Trunk Fat and Blood Pressure in Children Through Puberty

Qing He, MD, PhD; Mary Horlick, MD; Barbara Fedun, RN; Jack Wang, MS; Richard N. Pierson, Jr, MD; Stanley Heshka, PhD; Dympna Gallagher, EdD

Background—Fat distribution is well recognized as a cardiovascular risk factor in adults. The association between android fat distribution and cardiovascular risk factors, such as blood pressure (BP), was previously reported in an African-American and Caucasian pediatric population. The aim of the present study was to investigate the relationship between BP and body fat distribution in a large cross-sectional pediatric sample. The effects of race, sex, and puberty on this relationship were assessed.

Methods and Results—BP was measured in 920 healthy children and adolescents (African-American, Asian, and Caucasian, ages 5 to 18 years). Fat distribution was determined by skinfold thickness and dual-energy X-ray absorptiometry (DXA). Pubertal status was assessed by the criteria of Tanner. Regression analysis was used to explore the association between BP and fat distribution. Significant positive relationships between systolic and diastolic BP and trunk fat adjusted for total fat were seen in boys at all pubertal stages in all 3 races by both DXA and skinfold measurements. In girls, trunk fat was not a significant predictor of BP.

Conclusions—Our results demonstrate a sex difference in the relationship between BP and trunk fat in that a significant positive relationship was present in boys only. These findings, based on 2 independent measures of fat distribution, may help identify the specific features of individuals at risk, allow earlier intervention, and suggest sex-specific determinants for BP. (Circulation. 2002;105:1093-1098.)

Key Words: fat distribution ■ blood pressure ■ pediatrics ■ puberty

The importance of fat distribution as a risk factor for cardiovascular diseases in adults is well documented. A pattern of excess fat in the central region (truncal fat) is associated with increased cardiovascular risks, such as elevated blood pressure (BP), compared with a pattern of fat deposits in the limb region (peripheral fat).1–4 Elevated BP is associated with an increased risk of cardiovascular disease, morbidity, and mortality, and this process may begin early in life.5,6 Adolescents with essential hypertension were found to have a high prevalence of left ventricular hypertrophy and abnormal left ventricular geometry to a degree that would be associated with increased risk of cardiovascular disease morbidity in adults.7 Analyses of data from the Bogalusa Heart Study8 revealed that the prevalence of clinically diagnosed hypertension was significantly higher in adult subjects whose childhood BP was in the top quintile. Furthermore, subjects with coronary artery fibrous plaques at 18 years of age tended to have higher mean systolic BP (SBP) than those without.5 Similar associations between fat distribution and altered BP were found in a pediatric sample,9 where greater deposition of central fat was associated with increased cardiovascular risk factors, including elevated BP.

The purpose of this study was to investigate the relationship between BP and body fat distribution in a large cross-sectional pediatric sample, including 3 race groups (African-American, Asian, and Caucasian), where fat distribution was determined using skinfold thickness and dual energy X-ray absorptiometry (DXA). The effects of race, sex, and puberty on the relationship between BP and fat distribution were assessed.

Methods

Subjects
Subjects were 442 girls (145 African-American, 161 Asian, and 136 Caucasian) and 478 boys (128 African-American, 184 Asian, and 166 Caucasian) enrolled in a cross-sectional body composition study.10 Ages ranged from 5 to 18 years, and 39% (358 of 920) were prepubertal. Volunteers were recruited through local newspaper notices, announcements at schools and after-school centers, and by word of mouth. Consent was obtained from each volunteer’s parent or guardian, and assent was obtained from each volunteer as well. Race was determined by consistent background of both parents and 4 grandparents by questionnaire using the categories Asian, non-Hispanic African-American, or non-Hispanic Caucasian. Participants whose backgrounds did not meet these criteria were excluded from analysis. Asian participants were of Chinese and Korean background. There were no height or weight restrictions to enter the study. A medical history from the parent or guardian and a physical examination confirmed normal health status. The Institutional Review Board of St Luke’s-Roosevelt Hospital Center approved the study.

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From the Obesity Research Center, St Luke’s-Roosevelt Hospital; Institute of Human Nutrition (Q.H., S.H., D.G.); and Children’s Hospital of New York (M.H.), College of Physicians & Surgeons, Columbia University, New York, NY.
Correspondence to Dr Dympna Gallagher, Obesity Research Center, 1090 Amsterdam Ave, New York, NY 10025. E-mail dg108@columbia.edu
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Measurements
All medical and body composition evaluations were carried out on the same day at least 1 hour after a light meal, with the subject clothed in a hospital gown and wearing foam slippers.

Anthropometrics
Body weight was measured to the nearest 0.1 kg (Tronix) and height to the nearest 0.5 cm using a stadiometer (Holtain). Skinfold thicknesses were measured to the nearest 1.0 mm with a Lange caliper at the following 7 sites: triceps, biceps, chest, subscapular, abdomen, thigh, and calf. All skinfold measurements were taken on the right side of the body, using the procedures recommended by Lohman et al. The average of 2 readings was recorded with the measurement to ±2.0 mm. All subjects were measured by 1 of 2 investigators. The intraclass correlation coefficients between the 2 investigators for skinfold measurements on a sample of 5 subjects were as follows: triceps, 0.97; biceps, 0.89; chest, 0.99; subscapular, 0.92; abdomen, 0.99; thigh, 0.95; and calf, 0.97.

Dual Energy X-Ray Absorptiometry
Total body fat was measured with a whole-body DXA scanner (DPX, Lunar Corp) using pediatric software version 3.8G. The calculation of regional soft tissue mass has been previously described in detail. Repeated daily measurements in 3 adult subjects showed a coefficient of variation (CV) of 5% for arm fat soft tissue, 1% for leg fat soft tissue, and 2% for trunk fat soft tissue, respectively. Because of concerns about unnecessary radiation exposure in healthy children, scan reproducibility in children was not performed. Measured phantom bone mineral density was stable throughout the study period at 1.166 to 1.196 g/cm². Ethanol and water bottles, simulating fat and fat-free soft tissues, respectively, were scanned as soft-tissue quality control markers monthly. The range in measured R values over the study period was 1.255 to 1.258 (CV, 0.127%) and 1.367 to 1.371 (CV, 0.103%) for ethanol and water, respectively.

Blood Pressure
BP was measured by the study pediatrician or nurse according to the guidelines. All BP data were obtained with subjects in the seated position, using a mercury sphygmomanometer and an appropriately-sized cuff. The onset of the fourth Korotkoff sound was used to determine diastolic BP (DBP) in children 5 to 12 years of age, and the onset of the fifth Korotkoff sound was used to determine DBP in adolescents 13 to 18 years of age.

Pubertal Staging
Pubertal status was established by the criteria of Tanner for breasts in girls, genitalia in boys, and pubic hair in boys and girls by the pediatric endocrinologist or study nurse for younger subjects and by self-assessment in volunteers 11 years and older. Fasting blood samples for testosterone (boys), estradiol (girls), and gonadotropins (boys and girls) were obtained in a subset of 105 boys and girls in Tanner stages 1 through 5. Results were consistent with pubertal stage assessed by physical examination except for 6 boys in Tanner stages 2 to 3. For the purpose of analyses, subjects were subdivided into 3 pubertal groups, prepuberty (Tanner stage 1 for breasts or genitalia and pubic hair), early puberty (Tanner stages 2 and 3 for breasts or genitalia), and late puberty (Tanner stages 4 and 5 for breasts or genitalia).

Statistical Analysis
Race differences in BP for the total sample and within each pubertal stage were compared using the Kruskal-Wallis test. Fat distribution has commonly been expressed as ratios in previous studies. Because of several problems associated with the use of ratios in statistical analysis, we chose to use regression models with relevant variables as covariates, eg, trunk fat adjusted for total fat, as an index of fat distribution when investigating the relationship between fat distribution and BP. Two models were developed on the basis of skinfolds and DXA regional fat measurement. In the Skinfold model, trunk fat was defined as the sum of chest, subscapular, and abdominal skinfolds, and total fat was the sum of triceps, biceps, chest, subscapular, abdomen, thigh, and calf. In the DXA model, trunk fat was defined as the Lunar DXA trunk region, and total fat was whole body fat mass. Sex, race, pubertal group, height, and selected 2-way interactions (trunk fat and sex, trunk fat and race, and trunk fat and pubertal group) were included as covariates. To make residuals of the regression models normally distributed, log transformation was used to transform the dependent variable SBP.

Some independent variables in these analyses are highly correlated, and collinearity effects are likely in the regression models. Our interest in these variables is only as covariates, so that their effects on trunk fat are removed. Accordingly, the coefficients and standard errors of these covariates are not presented in the tables or given any interpretation in the discussion. All statistics were computed using SAS PC software version 8, and P<0.05 was considered to be statistically significant.

Results
Subject characteristics are summarized in Table 1. Significant race differences in SBP were found between African-American and Caucasian girls only, with African-American girls being 3 mm Hg higher on average. For DBP, significant race differences were found between African-American and Asian boys only, with African-American boys being 2 mm Hg higher on average.

The mean deviation and SD for both SBP and DBP are presented for boys and girls separately by pubertal groups (Table 2). Within each pubertal group, no significant race differences for either SBP or DBP were found for boys and girls.

Multiple regression analysis was conducted with BP as the dependent variable (Table 3). Both Skinfold and DXA models for SBP and DBP were statistically significant, with R² values ranging from 0.24 to 0.44. Race and the interaction between race and trunk fat were not significant contributors, and they were excluded from additional consideration. Trunk fat by skinfold and DXA measures was positively related to SBP and DBP after adjusting for other covariates. Significant interactions between trunk fat and sex and between trunk fat and pubertal group were found in some of the models.

To additionally explore the sex and trunk fat interaction, regression analysis was applied for boys and girls separately (Table 4). For boys, both SBP and DBP were positively related to trunk fat in all pubertal groups using both Skinfold and DXA models. For girls, trunk fat was not significantly associated with DBP in any pubertal group. However, because significant interactions between pubertal group and trunk fat were found in the SBP-skinfold model and the SBP-DXA model for girls, these interactions were additionally explored using regression analysis in each pubertal group. No significant association was found between BP and trunk fat in any single pubertal group in girls by either Skinfold or DXA models.

Discussion
This study of 920 healthy children and adolescents demonstrates a sex difference in the relationship between BP and body fat distribution in that a significant positive
relationship between trunk fat and BP was present in boys only. This sex difference was not influenced by race (African-American, Asian, or Caucasian) or stage of sexual maturation and was independent of height and total body fat.

Understanding the predictors of BP in children is important, because childhood BP has been shown to track into adulthood.8,19,20 In the Bogalusa Heart Study, 8 children with BP levels in the highest quintile were 2 times more likely to be in the highest quintile 15 years later. Identification of body composition features associated with BP would allow detection of children at risk for hypertension who could benefit from monitoring.

**Measurement of Body Fat in Children**

Presently, body mass index (BMI) is used by clinicians as an index of obesity and is a predictor of BP in children and adolescents.21,22 However, the normal increase in BMI with growth and maturation generally reflects gains in fat-free mass more than fat mass, and for any given BMI, there is a

### TABLE 1. Subject Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>African-American</th>
<th>Asian</th>
<th>Caucasian</th>
<th>African-American</th>
<th>Asian</th>
<th>Caucasian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>11.7 (3.5)</td>
<td>11.6 (3.7)</td>
<td>11.2 (3.5)</td>
<td>11.4 (3.6)</td>
<td>11.1 (3.7)</td>
<td>11.0 (3.1)</td>
</tr>
<tr>
<td>Height, cm</td>
<td>154.1 (20.8)</td>
<td>150.3 (19.6)</td>
<td>149.8 (20.1)</td>
<td>148.5 (17.0)</td>
<td>143.1 (16.3)</td>
<td>146.4 (16.6)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>51.8 (21.6)</td>
<td>47.4 (18.1)</td>
<td>46.0 (19.5)</td>
<td>49.6 (20.9)</td>
<td>41.5 (15.9)</td>
<td>43.4 (15.8)</td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>102.9 (15.0)</td>
<td>101.1 (14.2)</td>
<td>100.0 (11.9)</td>
<td>98.4 (11.6)*</td>
<td>96.3 (10.3)</td>
<td>95.0 (9.3)*</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>68.8 (9.7)*</td>
<td>66.4 (9.7)*</td>
<td>66.6 (9.2)</td>
<td>65.6 (9.7)</td>
<td>64.2 (8.6)</td>
<td>64.2 (8.3)</td>
</tr>
<tr>
<td>Skinfold thickness, mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdomen</td>
<td>13.8 (13.1)</td>
<td>17.1 (10.8)</td>
<td>13.9 (11.6)</td>
<td>18.3 (12.4)</td>
<td>19.3 (10.2)</td>
<td>16.8 (9.7)</td>
</tr>
<tr>
<td>Biceps</td>
<td>7.3 (6.1)</td>
<td>8.2 (5.4)</td>
<td>7.8 (6.3)</td>
<td>9.9 (7.7)</td>
<td>9.9 (6.5)</td>
<td>10.1 (6.2)</td>
</tr>
<tr>
<td>Chest</td>
<td>9.1 (9.3)</td>
<td>11.7 (8.9)</td>
<td>9.5 (8.6)</td>
<td>11.1 (8.5)</td>
<td>12.5 (7.6)</td>
<td>10.6 (6.9)</td>
</tr>
<tr>
<td>Calf</td>
<td>17.7 (10.1)</td>
<td>16.6 (6.0)</td>
<td>17.7 (9.0)</td>
<td>23.3 (11.6)</td>
<td>19.1 (8.3)</td>
<td>20.3 (8.8)</td>
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<tr>
<td>Subscapular</td>
<td>11.9 (9.9)</td>
<td>12.6 (7.3)</td>
<td>10.2 (7.7)</td>
<td>15.4 (11.4)</td>
<td>14.7 (8.5)</td>
<td>11.8 (8.4)</td>
</tr>
<tr>
<td>Thigh</td>
<td>19.0 (15.6)</td>
<td>19.5 (10.1)</td>
<td>20.0 (12.3)</td>
<td>29.0 (16.5)</td>
<td>25.2 (10.7)</td>
<td>27.4 (12.7)</td>
</tr>
<tr>
<td>Triceps</td>
<td>13.2 (10.0)</td>
<td>14.8 (6.8)</td>
<td>13.9 (8.1)</td>
<td>18.2 (10.6)</td>
<td>18.2 (8.4)</td>
<td>16.9 (7.9)</td>
</tr>
<tr>
<td>Sum</td>
<td>91.9 (69.6)</td>
<td>100.4 (50.1)</td>
<td>93.2 (59.4)</td>
<td>124.4 (72.0)</td>
<td>119.2 (54.3)</td>
<td>114.2 (55.8)</td>
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<tr>
<td>DXA fat, kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arms</td>
<td>0.8 (1.2)</td>
<td>0.8 (0.6)</td>
<td>0.7 (0.9)</td>
<td>1.2 (1.4)</td>
<td>0.9 (0.7)</td>
<td>0.9 (0.7)</td>
</tr>
<tr>
<td>Legs</td>
<td>4.4 (4.5)</td>
<td>3.7 (2.4)</td>
<td>4.0 (3.3)</td>
<td>6.5 (5.1)</td>
<td>4.5 (2.9)</td>
<td>5.1 (3.4)</td>
</tr>
<tr>
<td>Trunk</td>
<td>3.8 (4.5)</td>
<td>4.1 (3.3)</td>
<td>3.4 (3.5)</td>
<td>5.6 (5.1)</td>
<td>4.8 (3.5)</td>
<td>4.5 (3.6)</td>
</tr>
<tr>
<td>Total body fat</td>
<td>9.5 (10.4)</td>
<td>9.3 (6.4)</td>
<td>8.7 (7.8)</td>
<td>14.1 (11.7)</td>
<td>11.1 (7.2)</td>
<td>11.2 (7.8)</td>
</tr>
</tbody>
</table>

All values are given as mean (SD).

*Race difference in BP within same sex, P<0.05.

### TABLE 2. BP (mm Hg) in Different Pubertal Groups

<table>
<thead>
<tr>
<th>Pubertal Group</th>
<th>Boys</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>African-American</td>
<td>Asian</td>
<td>Caucasian</td>
<td>African-American</td>
<td>Asian</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>Mean (SD)</td>
<td>n</td>
<td>Mean (SD)</td>
<td>n</td>
</tr>
<tr>
<td>Prepuberty SBP</td>
<td>39</td>
<td>94.1 (10.5)</td>
<td>73</td>
<td>93.0 (10.7)</td>
<td>57</td>
</tr>
<tr>
<td>Prepuberty DBP</td>
<td>39</td>
<td>63.6 (9.5)</td>
<td>73</td>
<td>62.3 (8.5)</td>
<td>57</td>
</tr>
<tr>
<td>Early puberty SBP</td>
<td>32</td>
<td>105.3 (17.8)</td>
<td>60</td>
<td>103.6 (13.4)</td>
<td>55</td>
</tr>
<tr>
<td>Early puberty DBP</td>
<td>32</td>
<td>70.4 (9.0)</td>
<td>60</td>
<td>67.4 (8.2)</td>
<td>55</td>
</tr>
<tr>
<td>Late puberty SBP</td>
<td>42</td>
<td>109.3 (12.5)</td>
<td>41</td>
<td>111.8 (12.4)</td>
<td>40</td>
</tr>
<tr>
<td>Late puberty DBP</td>
<td>42</td>
<td>72.5 (8.5)</td>
<td>41</td>
<td>72.1 (10.4)</td>
<td>40</td>
</tr>
</tbody>
</table>

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range of percent body fat. Total body fat measured by both skinfolds and DXA are more precise than BMI. These two independent measures of body composition demonstrate that central fat distribution (trunk fat adjusted for total body fat) is an additional predictor of BP in boys only.

### Race Difference

Race differences in BP have been reported in many studies of adults, in which a higher prevalence of hypertension has been found among African-American women, placing this group at a higher risk for cardiovascular-related morbidities and mortality. Previous studies to determine when in the lifespan this race difference appears have been inconclusive. Daniels et al reported significantly greater SBPs and DBPs (≈1.5 mm Hg) in African-American compared with Caucasian girls. However, this difference disappeared when the data were stratified by stage of sexual maturation, which is consistent with the present study.

### Sexual Maturity

Sex differences in the pattern of BP during adolescence were observed in the National Health Examination Survey III.

### Table 3: Multiple Regression Models With BP (mm Hg) as the Dependent Variable

| Independent Variables | Pubertal Group | Sex† | Height | Trunk Fat‡ | Total Fat§ | Sex-Trunk Fat|| Puberty-Trunk Fat |
|-----------------------|----------------|------|--------|------------|------------|-----------------|---------------------|
|                       | t   | P   | t   | P   | t   | P   | t   | P   | t   | P   | t   | P   | t   | P   | t   | P   |
| Skinfold model        |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| SBP                   | 1.54 | NS  | −1.22 | NS  | 9.06 | 0.0001 | 4.91 | 0.0001 | −0.96 | NS  | −2.06 | 0.04 | −1.07 | NS  | 0.44 | 0.0001 |
| DBP                   | 1.26 | NS  | −0.44 | NS  | 4.53 | 0.0001 | 2.87 | 0.004  | 0.56  | NS  | −2.33 | 0.02 | −0.19 | NS  | 0.24 | 0.0001 |
| DXA model             |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| SBP                   | 1.79 | NS  | −1.85 | NS  | 7.49 | 0.0001 | 5.61 | 0.0001 | −2.01 | 0.04 | −2.98 | 0.003 | −2.14 | 0.03 | 0.44 | 0.0001 |
| DBP                   | 1.55 | NS  | −1.15 | NS  | 3.29 | 0.001  | 3.83 | 0.0001 | −1.03 | NS  | −2.06 | 0.01 | −1.06 | NS  | 0.24 | 0.0001 |

*Pubertal group (prepuberty=1, early puberty=2, late puberty=3).
†Sex (boy=1, girl=2).
‡Trunk fat (Skinfold model: trunk fat=sum of chest, subscapular and abdomen skinfolds; DXA model: trunk fat=body fat measured by DXA in trunk region).
§Total fat (Skinfold model total fat=sum of chest, subscapular, abdomen, triceps, biceps, thigh, and calf skinfolds).
¶Interaction: sex and trunk fat; pubertal group and trunk fat.
#Log-transformed.
NS: P>0.05.
**All model intercepts are significantly different from zero.
Girls’ BP increased markedly during the prepubescent growth spurt, ages 10 to 11 years, and stabilized after puberty, whereas boys experienced a gradual increase in BP from pubescence through age 18 years. Furthermore, sexual maturation, as measured by Tanner’s criteria, was found to be a predictor of BP when the influence of weight and skeletal age were omitted.

Fat distribution has been reported to be a predictor of cardiovascular risk factors in boys and girls ages 9 to 17 years, using DXA measurements. A strong relationship between android fat distribution and cardiovascular risk factors, including BP, was observed in an African-American and Caucasian pediatric population, but sexual maturity was not accounted for. In contrast, sexual maturity was a covariate in the present study, with different findings between girls and boys.

Sex Differences
In adults, sex differences in associations between adiposity measures and BP have been reported. Haines et al reported sex differences in the relationship between body fat distribution and cardiovascular risk factors, including BP, in 2948 white adults. Forearm skinfold was strongly associated with cardiovascular risk factors in men, whereas 2 trunk skinfolds were stronger contributors in women. In a study in southern China, a significant independent association between fat distribution (indexed by waist/hip ratio) and SBP was found in women only.

Fat distribution as measured by either anthropometry or DXA was reported as a risk factor for cardiovascular disease in children. To our knowledge, the present study is the first to identify a sex difference in the association between fat distribution and BP in children and adolescents.

Limitations of Our Study
Our study protocol was established in 1995 and followed the 1987 guidelines, which recommended a single BP measurement. Multiple measures of BP in future studies may strengthen the associations observed in this study.

The methods used to estimate fat distribution (skinfolds and DXA) do not specifically measure the visceral fat depot. Although the results demonstrate an association of trunk fat with BP, this study cannot clarify whether there is a stronger association with visceral fat than with subcutaneous abdominal fat.

It must be acknowledged that the definition of ethnicity based on self-report is limited because of the genetic admixture of populations in the United States. A more objective estimate of biogeographical ancestry involves the use of genetic markers, characterized by particular alleles, which have differential frequencies among racial or ethnic populations.

Conclusion
Central fat distribution measured by skinfolds and DXA is a predictor of BP in African-American, Asian, and Caucasian boys at all stages of puberty but not in girls. These findings, which are based on 2 independent measures of fat distribution in a healthy population, are of particular importance because BP tracks from childhood to adulthood, and childhood BP is predictive of later morbidity. Identification of specific features of individuals at risk will allow earlier intervention. Future studies should include measurement of visceral fat mass and circulating metabolic factors to explore mechanisms for the association of central fat with BP in boys.

Acknowledgments
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