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Adjusting Adiposity and Body Weight Measurements for Height Alters the Relationship With Blood Pressure in Children

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BACKGROUND
Adiposity measures are associated with increased pediatric blood pressure (BP). 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 BP before and after adjusting each value for height.

METHODS
Participants included 281 African-American (AA), European-American (EA), and Hispanic-American (HA) children aged 7–12 years. BP 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 (SES) was calculated with the Hollingshead index. Adiposity measures were indexed for height using log-log regression analysis. Partial correlations identified measures associated with BP. Linear regression was used to test the association of those measures with absolute BP, whereas logistic regression was used to evaluate the odds for hypertension.

RESULTS
More AAs (16.3%) presented with potential hypertension than EA (5.1%) or HA (2.7%) children. After adjusting for covariates, fat mass, body mass index, and waist circumference were positively significantly associated with absolute BP and hypertension in AA and EA 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 BP among HA children.

CONCLUSIONS
In this multiethnic pediatric population, waist circumference was the strongest significant adiposity predictor of hypertension risk among AA and EA children. Additional research is needed to determine which environmental and genetic factors contribute to pediatric hypertension, particularly among HA groups.

Keywords: *adipose tissue; blood pressure; ethnic groups; hypertension; waist circumference*

Am J Hypertens 2010; **23**:904-910 © 2010 American Journal of Hypertension, Ltd.

Obesity and hypertension are associated with cardiovascular disease risk in adults, and rates of both conditions are increasing among the pediatric population.[1–4] In particular, elevated pediatric systolic BP (SBP) predicts hypertension risk in adolescence and adulthood, and an association between anthropometric measurements and pediatric SBP has been noted.[5–7] 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 BP is generally accepted, these associations can be confounded by the relationship of height with both SBP and fat mass. Among adults, height does not play a significant role in determining BP. However, in children, evidence suggests that both SBP and adiposity increase with pediatric height, and that the standard calculation of body mass index (BMI) (dividing height by a power of 2) may be inadequate in children.[9–11] 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 BMI and percent body fat can overestimate total adiposity in taller children and underestimate adiposity among shorter children.[9,13–15] 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

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Received 31 December 2009; first decision 19 February 2010; accepted 14 March 2010; advance online publication 22 April 2010. doi:10.1038/ajh.2010.82

weight and height.[16] Wells *et al.*[17] suggest indexing adiposity measures to height as preferable to using BMI or percent body fat, because a height-adjusted adiposity index would provide an "independent measure of body fatness." We thus hypothesized that (i) total fat mass, BMI, and waist circumference would be associated with BP in a pediatric multiethnic population, and (ii) that the association of these body fat measures with pediatric BP would decrease after those values were adjusted for height using log-log regression analysis. Because socioeconomic status (SES), 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 AA (n = 92), EA (n = 116), or HA (n = 73) measured between 2004 and 2008 for a cross-sectional study designed to investigate racial/ethnic differences in metabolic outcomes. Approximately 95% of HA children were first-generation immigrants from Central and South America. Children were recruited from the Birmingham, Alabama, area with community fliers/presentations and newspaper advertisements. Exclusion criteria included factors that could influence body composition, such as diagnosis of major medical conditions including hypertension, hyperlipidemia, 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 BP 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 (Birmingham, AL) Institutional Review Board for Human Use, with children and parents providing informed consent before 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 University of Alabama at Birmingham General Clinical Research Center at ~1730 h for an overnight stay. BP was measured in the evening and morning. A 24-h diet recall was administered at each visit using the triple-pass method.

Blood pressure. Four BP measurements were taken using an automated pediatric BP cuff (Dinamap Pro 200, GE Medical Systems, Piscataway, NJ). Two measurements were obtained at ~1800 h during the overnight visit. Two additional measurements were taken at ~0700 h the following morning. BP was recorded after a minimum 10 min of seated rest. A 5-min rest separated the first and second measurements. There was no significant difference between evening and morning BP measurements; thus, the four values were averaged to obtain a single systolic/diastolic measurement. BP percentile (BP%) was calculated using BP 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), prehypertensive (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. BMI (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, Gays Mills, WI) as described by Lohman and Going 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 with a GE Lunar Prodigy densitometer (Lunar Radiation, Madison, WI). Subjects were scanned in light clothing while lying flat on their backs with arms at their sides. Dual energy X-ray absorptiometry scans were analyzed with pediatric software enCORE 2002 version 6.10.029.

Socioeconomic status. SES was measured with the Hollingshead four-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 1 (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 BP. A registered dietitian administered two 24-h 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, MN), and values from the two visits averaged for analysis. Physical activity levels were recorded for seven full days with

Table 1 | Slope values (95% CIs): regression of log fat mass or log weight (dependent variables) on log height (independent variable)

	Fat mass			Weight		
Group	**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

CI, confidence interval.

a uniaxial ActiGraph accelerometer (GT1M – Standard Model 198-0100-02; ActiGraph LLC, Pensacola, FL). Epoch length was set at 1 min and data expressed as counts/min. Daily counts were analyzed as average time (min/day) spent on moderate, hard, and very hard activities. Actigraph monitors have been shown to exhibit high interinstrument 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 SBP 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 nonindexed values.

Linear regression was used to test the association of each body composition and index measure with SBP 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 nonindexed values. A stronger relationship with body weight, cardiac outcomes, and adult hypertension is reported for SBP; hence, when analyzing BP as a continuous variable we utilized absolute SBP measures.[26–28] 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 whether body mass measures were associated with hypertension (BP% $\geq$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, Cary, NC) with a significance level of $P < 0.05$.

Table 2 | Baseline characteristics

Characteristic	AA ($n = 92$)	EA ($n = 116$)	HA ($n = 73$)
Age (years)	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/m^2)	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 (g)	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 (g)	2.0 (0.6)^{a}	2.1 (0.6)^{a}	2.3 (0.6)^{b}
Moderate/vigorous activity(min/day)	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}

Data are mean ± s.d. or percentages. Superscripts indicate significant differences (determined by ANOVA) between racial/ethnic groups at $P < 0.05$, i.e., a ≠ b ≠ c.
AA, African-American; ANOVA, analysis of variance; BMI, body mass index; BP%, blood pressure percentile; EA, European-American; HA, Hispanic-American; SBP, systolic blood pressure.

RESULTS

Descriptive statistics are presented in Table 2. AA children had higher average SBP and a larger percentage of prehypertensive 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.

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

		Total sample		AA		EA		HA	
	Variable	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	—	—[a]	7.01	0.24	—	—[a]
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.
AA, African-American; BMI, body mass index; EA, European-American; HA, Hispanic-American; SBP, systolic blood pressure.
[a] Overall model not significant at $P < 0.05$.

However, none of these variables contributed to differences in BP and hence were removed from subsequent analyses.

After adjusting for covariates, BP% category (normotensive, prehypertensive, 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, AA 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: 2.24 (95% confidence interval: 1.05–4.81)) and BMI (odds ratio: 1.17 (95% confidence interval: 1.04–1.32)) were positively associated with hypertension (BP% category), whereas use of the fat mass and weight/height indices eliminated this association (**Figure 1**). However, waist circumference (odds ratio: 1.07 (95% confidence interval: 1.02–1.12)) remained associated with hypertension when using waist/height index in the analysis (odds ratio: 2.45 (95% confidence interval: 1.22–4.94)).

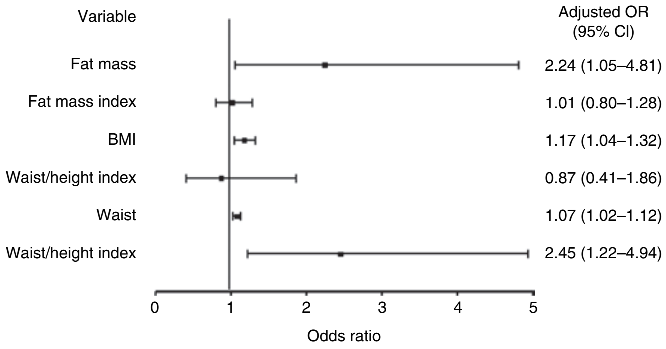

Figure 1 | Adjusted odds ratio for risk of prehypertension (BP% 90–94th percentile) or hypertension (BP% ≥ 95th percentile). Models adjusted for age, height, gender, ethnicity, and socioeconomic status. Analyses with index values not adjusted for height. BMI, body mass index; BP, blood pressure; CI, confidence interval; OR, odds ratio.

DISCUSSION

This study suggests that previously identified associations of anthropometric measures with BP may be partially attributable to the confounding association of height with pediatric

BP. When indexed to remove the association with height, only waist circumference remained positively associated with BP, 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 age-adjusted increases in pediatric 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 BP could be due to changes in both lean and fat mass, and that BMI may account for the independent effects of both measures, minimizing its utility as a proxy for adiposity.[26] Our study benefited from a more precise measure of total body fat via dual energy X-ray absorptiometry. In agreement with previous work, greater total fat predicted higher BP, 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 BP 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.[30–36] 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 BP; however, female children may have greater adiposity at a given height, and our use of gender-specific calculations to index body composition values for height could have controlled for this. Further analysis could identify whether total central adiposity per se or a specific fat depot (i.e., subcutaneous vs. intra-abdominal 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 included 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 nonindexed measures were consistent with previous studies involving larger samples sizes.[5–7,37] 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.[3,39–41] In our sample, ~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 relocation 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 BP. 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, which could have impacted our findings. Previous studies completed within Latin-American countries that identified waist circumference or BMI as predictive of pediatric BP studied populations with higher rates of hypertension and obesity than found in our cohort, and did not index weight or waist measurement for height.[44–46] Studies investigating ethnic diversity in BP have typically included only EA and AA, despite a lower prevalence of hypertension among HA compared to AA adults.[47] 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.[48] Similarly, factors not measured here, such as higher rates of renal sodium excretion, decreased vascular resistance, and genetic polymorphisms could influence BP more than central adiposity among HA in our cohort. Additionally, most HA in this 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.[47,49,50] Morales *et al*. also reported higher BP in second generation Mexican Americans compared to the first generation, inferring an environmental component to hypertension.[51] Hence, we might have seen higher SBP among our HA children had their families lived longer in the United States.[49,50]

Conversely, almost one-fifth of AA children in this study had elevated BP 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. Hence, additional genetic/epigenetic factors not captured in this study possibly contributed to a greater incidence of high BP in this group.[52–54] Furthermore, AA children and adults experience lower SES, greater stress and decreased access to health care, factors associated with elevated BP.[55–57]

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-h ambulatory BP 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 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 chronic obesity could affect BP differently in children over time. However, our use of a predominately normal-weight sample allowed us to evaluate biological and environmental contributions to BP 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: The authors thank Robert Petri and Alexandra Luzuriaga-McPherson for their assistance with data collection. This work was funded by the National Institutes of Health grants R01-DK067426, P30-DK56336, P60-DK079626, M01-RR-00032, and the National Cancer Institute Cancer Prevention and Control Training Program CA47888.

Disclosure: The authors declared no conflict of interest.

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