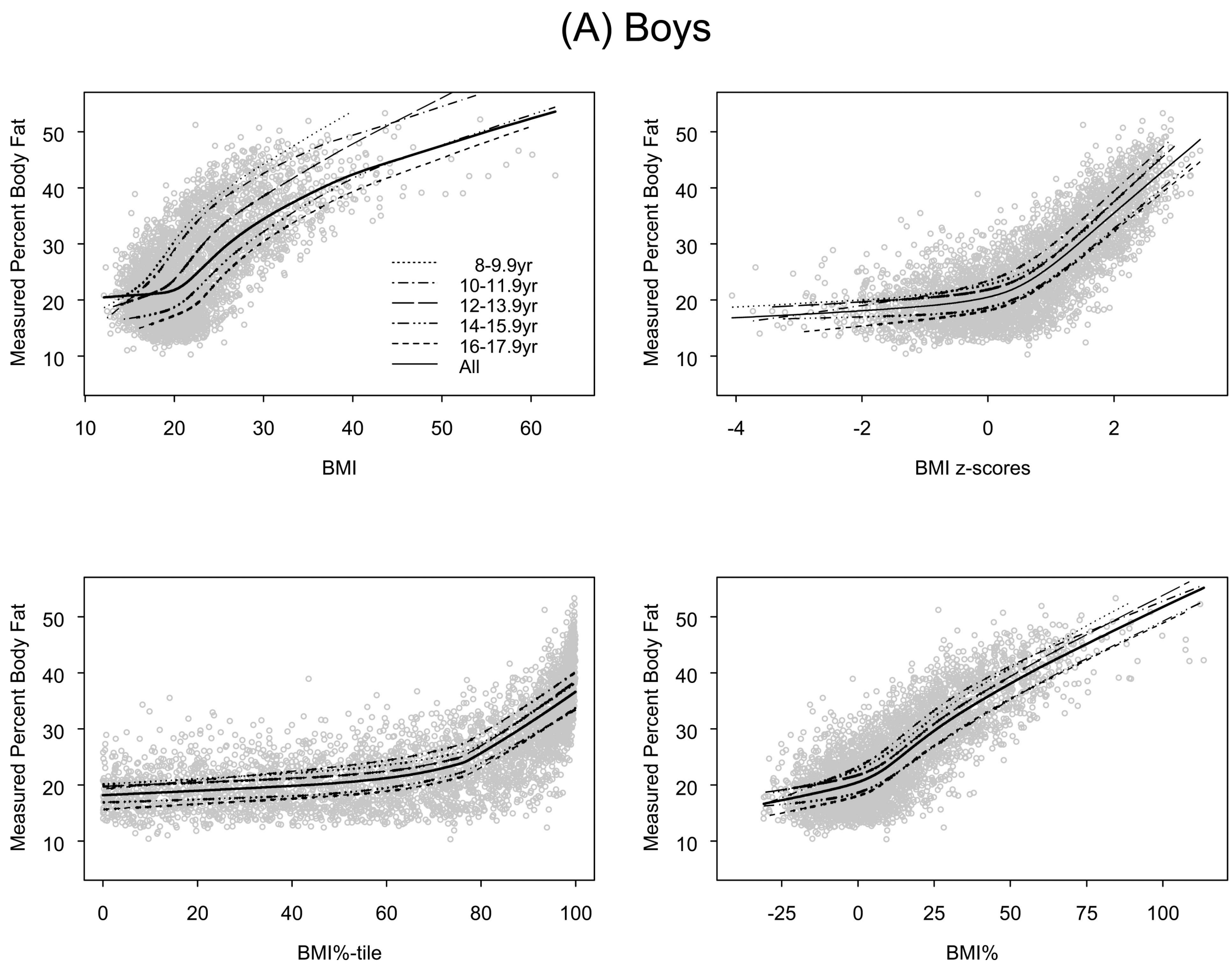

(A) Boys
Measured Percent Body Fat
BMI
8-9.9yr
10-11.9yr
12-13.9yr
14-15.9yr
16-17.9yr
All
BMI z-scores
BMI%-tile
BMI%

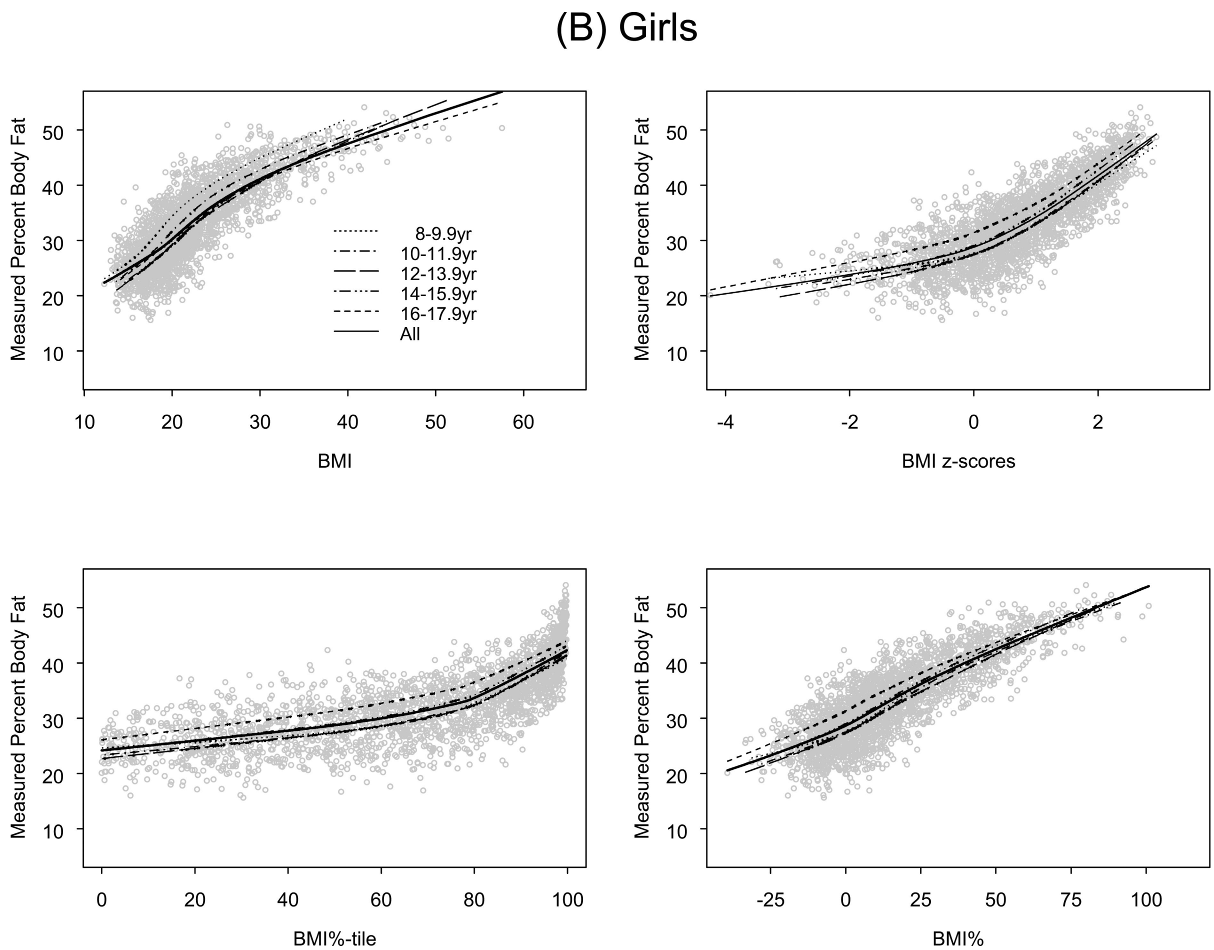
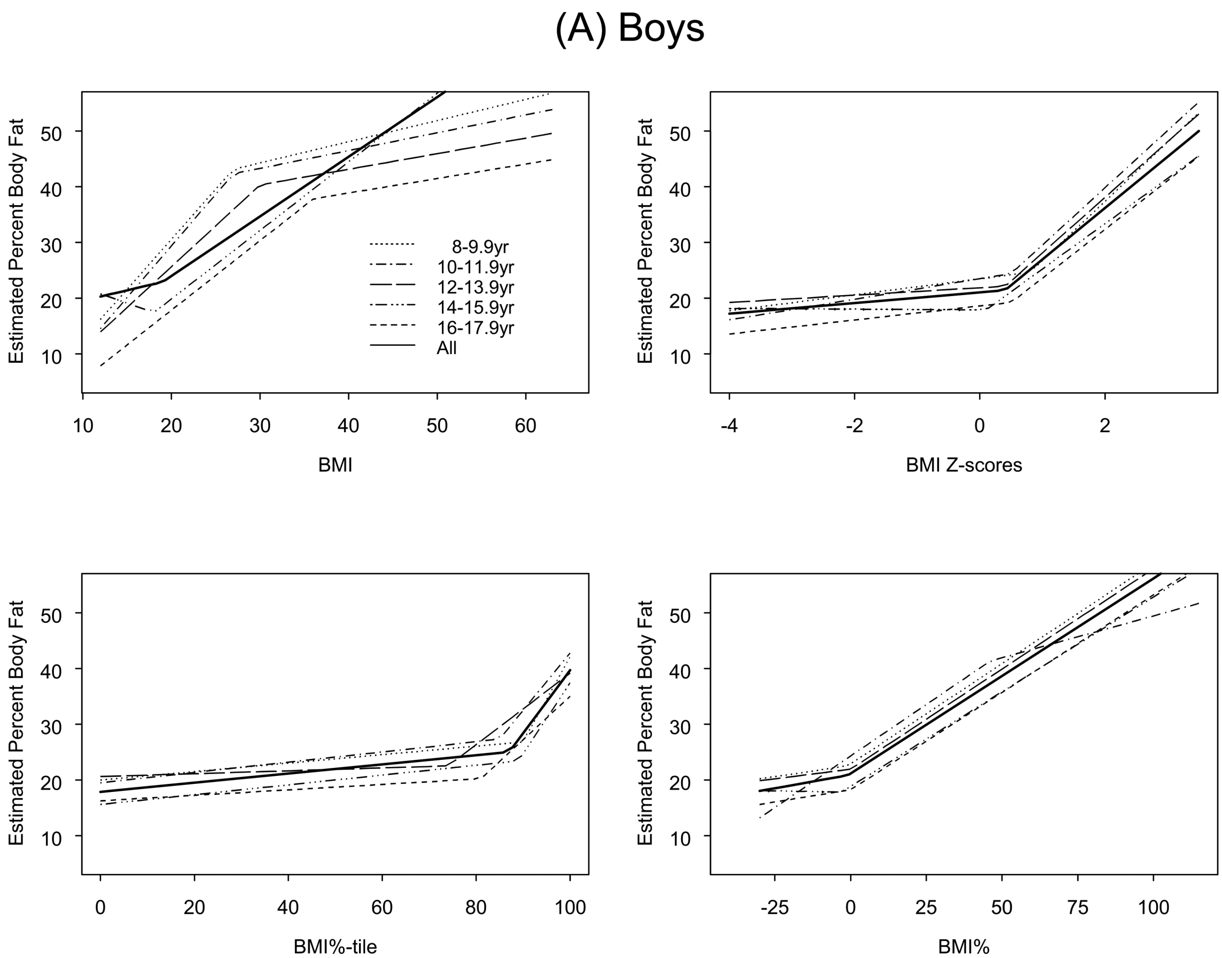


Figure 1.

Scatter plots of DXA-measured percentage of body fat vs. BMI metrics by age groups among (A) boys and (B) girls: ▪▪▪▪▪ 8-9.9 years; ▬ ▬ ▬ 10-11.9 years; ▬▬ ▬▬ 12-13.9 years; ▬ • • • ▬ 14-15.9 years; - - - - 16-17.9 years; ▬▬▬▬ all ages.


(A) Boys
Estimated Percent Body Fat
BMI
8-9.9yr
10-11.9yr
12-13.9yr
14-15.9yr
16-17.9yr
All
BMI Z-scores
BMI%-tile
BMI%

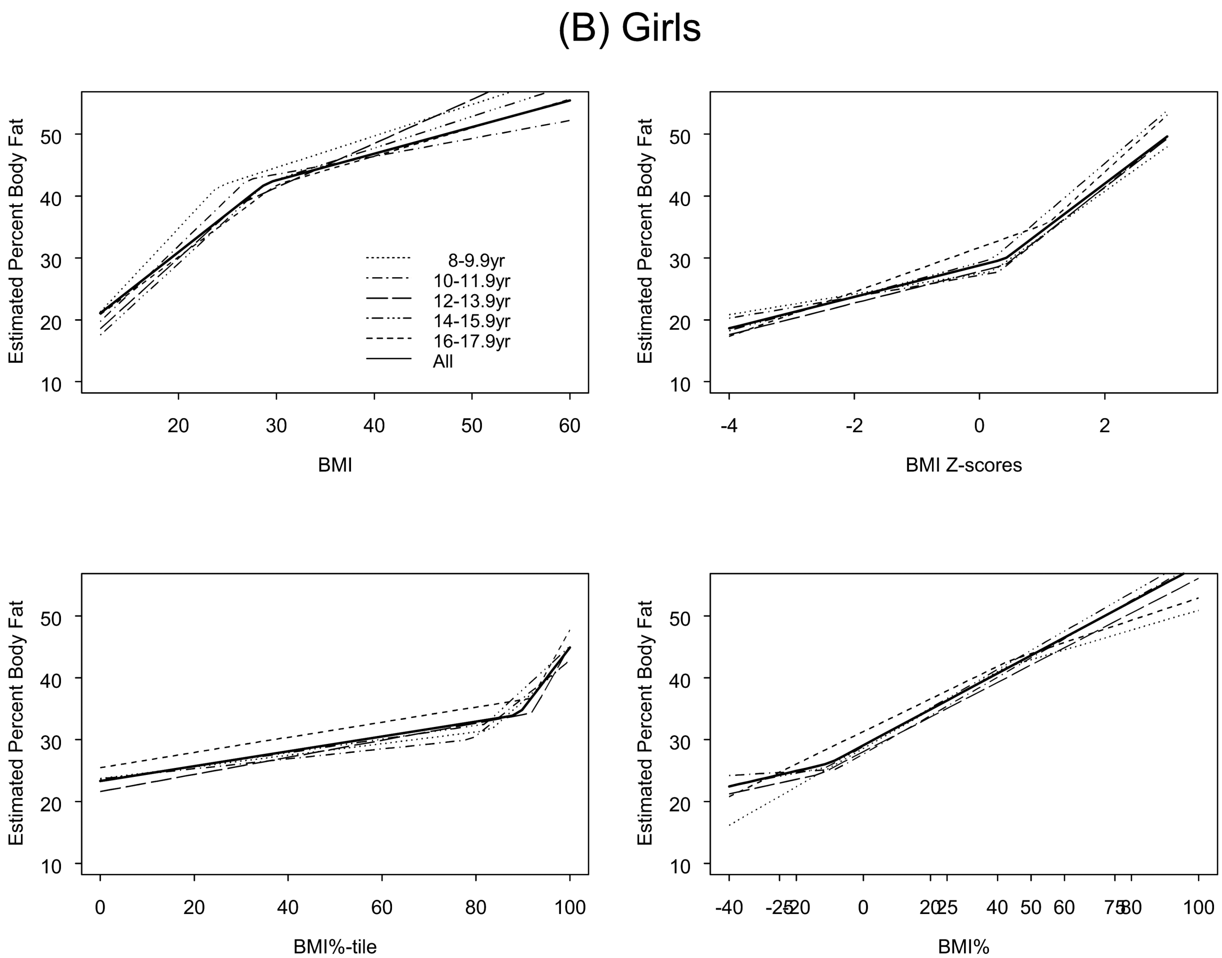
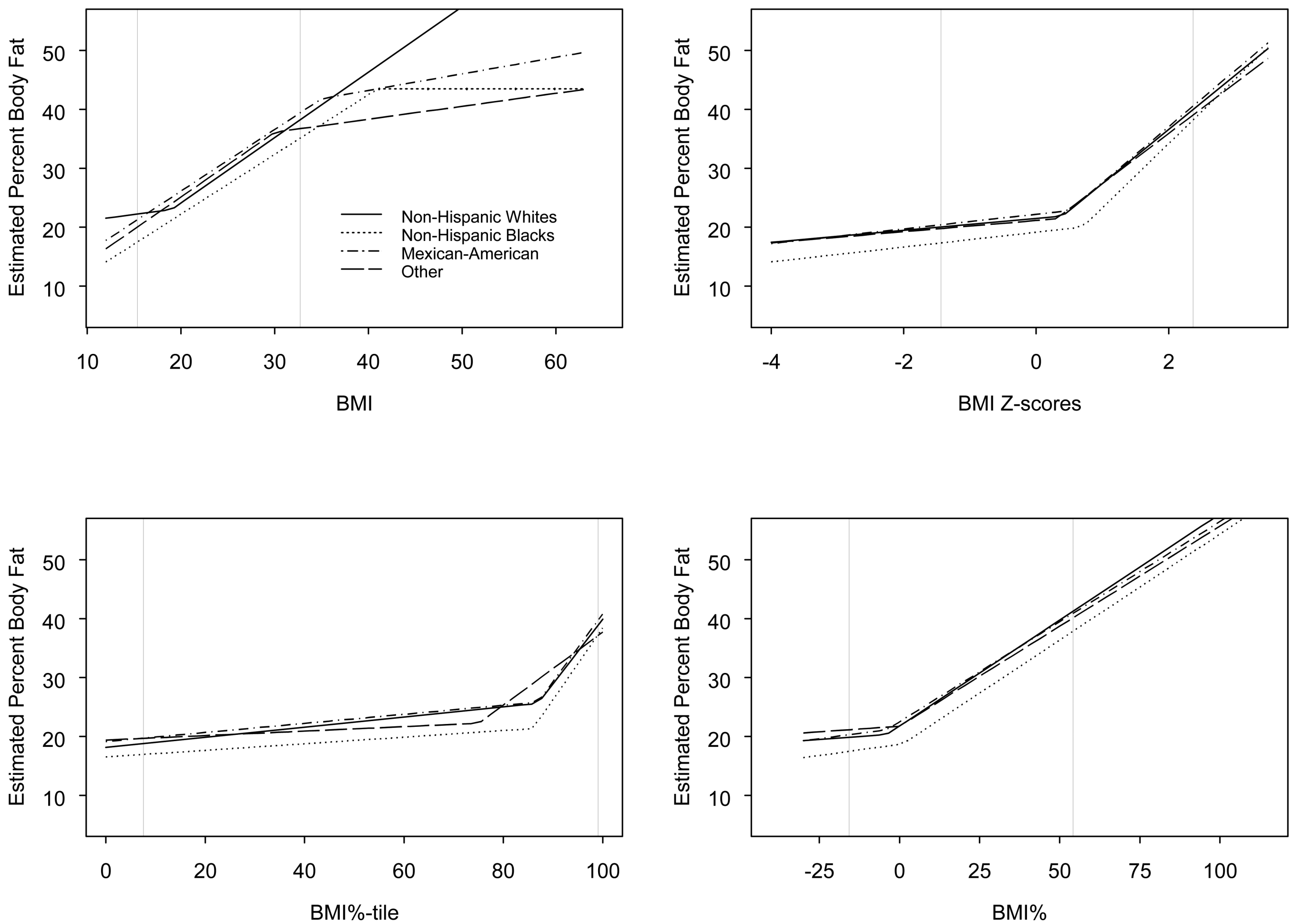


Figure 2.
Estimated percentage of body fat vs. BMI metrics by age groups among (A) boys and (B) girls: 8-9.9 years; 10-11.9 years; 12-13.9 years; 14-15.9 years; 16-17.9 years; all ages.

(A) Boys


Estimated Percent Body Fat
BMI
Non-Hispanic Whites
Non-Hispanic Blacks
Mexican-American
Other
BMI Z-scores
BMI%-tile
BMI%

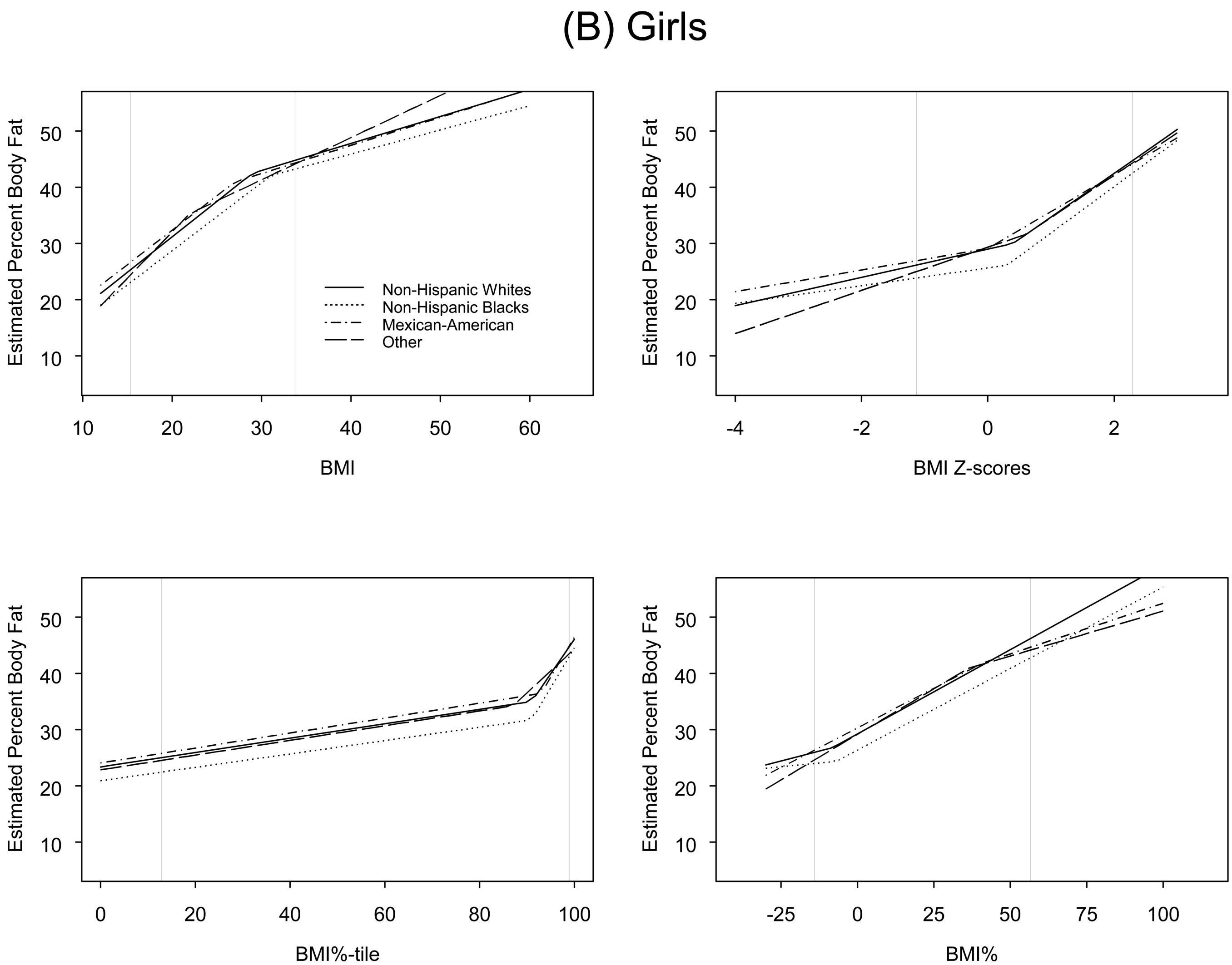


Figure 3.

Estimated percentage of body fat vs. BMI metrics by race/ethnicity groups among (A) boys and (B) girls: ▬▬▬ non-Hispanic Whites; ▪▪▪▪ non-Hispanic Blacks; ▬ ▬ ▬ Mexican-Americans; ▬▬ ▬▬ Other. Vertical lines represent the 5th and 95th quantiles of the corresponding BMI metrics.

Table 1

Subject characteristics by age

	All				Age in years: 8-9.99		10-11.9		12-13.9		14-15.9		16-17.9		
BOYS	N=3708				N=542		N=520		N=888		N=831		N=927		
Variable	**mean**	**sem**	**min**	**max**	**mean**	**sem**	**mean**	**sem**	**mean**	**sem**	**mean**	**sem**	**mean**	**sem**	**p**
Age in mo	155.1	1.04	96.0	215.0	107.1[a]	0.46	131.3[b]	0.34	155.2[c]	0.32	179.9[d]	0.29	203.0[e]	0.38	0.000
BMI (kg/m^2)	21.2	0.13	12.1	62.7	18.5[a]	0.24	19.8[b]	0.24	21.1[c]	0.26	22.7[d]	0.23	24.2[e]	0.24	0.000
BMI z-score	0.5	0.03	−4.1	3.4	0.6	0.07	0.5	0.07	0.4	0.07	0.5	0.05	0.5	0.05	0.669
BMI%-tile	63.6	0.78	0.0	100.0	65.0	1.77	64.7	1.76	62.2	1.76	62.7	1.46	63.2	1.33	0.652
BMI%	11.5	0.57	−30.9	113.4	11.8	1.22	12.1	1.10	11.2	1.14	11.1	0.97	11.3	0.91	0.950
Weight(kg)	54.4	0.52	18.9	191.7	34.2[a]	0.57	42.5[b]	0.73	53.8[c]	0.85	67.3[d]	0.85	74.8[e]	0.82	0.000
Height(cm)	157.2	0.48	114.4	198.2	135.1[a]	0.36	145.8[b]	0.60	158.5[c]	0.46	171.9[d]	0.45	175.4[e]	0.31	0.000
FM(kg)	14.8	0.23	2.9	97.0	10.1[a]	0.33	13.0[b]	0.42	15.6[c]	0.45	16.8[c,d]	0.43	18.4[d]	0.45	0.000
%BF	25.9	0.26	6.6	53.6	27.7[a]	0.44	28.6[a]	0.47	27.0[a]	0.41	23.4[b]	0.33	22.9[b]	0.30	0.000
GIRLS	N=2412				N=366		N=361		N=602		N=572		N=511		**p**
Age in mo	156.2	0.83	96.0	215.0	107.4[a]	0.33	132.0[b]	0.38	155.7[c]	0.37	179.2[d]	0.35	204.2[e]	0.40	0.000
BMI (kg/m^2)	21.6	0.20	12.3	57.6	18.5[a]	0.35	20.6[b]	0.31	22.1[c]	0.30	22.8[c,d]	0.33	23.9[d]	0.37	0.000
BMI z-score	0.5	0.04	−4.2	2.9	0.5	0.11	0.6	0.08	0.6	0.06	0.5	0.07	0.4	0.06	0.043
BMI%-tile	64.7	1.19	0.0	99.8	62.7	3.03	67.3	2.03	67.6	1.69	64.0	1.96	61.6	1.57	0.061
BMI%	12.6	0.86	−39.4	100.9	10.9	1.79	14.5	1.46	14.6	1.24	11.6	1.37	11.0	1.32	0.110
Weight(kg)	52.0	0.60	18.5	169.7	34.3[a]	0.88	46.3[b]	0.93	55.2[c]	0.85	59.4[d]	0.92	63.6[e]	0.95	0.000
Height(cm)	153.3	0.32	105.5	187.2	135.0[a]	0.61	148.8[b]	0.59	157.5[c]	0.44	161.2[d]	0.43	163.1[e]	0.29	0.000
Fat(kg)	17.9	0.36	3.5	89.7	11.5[a]	0.48	15.9[b]	0.52	18.8[c]	0.58	20.4[c]	0.61	22.6[d]	0.65	0.000
%BF	32.7	0.29	14.0	54.1	31.8[a]	0.56	32.6[a,b]	0.46	32.3[a]	0.49	32.7[a,b]	0.49	34.1[b]	0.44	0.003

Note: BMI%-tile = BMI percentile. FM = Fat mass. All the means and SEM's are obtained with the NHANES sampling design effects taken into account. P-values were computed based on testing significance of equality of means across the five age groups in survey linear regression models. For the imputed variables FAT and %BF, the means, SEM's and p-values were based on the pooling of results from the five NCHS-imputed data sets. Different superscripts indicate significant differences between pairwise race/ethnicity groups at the Bonferroni-corrected significance level 0.05/10 = 0.005; this test was conducted using the survey linear regression models.

Table 2

Subject characteristics by race/ethnicity

	Race/ethnicity								
	Non-Hispanic Whites		Non-Hispanic Blacks		Mexican-American		Other		
BOYS	N=941		N=1228		N=1259		N=280		
Variable	**mean**	**sem**	**mean**	**sem**	**mean**	**sem**	**mean**	**sem**	**p**
Age in mo	155.5	1.61	154.7	1.10	153.8	1.19	154.7	2.24	0.853
BMI (kg/m^2)	21.0[a]	0.20	21.5[a,b]	0.18	22.1[b]	0.17	21.2[a,b]	0.41	0.001
BMI z	0.5[a]	0.06	0.5[a]	0.04	0.7[b]	0.04	0.5[a,b]	0.09	0.001
BMI%-tile	62.9[a]	1.39	64.1[a]	1.03	68.4[b]	1.11	61.5[a,b]	2.42	0.002
BMI%	10.5[a]	0.93	12.3[a]	0.66	15.7[b]	0.68	11.4[a,b]	1.59	0.000
Weight(kg)	54.3	0.77	55.7	0.72	55.0	0.64	52.7	1.60	0.236
Height(cm)	157.9[a]	0.71	158.1[a]	0.54	155.0[b]	0.53	154.9[a,b]	1.21	0.001
FM(kg)	14.7[a]	0.34	14.1[a]	0.31	16.4[b]	0.25	14.4[a,b]	0.53	0.000
%BF	26.0[a]	0.39	23.6[b]	0.24	28.2[c]	0.28	26.2[a,c]	0.46	0.000
GIRLS	**N=692**		**N=785**		**N=743**		**N=192**		**p**
Age in mo	157.9[a]	1.15	153.7[a,b]	1.25	152.6[b]	1.58	153.7[a,b]	3.40	0.021
BMI (kg/m^2)	21.3[a]	0.28	23.1[b]	0.22	21.6[a]	0.35	21.6[a]	0.46	0.000
BMI z	0.5[a]	0.06	0.8[b]	0.03	0.6[a]	0.07	0.6[a,b]	0.09	0.000
BMI%-tile	62.8[a]	1.76	71.1[b]	0.88	65.3[a]	1.81	66.4[a,b]	2.44	0.001
BMI%	10.9[a]	1.19	18.7[b]	0.72	13.2[a]	1.33	13.2[a]	1.73	0.000
Weight(kg)	51.7[a]	0.82	55.9[b]	0.72	49.8[a]	1.10	50.6[a,b]	1.65	0.000
Height(cm)	154.2[a]	0.44	153.8[b]	0.45	149.9[a]	0.68	151.3[a,b]	1.10	0.000
FM(kg)	17.7	0.51	19.1	0.33	17.8	0.53	17.6	0.81	0.049
%BF	32.6[a,b]	0.43	33.8[a]	0.37	33.1[b]	0.61	31.9[b]	0.26	0.002

Note: BMI%-tile = BMI percentile. FM = Fat mass. All the means and SEM's are obtained with the NHANES sampling design effects taken into account. P-values were computed based on testing significance of equality of means across the four race/ethnicity groups based on the survey linear regression models. For the imputed variables FAT and %BF, the means, SEM's and p-values were based on the pooling of results from the five NCHS-imputed data sets. Different superscripts indicate significant differences between pairwise race/ethnicity groups at the Bonferroni-corrected significance level 0.05/6 = 0.008; this test was conducted using the survey linear regression models.

Table 3

Age-specific optimal cutoffs associated with maximum R^2 and prediction equations for %BF based on the four BMI metrics.

Age in years	Boys					Girls				
	BMI									
	cutoff	b0	b1	b2	R^2	cutoff	b0	b1	b2	R^2
8-9.9	27	43.1	1.796	0.38	0.78	24	41.5	1.690	0.51	0.74
10-11.9	27	42.3	1.852	0.32	0.74	27	42.6	1.525	0.29	0.71
12-13.9	30	40.3	1.465	0.28*	0.61	26	38.5	1.424	0.71	0.73
14-15.9	18	17.4	−0.561*	1.23	0.66	29	42.1	1.445	0.51	0.75
16-17.9	36	37.8	1.247	0.26	0.71	30	41.8	1.164	0.46	0.70
All	19	22.9	0.372	1.07	0.39	29	42.1	1.238	0.43	0.67

Age in years	BMI z-score									
	cutoff	b0	b1	b2	R^2	cutoff	b0	b1	b2	R^2
8-9.9	0.8	24.6	1.431	10.62	0.77	0.2	27.8	1.665	7.20	0.75
10-11.9	0.5	24.4	1.851	10.26	0.75	0.3	27.7	1.739	8.10	0.74
12-13.9	0.4	22.1	0.658	9.98	0.66	0.4	28.8	2.548	7.87	0.72
14-15.9	0.1	17.9	−0.062*	8.13	0.69	0.4	29.8	2.753	8.58	0.74
16-17.9	0.5	19.2	1.256	8.75	0.74	1.1	35.6	3.589	9.20	0.69
All	0.4	21.4	0.950	9.22	0.66	0.4	29.8	2.538	7.62	0.70

Age in years	BMI percentile									
	cutoff	b0	b1	b2	R^2	cutoff	b0	b1	b2	R^2
8-9.9	90	26.8	0.076	1.53	0.75	83	31.5	0.094	0.67	0.73
10-11.9	85	27.3	0.092	1.03	0.75	79	30.0	0.080	0.61	0.72
12-13.9	74	22.5	0.026	0.64	0.64	92	34.3	0.138	1.35	0.71
14-15.9	89	23.4	0.088	1.27	0.66	82	32.5	0.110	0.70	0.73
16-17.9	81	20.2	0.049	0.78	0.71	92	36.7	0.122	1.38	0.69
All	87	25.0	0.082	1.13	0.64	89	34.0	0.120	0.99	0.69

Age in years	BMI%									
	cutoff	b0	b1	b2	R^2	cutoff	b0	b1	b2	R^2
8-9.9	−1	22.5	0.081*	0.36	0.77	42	41.6	0.310	0.16	0.74
10-11.9	46	41.3	0.370	0.15	0.74	−8	25.2	0.031*	0.31	0.73
12-13.9	0	21.9	0.069*	0.36	0.64	−13	24.4	0.117*	0.28	0.72
14-15.9	−3	17.8	−0.010*	0.34	0.69	−11	25.5	0.102*	0.31	0.73
16-17.9	0	18.2	0.087	0.35	0.72	43	42.6	0.263	0.18	0.69
All	−1	20.8	0.095	0.35	0.65	−10	26.2	0.125	0.29	0.70

Note: All regression coefficients are significant except those indicated by The results were based on the pooling of results from the five NCHS-imputed data sets. All the results are obtained with the NHANES sampling design effects taken into account. b0=intercept at the cutoff. b1=slope before the cutoff. b2=slope after the cutoff.

*p>0.05.

Table 4

Race-specific optimal cutoffs associated with maximum R^2 and prediction equations for %BF based on the four BMI metrics.

	Boys					Girls				
	BMI									
Race/Ethnicity	cutoff	b0	b1	b2	R^2	cutoff	b0	b1	b2	R^2
Non-Hispanic Whites	19	23.0	0.211*	1.11	0.37	29	42.5	1.258	0.48	0.68
Non-Hispanic Blacks	41	43.5	1.014	0.00*	0.45	31	42.0	1.210	0.43	0.72
Mexican-American	35	41.8	1.045	0.28	0.45	27	40.9	1.223	0.50	0.67
Other	30	36.1	1.098	0.22*	0.40	22	35.3	1.645	0.75	0.68
	BMI z-score									
Race/Ethnicity	cutoff	b0	b1	b2	R^2	cutoff	b0	b1	b2	R^2
Non-Hispanic Whites	0.4	21.9	1.013	9.17	0.65	0.4	30.0	2.514	7.80	0.72
Non-Hispanic Blacks	0.7	20.0	1.258	10.90	0.70	0.3	26.1	1.583	8.24	0.74
Mexican-American	0.5	22.8	1.245	9.50	0.72	0.0	29.1	1.927	6.57	0.70
Other	0.3	21.4	0.949	8.51	0.68	0.6	31.6	3.840	7.53	0.72
	BMI percentile									
Race/Ethnicity	cutoff	b0	b1	b2	R^2	cutoff	b0	b1	b2	R^2
Non-Hispanic Whites	87	25.6	0.086	1.10	0.64	91	35.0	0.128	1.23	0.71
Non-Hispanic Blacks	86	21.3	0.056	1.22	0.69	91	31.7	0.119	1.42	0.72
Mexican-American	87	25.8	0.077	1.15	0.69	93	36.4	0.133	1.43	0.69
Other	75	22.2	0.038	0.62	0.67	87	34.2	0.131	0.78	0.72
	BMI%									
Race/Ethnicity	cutoff	b0	b1	b2	R^2	cutoff	b0	b1	b2	R^2
Non-Hispanic Whites	−4	20.3	0.039*	0.36	0.65	−8	26.8	0.141	0.30	0.72
Non-Hispanic Blacks	1	18.7	0.076	0.36	0.69	−7	24.3	0.053	0.29	0.75
Mexican-American	−4	21.1	0.072	0.34	0.71	41	41.8	0.281	0.18	0.70
Other	0	21.7	0.141	0.34	0.66	36	40.8	0.324	0.16	0.72

Note: All regression coefficients are significant except those indicated by The results were based on the pooling of results from the five NCHS-imputed data sets. All the results are obtained with the NHANES sampling design effects taken into account. b0=intercept at the cutoff. b1=slope before the cutoff. b2=slope after the cutoff.

* $p>0.05$.