Relationship of BMI Z score to Fat Percent and Fat Mass in Multiethnic Prepubertal Children

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Abstract

Objective: To examine the validity of body mass index z-score (zBMI) as a measure of percent body fat in prepubertal children.

Methods: 111 multi-ethnic, healthy, Tanner 1 children aged 6–12 years had fat percent and fat mass measured by the 4 compartment method as part of the Pediatric Rosetta Body Composition Cohort. Multiple regression models were developed with fat percent as the dependent variable and zBMI, age, sex, and ethnicity as independent variables.

Results: zBMI predicted fat percent, adjusted for age in both girls (p<0.001, RMSE 5.67 and R^2 0.54) and boys (p<0.001, RMSE 4.71, R^2 0.69). The average model percent error was 20.3% in girls and 21.6% in boys. $zBMI^2$ predicted fat mass when adjusted for age and zBMI in both girls (p<0.001, RMSE 2.27 and R^2 0.82) and boys (p<0.001, RMSE 2.08, and R^2 0.81). The average percent error was 7.2% in girls and 8.7% in boys. Age was associated with percentage body fat (p<0.01), while ethnicity was not (p>0.05).

Conclusions: Given the relatively large error in the models, BMI z-scores are not a useful indicator of fat mass in healthy, Tanner 1 children. $zBMI^2$ scores are associated with significantly lower absolute percent errors in girls and boys.

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INTRODUCTION

Obesity remains an epidemic in the pediatric age group with 17% of children and adolescents in the United States are considered to have obesity and almost 6% with morbid obesity [1]. Given the association between childhood obesity and a number of significant comorbidities, including type 2 diabetes, hypertension, dyslipidemia, cardiovascular disease, and premature mortality in early adulthood[2, 3], it is important to accurately identify children with excess adiposity for the purpose of intervening early in childhood.

Body Mass Index (BMI) is currently used in clinical practice as a marker of adiposity. Children over 2 years of age are classified as overweight or obese based on BMI Z scores (zBMI) or percentiles for age determined by the Centers for Disease Control and Prevention normative data [4]. BMI is a measure of weight in relation to height squared that is based on findings in adults and does not differentiate between muscle and adipose tissue [5].

Given the significant growth and changes in body proportions during childhood, there are many reasons to question the appropriateness and even the validity of BMI in children as an index of adiposity. Peterson et al. recently proposed the use of a tri-ponderal index, where weight is divided by height[3], as a more appropriate measure of adiposity during adolescence based on findings that weight may scale better in children with height powers between 2.5 and 3.5 rather than 2 [6]. zBMI does not account for variability in the age at which the puberty and the pubertal growth spurt occur leading to false classification of children. In addition, there is a large distribution of zBMI in children undergoing treatment for obesity [7] and the CDC growth charts are not designed well to estimate BMI percentiles beyond the 97%ile for age [8]. Moreover, BMI percentiles and z scores do not account for significant ethnic differences in fat distribution[9]. In addition, healthy children identified as normal weight by BMI but with excessive percent body fat had significantly lower cardiorespiratory fitness than children with low body fat [10], suggesting that the use of BMI may not identify all youth at risk for complications related to excess body fat.

Use of BMI in intervention studies as an outcome measure to establish efficacy of the dietary and physical activity interventions, is woefully inadequate. Intervention studies focusing on changes in BMI failed to detect the effects on actual body fatness when BMI was not affected [11–14]. Fat mass and fat free mass, not necessarily BMI, are associated with physical fitness [15, 16] and cardiometabolic risk [17], therefore, the use of BMI in studies has the potential to miss positive effects of interventions on health-related outcomes.

Several prior studies have investigated the association between BMI and body fat measured by dual energy x-ray absorptiometry (DXA) in children and adolescents across a wide range of ages with variable results [18–23]. DXA however, has previously been shown to overestimate percent body fat in children and adolescents with high percent fat and underestimate percent body fat in lean children [23]. Few studies have focused on the

relationship of BMI and adiposity in children prior to puberty. The period preceding the onset of puberty (adiposity rebound), is hypothesized to be one of the critical periods of obesity development in children and is probably the least understood [24, 25]. The aim of this study was to test the hypothesis that zBMI is a valid index of percent body fat and fat mass specifically in prepubertal children using the four-compartment model as a reference. A secondary aim was to investigate the effects of sex, ethnicity, and age on the zBMI and fat relationships in an effort to better understand and interpret zBMI in prepubertal children.

METHODS

Subjects were a subset of children enrolled in the Rosetta Body Composition Project, a cross sectional study of pediatric body composition in New York City between 1995 and 2000. Details of study design and findings have been previously published[19, 26–28]. The subset included 111 healthy, prepubertal children aged 6 to 12 who had body composition analysis by a four-compartment model (4C) as part of the Rosetta Body Composition Project. Participants were recruited through local newspaper notices, announcements at schools and activity centers and word of mouth. The study was approved by and conducted in accordance with the Institutional Review Board at St Luke's-Roosevelt Hospital. Consent was obtained from a guardian for each volunteer and when appropriate, assent was also obtained from the volunteer.

A consistent ethnic background (Caucasian, African American, Hispanic, or Asian) in both parents and all four grandparents was required to classify each volunteer. To confirm health status, a medical history was obtained from a guardian and a physical examination was performed at the time of assessment. Volunteers with current or prior medical conditions or medication use that would influence their body composition were excluded. Pubertal status was assessed via Tanner staging by a pediatric endocrinologist or nurse in children 10 years and under. Children 11–12 years were instructed by the pediatrician or nurse in the presence of the parent using breast chart for girls and Prader orchidometer beads for boys on how to rate and self-report pubertal status.

Anthropometry

Body weight was measured using an electronic scale (Weight Tronix, New York, NY) to the nearest 0.1kg, and height was measured using a stadiometer (Holtain, Crosswell, Wales) to the nearest 0.1cm and the average of three measurements was recorded. All subjects were wearing hospital gowns and foam slippers. BMI z-score (zBMI) were computed from CDC reference values [29].

Dual-energy X-ray absorptiometry

Whole body DXA scans were performed using Lunar models DPX with pediatric software version 3.8G and DPX-L with pediatric software 1.5G (GE lunar Corporation, General Electric, Madison, WI). [27] Subjects weighing less than 35kg were scanned in pediatric large mode and those weighing greater than 35kg were scanned in adult medium mode, as per the weight guidelines from the manufacturer. Each scan provided values for total body bone mineral content (BMC). The coefficient of variation for repeated BMC measurements

in adult subjects in our laboratory was 0.5%. Quality control involving a phantom was completed daily as previously described [27] before subject evaluation. Repeated studies of this phantom in our unit revealed a coefficient of variation of 0.6% for BMC. [30]

Total Body Water

Dilution of deuterium (^2H_2O) was used to measure total body water (TBW) in liters. As previously described [27], subjects drank a dose (0.1 g/kg body weight) of 99.8 atom % excess 2H2O (Icon Corp, Summit, NJ) followed by 30ml of spring water which was used to rinse the dosing cup. At 0 minutes prior to dose, 3ml saliva sample was collected. A second saliva sample was obtained after 120 minutes. Subjects were asked to refrain from eating or drinking until the second sample was collected. After the specimen was lyophilized, the dose concentration was measured using single frequency infrared spectrophotometer. The dose of 2H2O divided by the net 2H2O in the specimen was used to calculated TBW volume. The measured TBW was not corrected for nonaqueous exchange. The CV for TBW measurement in our laboratory is 1.7% in children[31].

Underwater Weighing

Body density was determined by hydrodensitometry using a 4 point platform scale system (36) (Precision Biomedical System, INC, University Park, PA) and nitrogen washout technique was used to determine residual lung volumes. Once submerged, the subject was asked to exhale as much air as possible during complete submersion. An average of the 3 highest underwater weights were recorded after 5 to 10 trials. The CV for Db by underwater weighing corrected for residual lung volumes in adults was 0.33% in the laboratory [32] Subjects wore bathing suits for all measurements.

Four Compartment Method

Fat percent was calculated using the Lohman 1989 equation [14]: %Fat = $100 \times ((2.749/ Db) - (0.714 \times TBW/ Weight) + (1.146 \times BMC/(1000*Weight) - 2.0503)$, where Db is body density kg/l, TBW is total body water in kg, Weight is total body weight in kg, and BMC is bone mineral content in g.

Statistical Analysis

Statistical analysis and calculations were performed using STATA version 12.1 statistical software. A p value of 0.05 was used to determine significance. Descriptive statistics were calculated for each variable and reported as mean and standard deviations. T-tests were used to compare anthropometric and body composition measurements between prepubertal males and females. To investigate the association between zBMI with 4C percent fat and fat mass, multiple regression analyses were performed adjusting for age and ethnicity. Dummy variables were used to model the effects of ethnicity (c=1 if subject was Caucasian, otherwise c=0; b=1 if subject was African American, otherwise b=0; h=1 if subject was Hispanic, otherwise h=0; a=1 if subject was Asian, otherwise a=0; o=1 if ethnicity could not be classified, otherwise o=0). Males and females were analyzed separately. For each linear regression model, residual plots were made to test the validity of the model. The Shapiro-Wilk normality test was used to test the hypothesis that the distribution of the residuals is

consistent with the normal distribution for each regression model. Percent error was calculated for each model as the absolute value of the difference between the predicted percent fat based on the regression model and percent fat measured by 4C divided by the measured percent fat.

RESULTS

Subject characteristics, anthropometric measurements, and body composition measurement are shown in **Tables 1**. Of the 111 Tanner 1 children, 61 were male and 50 were female. Subjects had a wide range of body size for age with zBMI for age ranging from −2.6 to 2.7. In this group, 19.8% had BMI above the 95th percentile for age. No differences were noted between sexes for height, weight, and zBMI. Compared to boys, girls had a higher percent body fat (p=0.0008). No differences were noted for bone mineral content or total body water. Sex specific plots of zBMI versus percent fat are shown in **Figures 1a and 1b (Supplementary Files)**.

Multiple regression analyses were performed with percent fat as the dependent variable, and zBMI and age as independent variables (Table 2, Models 1 and 5). Four boys with low zBMI ranging from −2.6 to −1.5 were considered outliers and excluded from the models. These boys, ages 8 to 10 years, were noted to have a relatively low weight for their height with an average weight z score of −1.4 (range −2.0 to −0.7) and height z score −0.36 (range −1.1 to 1.1). In Models 1 and 5, zBMI was associated with percent fat (p<0.0001) in girls (R^2 of 0.54) and boys ($R^2 = 0.69$). To test for nonlinear effects, $zBMI^2$ was included as an independent variable (Table 2, Models 3, 4, 7, and 8); in these models $zBMI^2$ was not associated with percent fat in either sex, and did not improve the models. Ethnicity was not a contributor to percent fat (Table 2, Models 1, 3, 4, and 7).

For the percent fat model with zBMI and age as independent variables (Models 2 and 6 in Table 2), residuals were calculated by subtracting the model predicted values for percent fat from the measured 4C values for percent fat. In girls, the median residual fat percent was 0.5% with interquartile range of 7.1%, range from −3.3% to 3.8% (Table 4, Supplementary Files). In boys, the median residual for fat percent was 0.5% with an interquartile range of 6.2%, range from −3.2% to 3.0%. Percent error was calculated as the absolute difference between the predicted and measured percent fat divided by the measured percent fat. The average percent error based on the models was 20.3% (standard deviation 20.2%) in girls and 22.5% in boys (standard deviation 21.0%).

Sex specific plots of zBMI versus fat mass are shown in **Figures 2a and 2b (Supplementary Files)**. In males and females, regression analyses were performed using fat mass as the dependent variable with zBMI and age as the independent variables (Models 2 and 6, Table 3). Age was a significant covariate in all models with a positive coefficient suggesting that fat mass increases as prepubertal children age. Ethnicity was not a significant covariate, and its inclusion did not improve the models (Models 1 and 5, Tables 3). Given that the initial plots suggested a nonlinear relationship between fat mass and zBMI, $zBMI^2$ was added as a covariate and was found to be significantly associated with fat mass in both

males and females (Models 3, 4, 7, 8 in Tables 3). The addition of $zBMI^2$ increased the explained variance in girls (R^2 from 0.71 to 0.82) and boys (R^2 0.77 to 0.81).

Residuals and absolute percent error were calculated in prediction Models 4 and 8 (Table 4, Supplementary Files) where zBMI, $zBMI^2$ and age were independent variables. The median residual for fat mass was −0.2 kg in girls and −0.1 kg in boys with 50% of the residuals ranging from −1.6 kg to 1.0 kg in girls and −1.1 kg to 1.1 kg in boys. The average absolute percent error was 7.2% (standard deviation 5.7%) in girls and 8.7% (standard deviation 7.8%) in boys.

DISCUSSION

In prepubertal children, ages 6 to 12 years, zBMI does not account well for the variability in percent fat and fat mass between children. Despite there being a linear relationship between zBMI and percent fat, zBMI accounted for only 54% and 69% of the variability in percent fat in girls and boys, respectively. The average percent error for each model was relatively large ranging from 20.3% in girls to 22.5% in boys.

zBMI was found to predict total fat mass better than percent fat, as previously reported [22]. However, the relationship between zBMI and fat mass is nonlinear, and with significant error. We found a quadratic relationship, where $zBMI^2$ when adjusted for age better predicted fat mass. In these models, $zBMI^2$ accounted for 82% variability in fat mass in girls and 81% variability in boys. The quadratic relationship suggests that small changes in zBMI are associated with larger changes in fat mass. This supports previous findings that BMI in lean children and adolescents is more strongly associated with fat free mass than with fat mass (measured using DXA) [19]. Based on calculated residuals, in 50% of the children, zBMI over predicted total fat mass by 1.0 kg in girls and 1.1 kg in boys, or under predicted fat mass by 1.6 kg and 1.1 kg respectively. In this cohort of children with an average fat mass of 7.9 kg, the magnitude of the residuals was large suggesting that zBMI may misclassify children.

The secondary aim of this study was to investigate the effects of ethnicity, age and sex on the zBMI-fat relationships. Ethnicity was not a significant predictor in the models, most likely due to the relatively small sample size in each ethnic group. Previous studies have consistently shown that fat mass varies significantly in different ethnic groups prior to puberty [9, 28] and including at birth [33]. A recent study reported on the inaccuracy of weight/length indices for adiposity in preterm infants at birth [34]. The results show that both sex and age have an effect on the BMI fat relationship. Significantly higher percent fat was found in Tanner 1 girls compared to boys despite no significant differences in weight, height, or age, which is consistent with previous findings of sex differences in fat mass and distribution in children beginning at birth[35]. Age was a significant predictor of fat mass and fat percent with positive coefficient in most models suggesting that as children age and grow, their percent fat and fat mass increase.

Strengths/Limitations

This study sought to test the validity of zBMI as a measure of percent fat and fat mass in healthy, Tanner 1 children. A strength of this study was the use of the 4C model as the reference measurement for body fat. Prior studies examining the relationship of BMI or zBMI with adiposity in children including the NHANES [36] used DXA to measure body fat due to the ease of use. Yet, DXA underestimates percent body fat in lean children and overestimates percent fat in children with obesity. [27]. We note that the current data were obtained between 1995 to 2000 and the NHANES data have shown that the prevalence of obesity in children ages 6 to 11 years has increased over the past 20 years [1], which may limit the generalizability of our findings to current populations. Even so, the study cohort was notably heavier than the current population with 20% of children included with a BMI percentile ≥ 95%ile compared to 17% percent of 6 to 11 year olds today [1]. In addition, self-assessment of breast development by girls and genital development by boys based on instructions from the pediatrician may be associated with error.

Conclusions

Our study highlights the limitation of the use of zBMI as an index of adiposity in prepubertal children. Despite strong associations between zBMI and both fat mass and percent fat in models, all models had significant associated error. The use of zBMI alone as a screening tool for adiposity has the potential of misclassifying youth and needs to be used with caution in children prior to puberty. The addition of other anthropometric measurements such as waist circumference and skinfolds measurements to zBMI assessment in prepubertal children may help to identify those children with excess adipose tissue in clinical practice.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1.

Descriptive characteristics and body composition

	All (N=111)	Male (N=61)	Male excluding outliers (N=57)[1]	Female (N=50)
Age (yr)	8.5 (1.3)	8.3 (1.2)	8.8 (1.2)	8.7 (1.4)
Ethnicity	38.7%	42.6%	43.9%	34.0%
Caucasian	15.3%	8.2%	7.0%	24.0%
African American	14.4%	14.8%	15.8%	14.0%
Hispanic	16.2%	19.7%	17.5%	12.0%
Asian	15.3%	14.8%	15.9%	16.0%
Other				
Ht (cm)	135.1 (8.3)	134.7 (9.0)	134.7 (9.0)	135.5 (7.4)
Ht Z-score	0.34 (1.0)	0.4 (1.0)	0.4 (1.0)	0.3 (1.0)
Wt (kg)	33.8 (8.9)	33.8 (8.4)	34.3 (8.4)	33.9 (9.6)
Wt Z-score	0.6 (1.1)	0.7 (1.1)	0.8 (1.0)	0.4 (1.2)
BMI (kg/m^2)	18.4 (3.8)	18.4 (3.4)	18.7 (3.3)	18.3 (4.2)
BMI Z-score	0.5 (1.1)	0.6 (1.1)	0.8 (0.8)	0.4 (1.2)
BMI percentile	63.8 (29.1)	68.4 (26.8)	73.0 (21.1)	58.1 (31.2)
CDC p95	19.8%	21.3%	22.8%	18.0%
Fat Mass (kg)	7.9 (5.0)	7.1 (4.6)	7.3 (4.7)	8.9 (5.2)
Total Body Water (L)	18.4 (3.7)	18.8 (3.6)	19.1 (3.6)	17.8 (3.9)
Bone Mineral Content (g)	1203.9 (222.5)	1206.7 (229.1)	1213.7 (217.0)	1200.4 (216.3)
Fat Percent	22.0 (8.6)	19.6 (8.2)	19.9 (8.3)	24.9 (8.2) ***

Values are mean (standard deviation).

*= P < 0.05

**=P< 0.01

***
= P <0.001 compared to prepubertal males

[1] Four male subjects with low zBMI ranging from −2.6 to −1.5 were considered outliers based on the initial scatter plots.

Table 2:

Prediction models for percent fat in prepubertal children

Factor		Females (n=50)				Males (n=57)			
		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
zBMI	-	5.45 (0.81)***	5.56 (0.75)***	4.84 (1.02)***	5.01 (0.97)***	8.03 (0.75)***	8.03 (−0.75)***	5.74 (1.99)**	6.30 (1.95)**
$zBMI^2$	-			0.62 (0.64)	0.51 (0.58)			1.15 (0.93)	0.87 (0.91)
Age (yrs)	-	0.87 (0.65)	0.95 (0.62)	0.87 (0.65)	0.92 (0.62)	1.82 (0.55)**	1.72 (0.54)**	1.81 (0.55)**	1.73 (0.54)**
Ethnicity	Caucasian (reference group)								
	Black	−1.37 (2.22)		−1.25 (2.22)		0.20 (2.54)		0.59 (2.54)	
	Hispanic	0.63 (2.72)		0.17 (2.76)		−2.86 (1.82)		−2.63 (1.81)	
	Asian	−0.82 (2.79)		−1.07 (2.80)		−0.94 (1.78)		−0.56 (1.80)	
	Other	−1.58 (2.52)		−2.36 (2.65)		−3.62 (1.81)*		−3.89 (1.81)*	
Constant	-	15.50 (6.21)*	14.17 (5.82)*	15.10 (6.23)*	13.89 (5.85)*	−1.61 (4.92)	−1.97 (4.91)	−1.31 (4.90)	−1.82 (4.91)
R-squared	-	0.55	0.54	0.56	0.55	0.72	0.69	0.73	0.70
Root MSE		5.87	5.67	5.87	5.69	4.64	4.71	4.62	4.71
p-value		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Percentage body fat from 4-C model, %

Values are coefficient (standard error)

*
= P < 0.05

**
= P < 0.01

***
= p < 0.001

Presented in Table 2 are the results from prediction models investigating the relationship of percent fat (%) to zBMI in prepubertal children. Analysis with females are included in models 1 to 4 and males in Models 5 to 8. The independent variables are listed in Factor column. In all models, zBMI significantly predicted percent fat. $zBMI^2$ was not associated with fat percent (p>0.05; Model 3, 4, 7, 8). Ethnicity was not a significant determinant of percent fat (Models 1, 3, 5 and 7).

Table 3:

Prediction models for fat mass in prepubertal children

| | | Body fat mass from a 4 compartment model, kg | | | | | | | |
| | | Females (n=50) | | | | Males (n=57) | | | |
Factor		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
zBMI	-	4.08 (0.41)***	4.09 (0.38)***	2.79 (0.40)***	2.77 (0.39)***	4.69 (0.37)***	4.65 (0.36)***	2.05 (0.90)*	1.96 (0.86)*
$zBMI^2$	-			1.32 (0.25)***	1.23 (0.23)***			1.33 (0.42)**	1.36 (0.40)**
Age (years)	-	1.12 (0.33)**	1.13 (0.31)**	1.10 (0.26)***	1.07 (0.25)***	1.43 (0.27)***	1.34 (0.26)***	1.42 (0.25)***	1.35 (0.24)***
Ethnicity	Caucasian (reference group)								
	Black	-0.82 (1.11)		-0.54 (0.88)		-0.83 (1.24)		-0.38 (1.15)	
	Hispanic	-0.45 (1.36)		-1.41 (1.08)		-1.49 (0.89)		-1.23 (0.82)	
	Asian	0.42 (1.40)		-0.10 (1.10)		-1.36 (0.87)		-0.92 (0.81)	
	Other	0.54 (1.27)		-1.11 (1.04)		-0.80 (0.89)		-1.12 (0.82)	
Constant	-	-2.73 (3.12)	-2.97 (2.94)	-3.58 (2.45)	-3.65 (2.33)	-8.50 (2.41)**	-8.35 (2.37)**	-8.16 (2.22)**	-8.12 (2.17)***
R-squared	-	0.72	0.71	0.83	0.82	0.79	0.77	0.82	0.81
Root MSE		2.94	2.86	2.31	2.27	2.27	2.27	2.09	2.08
p-value		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Values are coefficient (standard error)

*
= P < 0.05

**
=P< 0.01

***
= p<0.001

Presented in Table 3 are the results from prediction models investigating the relationship of fat mass (kg) to zBMI in prepubertal children. Analysis with females are included in models 1 to 4 and males in Models 5 to 8. The independent variables are listed in Factor column. In all models, zBMI significantly predicted fat mass. The addition of $zBMI^2$ was a significant predictor of fat mass (Models 3,4,7,8); age was a significant covariate in all models; ethnicity was not a significant determinant of fat mass (Models 1,3,5,7)