Adjusting adiposity and body weight measurements for height alters the relationship with blood pressure in children

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Abstract

BACKGROUND—Adiposity measures are associated with increased pediatric blood pressure. However, this correlation can be confounded by the relationship of both variables to height. We evaluated whether adiposity and anthropometric measures were associated with pediatric blood pressure before and after adjusting each value for height.

METHODS—Participants included 281 African-American, European-American, and Hispanic-American children aged 7–12 years. Blood pressure percentiles were calculated according to pediatric guidelines using the average of four measurements. Total fat mass was determined using dual-energy x-ray absorptiometry. Socioeconomic status was calculated with the Hollingshead index. Adiposity measures were indexed for height using log-log regression analysis. Partial correlations identified measures associated with blood pressure. Linear regression was used to test the association of those measures with absolute blood pressure, while logistic regression was used to evaluate the odds for hypertension.

RESULTS—More African-Americans (16.3%) presented with potential hypertension than European-American (5.1%) or Hispanic-American (2.7%) children. After adjusting for covariates, fat mass, body mass index, and waist circumference were positively significantly associated with absolute blood pressure and hypertension in African-American and European-American children ($P < 0.05$). When these measures were height-indexed, only waist remained significantly positively associated with hypertension risk in these two groups. No measures were significantly associated with blood pressure among Hispanic-American children.

CONCLUSIONS—In this multiethnic pediatric population, waist circumference was the strongest significant adiposity predictor of hypertension risk among African-American and European-American children. Additional research is needed to determine which environmental and genetic factors contribute to pediatric hypertension, particularly among Hispanic-American groups.

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INTRODUCTION

Obesity and hypertension are associated with cardiovascular disease risk in adults, and rates of both conditions are increasing among the pediatric population.[1,2,3,4] In particular, elevated pediatric systolic blood pressure (SBP) predicts hypertension risk in adolescence and adulthood, and an association between anthropometric measurements and pediatric SBP has been noted.[5,6,7] Furthermore, ethnic/racial differences in obesity and hypertension risk have been identified, with African-American (AA) and Hispanic-American (HA) children at greater risk than their European-American (EA) counterparts.[8,3]

Although a positive relationship between adiposity and blood pressure is generally accepted, these associations can be confounded by the relationship of height with both SBP and fat mass. In children, evidence suggests that both SBP and adiposity increase with pediatric height, and that the standard calculation of body mass index (dividing height by a power of 2) may be inadequate in children.[9,10,11] This multicollinearity of height with both variables could result in overestimation of the association of adiposity measures with SBP if height is simply included as a covariate in a regression model.[12] In fact, height-based measures such as body mass index (BMI) and percent body fat can overestimate total adiposity in taller children and underestimate adiposity among shorter children.[13,9,14,15] Investigators have previously used allometric scaling (indexing) to adjust body size (weight) by body shape (height) by log-log regression analysis, thus removing the association between body weight and height.[16] Wells et al.[17] suggest indexing adiposity measures to height as preferable to using BMI or percent body fat, since a height-adjusted adiposity index would provide an "independent measure of body fatness". We thus hypothesized that 1) total fat mass, BMI, and waist circumference would be associated with blood pressure in a pediatric multiethnic population, and 2) that the association of these body fat measures with pediatric blood pressure would decrease after those values were adjusted for height using log-log regression analysis. Since socioeconomic status, dietary intake, and physical activity levels are suggested to play a role in hypertension risk, these factors were also evaluated in the present study.

METHODS

Participants were 281 children aged 7–12 years and classified by parental report as African-American (n = 92), European-American (n = 116), or Hispanic-American (n = 73). Approximately 95% of HA children were first generation immigrants from Central and South America. Data includes all children measured as part of a cross-sectional study between 2004 and 2008 designed to investigate racial/ethnic differences in metabolic outcomes. Children were recruited from the Birmingham, Alabama, area with community fliers and presentations, and newspaper advertisements. Exclusion criteria included factors that could influence body composition, such as diagnosis of major medical conditions including hypertension, hyperlipedemia, and type 1 or type 2 diabetes. Children were also excluded if they had taken medications during the past 90 days known to affect body composition or blood pressure levels (glucocorticoid, antidepressant, or stimulant therapy). Only children with a pubertal status ≤ 3 (determined by physician exam) according to the criteria of Marshall and Tanner were included.[18,19] The study was approved by the University of Alabama at Birmingham (UAB) Institutional Review Board for Human Use, with children and parents providing informed consent prior to participation.

Protocol

Data were obtained during two study visits. During the first outpatient visit, body composition and anthropometric measurements were taken. Children wore an accelerometer for 7 days to record physical activity levels. During the second visit, participants were admitted to the UAB General Clinical Research Center at approximately 1730 hours for an overnight stay. Blood pressure was measured in the evening and morning. A 24-hour diet recall was administered at each visit using the triple-pass method.

Blood pressure

Four blood pressure measurements were taken using an automated pediatric blood pressure cuff (Dinamap Pro 200, GE Medical Systems). Two measurements were obtained at approximately 1800 hours during the overnight visit. Two additional measurements were taken at approximately 0700 hours the following morning. Blood pressure was recorded after a minimum 10 minutes of seated rest. A five-minute rest separated the first and second measurements. There was no significant difference between evening and morning blood pressure measurements; thus, the four values were averaged to obtain a single systolic and diastolic measurement. Blood pressure percentile (BP%) was calculated for each child using blood pressure tables developed by the National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents.[20] Children were classified as normotensive (systolic or diastolic BP% < 90th percentile), pre-hypertensive (BP% 90–94th percentile) or hypertensive (BP% ≥ 95th percentile).

Body composition

Body weight was measured to the nearest 0.1 kg in light clothing without shoes (Scale-tronix 6702W; Scale-tronix, Carol Stream, IL). Height was determined without shoes using a mechanical stadiometer. Body mass index (weight kg/height m^2) was calculated from these values. Waist circumference was measured by the same registered dietitian using a flexible tape measure (Gulick II; Country Technology, Inc., Gays Mills, WI) at the area between the ribs and iliac crest as described by Lohman et al. and recorded to the nearest 0.1 cm.[21] The waist/height ratio was calculated from waist and height measurements.

Total fat mass was evaluated via dual energy x-ray absorptiometry (DXA) with a GE Lunar Prodigy densitometer (LunarRadiation Corp., Madison, WI). Subjects were scanned in light clothing while lying flat on their backs with arms at their sides. DXA scans were analyzed with pediatric software enCORE 2002 version 6.10.029.

Socioeconomic Status

Socioeconomic status (SES) was measured with the Hollingshead 4-factor index of social class, which combines the educational attainment and occupational prestige for working parents in the child's family. Scores ranged from 8 to 66, with the higher scores indicating higher theoretical social status.[22]

Determination of height-indexed fat mass values

To calculate height-indexed values, each body composition measure was regressed on height using log-log regression analysis. Variables were log transformed with (log)height as the independent variable. Dependent variables included (log) fat mass, (log) body weight, and (log) waist. The value of the slope was used as the power of p (index = fat mass/height ^{p}) such that each index was confirmed as no longer correlated with height. Regression analyses were determined within each ethnic group, and by gender in each group. Calculations resulted in a fat mass index, weight/height index, and waist/height index. Regression slopes for the waist/height index indicated that it was appropriate to divide waist measurements by

height with a power of one (waist/height[1]) in all participants. Slope values for the fat mass and weight/height indices are shown in Table 1. Gender-specific slopes within each ethnic group were used to calculate each height-indexed value.

Diet recalls and physical activity

Diet and physical activity levels were measured to control for possible effects on blood pressure. A registered dietitian administered two 24-hour diet recalls using the multi-pass method.[23] Data was entered into the Nutrition Data System for Research software version 2006 (Nutrition Coordinating Center, University of Minnesota, Minneapolis), and values from the two visits averaged for analysis. Physical activity levels were recorded for seven full days with a uniaxial ActiGraph accelerometer (GT1M – Standard Model 198-0100-02, ActiGraph LLC, Pensacola, FL). Epoch length was set at one minute and data expressed as counts per minute (counts min^{-1}), and daily counts were analyzed as average time (minutes/day) spent on moderate, hard, and very hard activities. Actigraph monitors have been shown to exhibit high inter-instrument reliability.[24]

Statistical analysis

Descriptive statistics were analyzed between ethnic groups using analysis of variance with Tukey's post-hoc analysis. Average SBP between ethnic groups was also analyzed with analysis of covariance controlling for age, height, gender, and SES. The association of body mass and anthropometric measures with systolic blood pressure was assessed in multiple ways, and a modified Bonferroni procedure was utilized to adjust for multiple comparisons. [25] The relationships of fat mass, fat mass index, weight, BMI, weight/height index, waist, and waist/height index to BP% categorical classification were evaluated with partial correlations controlling for age, gender, and SES. Height was included as a covariate for non-indexed values.

Linear regression was used to test the association of each body composition and index measure with absolute SBP values in the total sample after adjusting for age, gender, and SES We determined that we were adequately powered to repeat the analyses within racial/ethnic groups, which required a sample size n=43 for an alpha = 0.80 at a $P < 0.05$ per group. Height was included as a covariate for non-indexed values. A stronger relationship with body weight, cardiac outcomes, and adult hypertension is reported for systolic blood pressure (SBP); hence, when analyzing blood pressure as a continuous variable we utilized absolute SBP measures.[26,27,28] To improve normality of residuals, fat mass, weight, waist, and height were log-transformed in the models including those variables. Logistic regression was used to determine if body mass measures were associated with hypertension (BP% ≥ 95th percentile) in the total sample. Analyses were not repeated within ethnic groups due to the small numbers of EA and HA children with hypertension. All analyses were performed using SAS version 9.1 (SAS Institute, Inc., Cary, NC) with a significance level of $P < 0.05$.

RESULTS

Descriptive statistics are presented in Table 2. AA children had higher average SBP and a larger percentage of pre-hypertensive and hypertensive children compared to EA and HA (all at $P < 0.01$). HA children were shorter, had greater fat mass with a higher BMI percentile and waist circumference, and also consumed more calcium, potassium and magnesium than the other two groups ($P < 0.05$). There were no group differences in age or physical activity levels. All statistical models included dietary and physical activity variables as covariates, and these variables were evaluated for interaction effects with other covariates. However, none of these variables contributed to differences in blood pressure and hence were removed from subsequent analyses.

After adjusting for covariates, BP% category (normotensive, pre-hypertensive, hypertensive) was significantly associated with fat mass, BMI and waist circumference in the total sample. After indexing measures for height, only waist (waist/height index) remained associated with BP% category ($P < 0.05$; Table 3). . When analyzed within ethnic groups, only higher waist measurements (waist/height index) remained significantly associated with greater BP% category for AA and EA children (all at $P < 0.05$) when height-adjusted measures were used. After modified Bonferroni adjustment, BMI and waist/height index in the total sample and among EA children remained associated with BP% category. No measures of body mass were associated with BP% category in HA children.

Fat mass, BMI, and waist circumference were associated with increasing SBP levels after controlling for covariates in AA and EA children (all at $P < 0.05$; Table 4). However, substitution of height-adjusted indices for fat mass and weight in linear regression models removed this association. The waist/height index remained positively associated with SBP in AA ($P < 0.01$) and EA ($P = 0.02$). Across all models, African-American ethnicity was positively associated with hypertension risk (all at $P \leq 0.05$). Additionally, SES was associated with hypertension in AA only (all at $P < 0.05$).

Logistic regression revealed that fat mass (odds ratio [OR: 2.24 [95% CI: 1.05–4.81]) and BMI (OR: 1.17 [95% CI: 1.04–1.32]) were positively associated with hypertension (BP% category), while use of the fat mass and weight/height indices eliminated this association (Figure 1). However, waist circumference (OR: 1.07 [95% CI: 1.02–1.12]) remained associated with hypertension when using waist/height index in the analysis (OR: 2.45 [95% CI: 1.22–4.94]).

DISCUSSION

This study suggests that previously identified associations of anthropometric measures with blood pressure may be partially attributable to the confounding association of height with pediatric blood pressure. When indexed to remove the association with height, only waist circumference remained positively associated with blood pressure, suggesting that central adiposity may play a stronger role than total adiposity in pediatric hypertension.

Most previous studies have utilized anthropometric data alone as a proxy for body fatness. However, Maynard and colleagues found that among children, age-adjusted increases in BMI and BMI percentile are primarily attributable to increases in lean mass rather than fat mass.[29] Brion et al. also proposed that the association of BMI with blood pressure could be due to changes in both lean and fat mass, and that BMI may account for the independent effects of both measures.[26] Similarly, the weight/height index may be related to lean mass, minimizing its utility as a proxy for adiposity. Our study benefited from a more precise measure of total body fat via DXA. In agreement with previous work, greater total fat predicted higher blood pressure, though after indexing for height total fat did not predict hypertension. BMI may be a useful clinical tool to identify obese children at risk for hypertension; however central, rather than total, body fat is related to SBP in our sample. Consistent with other studies, however, central adiposity was associated with SBP in our sample even after indexing for height. Several previous studies suggest waist circumference is a superior predictor of blood pressure compared to BMI among normal weight and overweight children, though others have found waist circumference to be a reliable indicator of hypertension risk only among overweight/obese European children or among females. [30,31,32,33,34,35,36] Sample size did not allow for a comparison between weight categories in our population. We found no gender difference in the association between body composition measures and blood pressure; however, female children may have greater levels of fat at a given height, and our use of gender-specific calculations to index body compositon values

for height could have controlled for this. It is possible that further analysis could identify whether total central adiposity per se or a specific fat depot (i.e., subcutaneous versus intraabdominal fat) is associated with hypertension risk, and whether this association differs between normal weight and overweight children.

Although only 30% of participants were overweight as defined by a BMI ≥ 85th percentile, our sample did include a greater number of hypertensive children than the current estimated prevalence among the general population. We oversampled AA and HA children relative to their percentage of the general population, which might have affected our results. However, power analysis confirmed an adequate sample size with three ethnic groups for these analyses, and our results using non-indexed measures were consistent with previous studies involving larger samples sizes.[5,7,37,6] In Alabama, 34% of all children are considered overweight, compared to 33.3% of 6–11 year olds nationally, suggesting that our sample is representative regarding body fat indices.[38] Population-wide studies have estimated pediatric hypertension prevalence of 3–14% in normal-weight children, and as high as 11–30% among obese children.[3,39,40,41] In our sample, approximately 5% of EA and 3% of HA children presented with hypertension; however, hypertension was identified in 16% of AA. Although this is a higher rate than reported in other studies, it is consistent with reports that residents of the Southeastern United States in general, and AA in particular, have worse health profiles compared to national averages even after an individual moves to another region.[42,43] Hence, while greater than the national average, our AA hypertension rates may still be representative of Southeastern Region children, and emphasize the need for research and health interventions in this area.

There were ethnic differences in both the prevalence of and factors contributing to higher blood pressure. HA children accounted for 40% of overweight participants, yet despite having the highest levels of total body fat and waist circumference, presented with the lowest average SBP and hypertension rates. Studies investigating ethnic diversity in blood pressure have typically included only EA and AA, despite a lower prevalence of hypertension among HA compared to AA adults.[44] Such differences are likely caused by a combination of biological and environmental factors. For example, investigations into obesity-related diseases have identified alternate etiologies between ethnic groups for fat accumulation and insulin resistance development, as summarized by Goran.[45] Similarly, it is possible that factors not measured here, such as higher rates of renal sodium excretion, decreased vascular resistance, and genetic polymorphisms could influence blood pressure more than central adiposity among HA in our cohort. Additionally, most HA in the current study are first generation immigrants. Less acculturated, first-generation HA immigrants of Central- and South American origin have lower rates of hypertension compared to EA and AA adults regardless of body weight or waist circumference.[44,46,47] Morales et al. also reported higher blood pressure in second generation Mexican Americans compared to the first generation, inferring an environmental component to hypertension.[48] Hence, we might have seen higher SBP among our HA children had their families lived longer in the United States.[46,47]

Conversely, almost one fifth of AA children in this study had blood pressure levels suggestive of hypertension despite having less body fat and a lower BMI percentile than HA children. AA ethnic/racial classification remained independently associated with hypertension risk in the total sample, and SES was associated with hypertension in AA only. It is possible that additional genetic/epigenetic factors not captured in this study contributed to a greater incidence of high blood pressure in this group.[49,50,51] It has further been shown that AA children and adults experience lower SES, greater stress and decreased access to health care, factors associated with elevated blood pressure.[52,53,54]

Our use of a multiethnic population allowed us to evaluate the unique contribution of adiposity measures to SBP within minority groups. Our study was limited in that most of our HA participants were first-generation immigrants claiming Central American ancestry, which could affect applicability of these results to Caribbean Hispanics or HA living in the United States for a longer period of time. Furthermore, individual hypertension is typically diagnosed from measurements obtained during multiple time points or from 24-hour ambulatory blood pressure monitoring. Our data was obtained during one overnight visit; however, such information is useful to evaluate population trends in hypertension risk. Additionally, gene-environment interactions we were unable to test for could possibly affect the study sample. We were unable to ascertain family history of hypertension from the data, and it is possible that genetic differences could have contributed to higher rates of hypertension, particularly among AA children. Also, 70% of our study population was of normal weight as defined by a BMI at or below the 85th percentile, and it is possible that chronic obesity could affect blood pressure differently in children over time. However, our use of a predominately normal weight sample allowed us to evaluate biological and environmental contributions to blood pressure that could have been overshadowed by the presence of significant obesity.

In conclusion, total fat mass and body weight are not associated with hypertension risk in healthy children after removing the association with height. Central adiposity, as measured by waist circumference, is associated with pediatric SBP in AA and EA, but not HA, children and might be a more accurate measure of hypertension risk in the clinic setting for those groups. Additional studies could further elucidate how genetic, biological, and environmental factors interact to increase SBP in otherwise healthy children.

Acknowledgments

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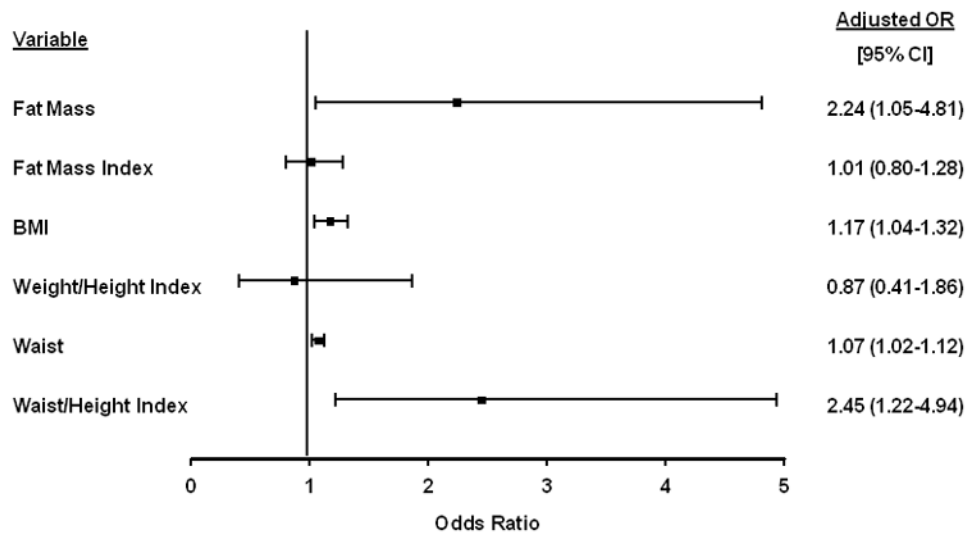
Figure 1.
Adjusted odds ratio for risk of pre-hypertension (BP% 90–94th percentile) or hypertension (BP% ≥ 95th percentile). Models adjusted for age, height, gender, ethnicity, and socioeconomic status. Analyses with index values not adjusted for height.

Table 1

Slope values (95% CIs): regression of logFat Mass or logWeight (dependent variables) on logHeight (independent variable)

Group	Fat Mass			Weight		
	β	95% CI	p	β	95% CI	p
African-American	4.12	2.45, 5.79	<0.0001	2.73	2.30, 3.17	<0.0001
Boys (n=50)	4.25	1.90, 6.60	0.0007	2.77	2.21, 3.33	<0.0001
Girls (n=42)	3.72	1.46, 5.99	0.0019	2.67	1.97, 3.38	<0.0001
European-American	3.12	1.92, 4.32	<0.0001	2.45	2.13, 2.76	<0.0001
Boys (n=61)	4.19	2.43, 5.96	<0.0001	2.76	2.30, 3.22	<0.0001
Girls (n=55)	2.49	1.04, 3.94	0.0012	2.14	1.71, 2.58	<0.0001
Hispanic-American	3.80	2.69, 4.92	<0.0001	2.63	2.27,2.99	<0.0001
Boys (n=38)	5.19	3.61, 6.79	<0.0001	3.06	2.63, 3.49	<0.0001
Girls (n=35)	1.99	0.54, 3.43	0.0084	1.94	1.41, 2.48	<0.0001

Table 2

Baseline characteristics

Characteristic	AA (n=92)	EA (n=116)	HA (n=73)
Age (y)	9.6 (1.5)	9.7 (1.6)	9.3 (1.5)
Height (cm)	141.2 (10.2)[a]	140.3 (10.5)[a]	136.7 (10.7)[b]
Weight (kg)	37.4 (10.2)	35.5 (8.6)	36.6 (9.6)
BMI(kg/m2)	18.5 (3.2)[a,b]	17.9 (2.6)[a]	19.3 (2.7)[b]
BMI percentile	63.8 (27.3)[a]	59.7 (26.5)[a]	77.8 (18.2)[b]
Waist (cm)	62.9 (8.5)[a]	63.1 (7.6)[a]	67.2 (9.8)[b]
Fat Mass (kg)	8.1 (6.1)[a]	8.2 (5.1)[a]	10.3 (5.5)[b]
Lean Mass (kg)	27.1 (5.6)[a]	25.4 (5.0)[b]	23.9 (4.7)[b]
SBP	106.2 (10.9)[a]	102.2 (10.3)[b]	100.6 (9.1)[b]
BP% >95th, n(%)	15 (16.3)[a]	6 (5.1)[b]	2 (2.7)[c]
BP% 90th > 95th, n(%)	8 (8.7)[a]	5 (4.3)[b]	3 (4.1)[b]
Sodium (gm)	3.4 (1.2)[a]	3.1 (0.9)[a]	3.2 (1.0)[a]
Calcium (mg)	740.5 (319.7)[a]	872.4 (318.2)[b]	985.9 (306.9)[c]
Magnesium (mg)	192.9 (537.3)[a]	210.3 (57.0)[a]	232.3 (63.8)[b]
Potassium (gm)	2.0 (0.6)[a]	2.1 (0.6)[a]	2.3 (0.6)[b]
Moderate/Vigorous activity(min/d)	59.7 (34.9)	60.8 (34.0)	52.1 (28.8)
Socioeconomic status	38.0 (10.7)[a]	49.2 (9.7)[b]	26.0 (12.6)[c]

BMI, body mass index; SBP, systolic blood pressure; BP%, blood pressure percentile Data are mean ± SD or percentages.

[a,b,c] superscripts indicate significant differences (determined by ANOVA or chi-square) between racial/ethnic groups at P<0.05, i.e. a≠b≠c.

Table 3

Separate partial correlation models evaluating association of systolic blood pressure with each body fat measure

	Total (n=281)	AA (n=92)	EA (n=116)	HA (n=73)
Fat Mass	0.12; p = 0.04	0.22; p = 0.05	0.24; p = 0.01	−0.04; p = 0.76
Fat Mass Index	0.11; p = 0.06	0.19; p = 0.08	0.13; p = 0.19	0.09; p = 0.50
Body Mass Index	0.22; p < 0.01	0.23; p = 0.04	0.26; p < 0.01	0.15; p = 0.23
Weight/Height Index	0.12; p = 0.05	0.24; p = 0.04	0.18; p = 0.07	−0.06; p = 0.64
Waist	0.14; p = 0.02	0.25; p = 0.03	0.23; p = 0.02	0.08; p = 0.51
Waist/height Index	0.14; p = 0.02	0.25; p = 0.03	0.22; p = 0.02	0.10; p = 0.42

Each correlation model adjusted for age, gender, height, and socioeconomic status. Analyses with index values not adjusted for height. AA, African-American; EA, European-American; HA, Hispanic-American.

Table 4

Linear regression models of SBP association with each body fat measure by race/ethnicity

Variable	Total Sample		AA		EA		HA	
	β	p	β	p	β	p	β	p
Model 1 Fat Mass	3.94	<0.01	<0.01	0.013	<0.01	<0.01	<0.01	0.78
Model 2 Fat Mass Index	0.04	0.99	17.3	0.10	0.78	0.30	−0.80	0.38
Model 3 BMI	0.92	<0.01	1.10	<0.01	1.11	<0.01	0.74	0.08
Model 4 Weight Height Index	0.67	0.63	--	--*	7.01	0.24	--	--*
Model 5 Waist	0.29	<0.01	0.56	<0.01	0.37	<0.01	0.07	0.61
Model 6 Waist Height Index	3.83	<0.01	8.00	<0.01	4.67	0.02	1.02	0.62

Covariates = age, height, gender, socioeconomic status. Analyses with index values not adjusted for height. Total Sample models also control for ethnicity with EA as reference group

*
overall model not significant at P<0.05. AA, African-American; EA, European-American; HA, Hispanic-American; BMI, body mass index.