Body Fat Patterning and Blood Pressure in Children and Young Adults
The Bogalusa Heart Study

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SUMMARY The relationship of central body fat (measured by subscapular skinfold) and peripheral body fat (measured by triceps skinfold) to blood pressure was investigated in 3784 subjects aged 5 to 24 years old from the biracial community of Bogalusa, Louisiana. After adjustment for height, age, sex, and race, significant relationships were found for both central body fat ($r = 0.19$ and $0.14$, $p<0.0001$) and peripheral body fat ($r = 0.15$ and $0.12$; $p<0.0001$) with systolic and diastolic (fourth phase) blood pressure, respectively. However, the relationship between peripheral body fat and blood pressure, after controlling for the level of central body fat, was negligible ($r = 0.00$ and $0.01$ for systolic and diastolic blood pressure, respectively). In contrast, the central body fat–blood pressure relationship remained statistically significant even after controlling for the peripheral body fat level. For central body fat, the partial correlations with systolic blood pressure were highest in young children ($r = 0.15$), dropped slightly during adolescence ($r = 0.12$), and became nonsignificant only in 18- to 24-year-old female subjects; correlations remained high in both black and white 18- to 24-year-old male subjects ($r = 0.18$ and $0.16$, respectively). Mean levels of systolic blood pressure from the lowest to the highest quartile of central body fat ranged from 100.4 to 108.9 mm Hg. The adult hypertension–central body fat relationship, which has been shown by others, appears to exist in children. Continued efforts at early identification and prevention of obesity in children are warranted.

(Hypertension 9: 236-244, 1987)

KEY WORDS • blood pressure • obesity • fat patterning • children

EVIDENCE linking body mass to adult hypertension is extensive. International comparisons have shown that populations that gain weight during aging also show increases in blood pressure, while more primitive populations, which show little gain in weight with advancing adult age, have little or no increase in blood pressure. Prevalence surveys have also shown an increase in hypertension among the obese, and longitudinal studies of weight gain in young adults have supported weight gain as an important predictor of subsequent hypertension. Finally, the causal nature of the relationship between body mass and hypertension is indicated by the reduction in blood pressure following weight reduction in obese hypertensive subjects.

As originally proposed by Vague and replicated by others, central deposition of body fat is a more important correlate of adult hypertension than is peripheral fat deposition. For example, Blair et al. have shown that among U.S. adults, subscapular skinfold (as a measure of central body fat) has an independent predictive contribution to blood pressure, while all the predictive contribution of triceps skinfold (as a measure of peripheral body fat) was accounted for by sub-
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scapular skinfold. In concert with these findings are longitudinal studies that show subscapular skinfolds and the waist-to-hip ratio (as an additional measure of central body fat) to be predictive of cardiovascular disease. 

While extensive information exists on the obesity–blood pressure relationship in adults, little work has been done on this subject in children and adolescents. Several investigators have shown that increased body mass and height are associated with increased levels of blood pressure in children, but little is known of the relative contribution of central versus peripheral fat. Therefore, the present study examined the body fat deposition relationship to blood pressure in 5- to 24-year-old subjects from Bogalusa, Louisiana.

Subjects and Methods

Study Population

Subjects for this report participated in the Bogalusa Heart Study, a long-term epidemiological study of cardiovascular risk factors in children. Bogalusa, Louisiana, is a semirural town with a population of 17,000. The racial composition is 67% white and 33% black.

The relationship between regional fat deposition and blood pressure was investigated in a cross-sectional survey of 4223 subjects aged 5 to 24 years old (70% participation of the age- and residence-eligible population) examined between 1981 and 1983.

Measurements

During the 1981 to 1983 examinations, subjects had anthropometric, health behavior, blood pressure, and lipid and lipoprotein measurements taken. Methods of measurement have been described in detail elsewhere. Procedures followed were in accordance with institutional guidelines.

Anthropometric measurements used in this study include two manual measurements of height to the nearest 0.1 cm and weight to the nearest 0.1 kg. The mean of two measurements for both height and weight was used in all analyses. Triceps and subscapular skinfolds were measured to the nearest 1.0 mm using Lange calipers (Cambridge Scientific, Cambridge, MA, USA), and the mean of three measurements at each skinfold site was used.

Blood pressure measurements on the right arm were resting, basal-like, seated measures of systolic and fourth phase diastolic Korotkoff sounds using mercury sphygmomanometers. Cuff sizes were selected based on upper-arm girth and length. The mean of six readings taken by two randomly assigned, trained nurses was used in the analyses.

Health behavior measures used in this study included cigarette smoking, alcohol, and oral contraceptive use. These behaviors were measured using questionnaires administered to subjects 8 years of age and older. Subjects were characterized as being current or non-current users of these health behaviors. Subjects under 8 years of age were considered noncurrent users for all three behaviors.

Within the school-age range (5–17 years of age) the reliability of these measures was tested by reexamination in a random, same-day sample (for anthropometric and blood pressure measures) and a random, 2-week retest sample for health behavior questionnaires. A high degree of reliability was noted for all information, with intraclass correlation coefficients between the initial and repeat measures of triceps and subscapular skinfolds of 0.98 each. The coefficient of variation for triceps skinfold was 5.4%, and for subscapular skinfold was 11.1%. For blood pressure, intraclass correlations were 0.89 (systolic) and 0.79 (diastolic). Test-retest reliability for current smoking and alcohol use were above 90%.

Statistical Analysis

Of the 4223 subjects, information on all anthropometric and blood pressure measurements was available in 3784, who were used in the analyses. Median skinfold and blood pressure measurements by age, race, and sex are presented to describe the sample. To analyze the association between blood pressure, subscapular skinfold, and triceps skinfold, the variance attributable to significant covariates (p<0.15) was first removed using multiple linear regression for each race-sex group. Significant regressors included in the model were weight, sex, and age. Covariates accounted for 41% and 36% of the variation in systolic and diastolic blood pressure, respectively. The largest amount of variation in the covariate adjustment procedure was attributable to height, which accounted for 24% and 18% of the systolic and diastolic blood pressure variability, respectively. Residual values for blood pressure from the regressions (observed-predicted) and age-race-sex specific ranks for triceps and subscapular skinfolds were used in analyzing blood pressure relationships to skinfolds.

Spearman correlations stratified by age, race, and sex were used to examine the relationship between residual blood pressure and skinfolds. As this analysis did not simultaneously control for each of the skinfold levels, further analyses were performed wherein partial correlations (r) for each of the skinfolds was calculated by principal component analysis. Those partial correlations were necessary as triceps skinfold is highly correlated with subscapular skinfold (r = 0.75). In addition, mean residual blood pressure levels were examined across quartiles of subscapular skinfold and triceps skinfold. This analysis, therefore, controls for the level of one skinfold while examining the relationship of the other skinfold to residual blood pressure. Analysis of variance was used in this analysis; the independent variables were the quartiles of triceps and subscapular skinfolds and their interaction term. Levels of blood pressure in this analysis were adjusted to the mean value of white boys at 13 years of age by adding the sample mean to the residual blood pressure value. Age group, race, and sex modifications on the skinfold–blood pressure relationship were also analyzed by adding the appropriate interaction terms in the analyses.
Results

The distributions of blood pressure and skinfolds by age, race, and sex are displayed in Table 1. For female subjects, median blood pressure rose linearly to age 17 years, at which time it reached a plateau. In contrast, for male subjects, blood pressure continued a linear elevation to 20 years of age, at which time it also began to plateau. Subscapular skinfold also rose with age, with female subjects having higher levels than male subjects. In addition, racial differences were present for subscapular skinfolds: white male subjects had higher levels than black male subjects, but black female subjects showed higher levels after 10 years of age compared with white female subjects. Triceps skinfolds showed a different age trend: peak levels in male subjects occur at puberty and decline thereafter, while in female subjects a continual rise was seen with age. For both sexes, triceps skinfolds were lower in blacks than whites.

Correlations between subscapular skinfold and blood pressure as well as triceps skinfold and blood pressure are shown in Table 2. For systolic blood pressure, the correlation with subscapular skinfold \((r = 0.19, p < 0.001)\) was slightly higher than with triceps skinfold \((r = 0.15, p < 0.001)\). The same trend was found for diastolic blood pressure, although correlations were at a lower level \((r = 0.14\) and 0.12 for subscapular and triceps skinfold, respectively). Significant age, race, and sex variations in the correlation between systolic blood pressure and subscapular skinfold existed: prior to age 13 years, whites showed a higher correlation \((r = 0.36)\) than did blacks \((r = 0.29)\). Those correlations dropped in magnitude after 13 years of age. In the oldest age group \((18-24\) years), the correlations of systolic blood pressure with both subscapular \((r = 0.24, p < 0.0001)\) or triceps skinfold \((r = 0.18, p < 0.0001)\) was significant in male subjects only. Similar trends were seen for diastolic blood pressure.

Partial correlation coefficients, which control the level of one skinfold, while evaluating the association of the other, are shown in Table 3. For all subjects, the partial correlation between subscapular skinfold (controlling for triceps skinfold) and blood pressure was 0.12 and 0.08 for systolic and diastolic blood pressure, respectively \((p < 0.001)\). The overall amount of variance explained by subscapular skinfold thickness after accounting for triceps skinfold thickness was, therefore, 1.4% \((0.12^2 \times 100)\) and 0.6% \((0.08^2 \times 100)\) for systolic and diastolic blood pressure, respectively. The corresponding partial correlations for triceps skinfold (controlling for subscapular skinfold) were 0.00 and 0.01 for systolic and diastolic blood pressure, respectively \((p > 0.05)\). Age, race, and sex trends in the partial correlations for subscapular skinfold and blood pressure were similar to the bivariate correlations previously noted. Partial correlations for subscapular skinfold with blood pressure were highest for systolic blood pressure before 13 years of age \((r = 0.15\) for all race-sex groups, \(p < 0.001)\). Partial correlations for subscapular skinfold with systolic blood pressure began to fall in magnitude during adolescence \((13-17\) years).
TABLE 2. Bivariate Correlation Coefficients of Subscapular or Triceps Skinfold on Blood Pressure*: The Bogalusa Heart Study

<table>
<thead>
<tr>
<th>Race and sex of group</th>
<th>Age (yr)</th>
<th>5-8 (r)</th>
<th>9-12 (r)</th>
<th>13-17 (r)</th>
<th>18-24 (r)</th>
<th>All ages (r)</th>
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<tbody>
<tr>
<td></td>
<td>Systolic blood pressure</td>
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</tr>
<tr>
<td>White male</td>
<td>Subscapular</td>
<td>0.32†</td>
<td>0.38†</td>
<td>0.15‡</td>
<td>0.18‡</td>
<td>0.25†</td>
</tr>
<tr>
<td></td>
<td>Triceps</td>
<td>0.25†</td>
<td>0.34†</td>
<td>0.05</td>
<td>0.11</td>
<td>0.19†</td>
</tr>
<tr>
<td>White female</td>
<td>Subscapular</td>
<td>0.37†</td>
<td>0.32†</td>
<td>0.09</td>
<td>-0.04</td>
<td>0.20†</td>
</tr>
<tr>
<td></td>
<td>Triceps</td>
<td>0.38†</td>
<td>0.32†</td>
<td>0.03</td>
<td>-0.05</td>
<td>0.17†</td>
</tr>
<tr>
<td>Black male</td>
<td>Subscapular</td>
<td>0.27‡</td>
<td>0.38†</td>
<td>0.03</td>
<td>0.26‡</td>
<td>0.23†</td>
</tr>
<tr>
<td></td>
<td>Triceps</td>
<td>0.17§</td>
<td>0.32†</td>
<td>-0.04</td>
<td>0.21§</td>
<td>0.17†</td>
</tr>
<tr>
<td>Black female</td>
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<td>0.33†</td>
<td>0.16§</td>
<td>-0.07</td>
<td>0.16</td>
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<tr>
<td></td>
<td>Triceps</td>
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<td>0.29†</td>
<td>0.15§</td>
<td>-0.07</td>
<td>0.14</td>
</tr>
<tr>
<td>All race-sex</td>
<td>Subscapular</td>
<td>0.27†</td>
<td>0.33†</td>
<td>0.11‡</td>
<td>0.06§</td>
<td>0.19†</td>
</tr>
<tr>
<td></td>
<td>Triceps</td>
<td>0.24†</td>
<td>0.29†</td>
<td>0.04</td>
<td>0.04</td>
<td>0.15†</td>
</tr>
<tr>
<td>Diastolic blood pressure</td>
<td>Subscapular</td>
<td>0.35†</td>
<td>0.34†</td>
<td>0.07</td>
<td>0.11</td>
<td>0.23†</td>
</tr>
<tr>
<td></td>
<td>Triceps</td>
<td>0.32†</td>
<td>0.26†</td>
<td>0.00</td>
<td>0.03</td>
<td>0.16†</td>
</tr>
<tr>
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<td>0.28†</td>
<td>0.35†</td>
<td>0.01</td>
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<td>0.12†</td>
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<tr>
<td></td>
<td>Triceps</td>
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<td>0.00</td>
<td>-0.12§</td>
<td>0.13†</td>
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<tr>
<td>Black male</td>
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<td>0.18‡</td>
<td>0.28†</td>
<td>-0.10</td>
<td>0.12</td>
<td>0.12‡</td>
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<tr>
<td></td>
<td>Triceps</td>
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<td>0.25‡</td>
<td>-0.10</td>
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<td>0.15†</td>
</tr>
<tr>
<td>Black female</td>
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<td>0.14</td>
<td>0.31†</td>
<td>0.21‡</td>
<td>0.03</td>
<td>0.17†</td>
</tr>
<tr>
<td></td>
<td>Triceps</td>
<td>0.13</td>
<td>0.29†</td>
<td>0.17§</td>
<td>0.02</td>
<td>0.15†</td>
</tr>
<tr>
<td>All race-sex</td>
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<td>0.30†</td>
<td>0.05</td>
<td>-0.01</td>
<td>0.14†</td>
</tr>
<tr>
<td></td>
<td>Triceps</td>
<td>0.19†</td>
<td>0.26†</td>
<td>0.02</td>
<td>-0.02</td>
<td>0.12†</td>
</tr>
</tbody>
</table>

* Spearman correlation coefficients of residual blood pressure with age-, race-, and sex-specific skinfold rank. 
† p < 0.001, ‡ p < 0.01, § p < 0.05.

years of age) in all race-sex groups (r = 0.12, p < 0.01) and diminished to nonsignificant levels for female subjects 18 to 24 years of age (r = -0.03 and -0.05 for whites and blacks, respectively, p > 0.05) while increasing in magnitude for male subjects 18 to 24 years of age (r = 0.16 and 0.18 for whites and blacks, respectively, p < 0.01). Similar trends in partial correlations with diastolic blood pressure were found but were lower in magnitude than those found with systolic blood pressure.

Results of the stratified analysis of skinfolds and levels of blood pressure agreed with the previous results. For both systolic and diastolic blood pressure, within quartiles of triceps skinfold, levels of blood pressure rose with increasing subscapular skinfold thickness (Figures 1 and 2). Mean systolic blood pressure ranged from 100.4 mm Hg for the nine subjects in the upper triceps/lowest subscapular skinfold quartile (n = 9), to 108.9 mm Hg for subjects in the upper triceps/upper subscapular skinfold quartile (n = 736). Similar trends were found for diastolic blood pressure. In contrast, within the first three quartiles of subscapular skinfold, no consistent elevation in blood pressure was found with increasing levels of triceps skinfold.
Table 3. Partial Correlation Coefficients of Subscapular and Triceps Skinfold on Blood Pressure*: The Bogalusa Heart Study

<table>
<thead>
<tr>
<th>Race and sex of group</th>
<th>Systolic blood pressure</th>
<th>Diastolic blood pressure</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Age (yr)</td>
<td></td>
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<tr>
<td></td>
<td>5–8 (r)</td>
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<td>18–24 (r)</td>
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<td>All ages (r)</td>
</tr>
<tr>
<td>White male</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subscapular</td>
<td>0.19*</td>
<td>0.16*</td>
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<tr>
<td>Triceps</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td>White female</td>
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<tr>
<td>Subscapular</td>
<td>0.11</td>
<td>0.25*</td>
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<tr>
<td>Triceps</td>
<td>0.13*</td>
<td>0.03</td>
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<td>Black male</td>
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<tr>
<td>Subscapular</td>
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<td>0.01</td>
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<td>Black female</td>
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<tr>
<td>Subscapular</td>
<td>0.18*</td>
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<tr>
<td>Triceps</td>
<td>0.02*</td>
<td>0.06</td>
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<tr>
<td>All race-sex</td>
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<tr>
<td>Subscapular</td>
<td>0.14*</td>
<td>0.16*</td>
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<tr>
<td>Triceps</td>
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<td>0.01</td>
</tr>
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</table>

*Partial correlation coefficients for subscapular skinfold (controlling for levels of triceps skinfold) and triceps skinfold (controlling for levels of subscapular skinfold).

†p < 0.001, ‡p < 0.01, §p < 0.05.

(p > 0.05; Figures 3 and 4). However, in the upper quartile of subscapular skinfold, a rise in both systolic and diastolic blood pressure was noted with increasing quartile of triceps skinfold. This interaction between subscapular and triceps skinfold quartile with blood pressure level was marginally significant for systolic (p = 0.05) and of greater magnitude for diastolic (p < 0.001) blood pressure. To determine if this interaction was a result of increasing levels of subscapular skinfold or triceps skinfold within the upper quartile, partial correlations were calculated. The partial correlation for subscapular skinfold (controlling for triceps skinfold) was 0.06 (p > 0.05) and for triceps skinfold was 0.02 (p > 0.40), indicating the association with blood pressure was attributable to subscapular skinfold.

Age, race, and sex modification on the relationship between blood pressure levels and subscapular skinfold quartile are shown in Table 4. This analysis showed significant age modification on the relationship with systolic blood pressure (p < 0.0001). The association was stronger in the youngest age group (mean change of 6.9 mm Hg from the lowest to highest quartile of subscapular skinfold) than in the oldest age group (mean change of 1.6 mm Hg from lowest to highest quartile of subscapular skinfold). Significant
Figure 1. Systolic blood pressure and subscapular skinfold (within triceps skinfold levels): Bogalusa Heart Study. Note increasing levels of blood pressure with increasing subscapular skinfold quartile.

Figure 2. Diastolic blood pressure and subscapular skinfold (within triceps skinfold levels): Bogalusa Heart Study. Note increasing levels of blood pressure with increasing subscapular skinfold quartile.

Figure 3. Systolic blood pressure and triceps skinfold (within subscapular skinfold levels): Bogalusa Heart Study. Note the lack of consistent elevations in blood pressure with increasing triceps skinfold quartile, except in the upper quartile of subscapular skinfold. Partial correlations in the upper subscapular skinfold quartile showed that the relationship was due to variation in subscapular skinfold (see text).

Figure 4. Diastolic blood pressure and triceps skinfold (within subscapular skinfold levels): Bogalusa Heart Study. Note lack of consistent elevations in blood pressure with increasing triceps skinfold quartile, with the exception of the upper subscapular skinfold quartile, where the apparent association with triceps skinfold was due to variation in subscapular skinfold (see text).

Sex modification was also present, with the association between blood pressure and subscapular skinfold greater in male than in female subjects. No race modification was present on the blood pressure–subscapular skinfold relationship.

Discussion

These observations in children and young adults show that centrally located body fat (subscapular skinfold) is independently correlated with blood pressure even after controlling for triceps skinfold. In contrast, no independent association exists between peripheral fat (as measured by triceps skinfold) and blood pressure; this statistical relationship is mediated through the strong interrelationship between central and peripheral body fat. Overall, the amount of variation in blood pressure explained by subscapular skinfold was small, ranging from 0 to 6.25% for individual age-race-sex groups. However, the amount of variation in blood pressure explained by subscapular skinfold was always much greater than that explained by triceps skinfold. Overall mean systolic blood pressure levels increased by 8.5 mm Hg from the lowest to highest quartile of subscapular skinfold. The relationship between subscapular skinfold and blood pressure was modified by both age (the relationship was stronger in younger subjects) and sex (the relationship was stronger in male subjects).

We used the triceps skinfold as a measure of peripheral body fat and subscapular skinfold as a measure of central body fat, as they were the only indices available in this study. The validity of these indices as measures of central (upper body) and peripheral (low body) obesity is questionable, as others studying the effects of body fat patterning have used the waist-to-hip girth ratio, intra-abdominal to subcutaneous abdominal fat ratio, as well as more recently developed complex functions of multiple skinfold sites. 

...
appears that any index used will not fully characterize the impact of body fat patterning on metabolism (see Reference 34 for review). The higher correlations between subscapular skinfold versus triceps skinfold and blood pressure were not the result of increased reliability of the subscapular measurement. In fact, our results indicate that the triceps skinfold and subscapular skinfold measurements were of equal reliability ($r = 0.98$).

The present study extends earlier findings in older adults who and in adolescents to blood pressure. This small amount of variation of blood pressure, which is explained by various indices of fitness, has been found by others, who showed that lean body mass and age contribute more to blood pressure variability than do measures of fat. In adolescent boys, Wilson et al. have also shown that elevated blood pressure was not related to abnormal oxygen consumption but rather to early maturation and excess size for age (in the absence of obesity).

An interesting age-related modification of the relationship between subscapular skinfold and blood pressure was observed in the present study. The relationship was strongest in young children and weakest in young adults. This finding may have been an artifact caused by the linear acceleration in growth that occurs between ages 5 and 14 years (and therefore allowed for a wider range of values for skinfold and blood pressure measurements). Alternatively, the finding that the association was stronger in young children may be indicative of a greater detrimental effect of adipocyte hyperplasia, which occurs during youth, versus adipocyte hypertrophy, which occurs later in life. Moreover, as our young adults were more likely to have had a longer duration of their obesity than the younger children, the decreasing association of subscapular skinfold with increasing age may represent a long-term hemodynamic adaptation (increased cardiac output with decreased peripheral resistance) in which adults with obesity have been shown to have only mild elevations in blood pressure.

While we did not show a significant difference in the subscapular skinfold–blood pressure association by race, Blair et al. did show the association to be greater among white adults than black adults for diastolic...
blood pressure only. Our results indicate a similar (although not statistically significant) trend, as the associated increase in both systolic and diastolic blood pressure from the lowest to the upper quartile of subscapular skinfold was greater in whites. Our analysis utilized age-, race-, and sex-adjusted values of blood pressure and skinfold, which may have lessened our ability to detect a race interaction.

The difference in the association that we observed between young men and young women in our oldest age group (18–24 years), in which the correlations between blood pressure and skinfold became nonsignificant in female subjects, was an unexpected finding. Our cross-sectional data indicate that even though subscapular skinfold is still increasing during this age in black female subjects, it is actually decreasing in white female subjects, and both groups have a nearly constant absolute weight. Mean blood pressures in female subjects of this age range also are relatively constant. These findings indicate a period in the female life cycle where the skinfold level and blood pressure are independent. We anticipate that as this cohort ages additional weight gain will occur, and one would anticipate the relationship to become positive again.

Although the exact etiological mechanism(s) responsible for human obesity and the obesity-hypertension relationship are unclear (see References 34 and 40–42 for reviews) the implication of the results of this study is that central body fat is an important contributor to blood pressure level in children. Further research that attempts to determine if this association is causal is warranted, as this study merely shows an association with cross-sectional data.

As the pathological process of atherosclerosis and essential hypertension begins in childhood, and as obesity is related to both blood pressure and lipid levels in children, the setting for cardiovascular disease in adults is presumably accelerated with the nature of obesity and fat deposition in children. Identification and intervention of obesity should therefore begin in earnest during childhood. This is especially true given the decrease in the probability of obtaining a normal weight level in adulthood once a child continues an obese pattern as an adolescent.

Acknowledgments

The Bogalusa Heart Study represents the collaborative efforts of many people whose cooperation is gratefully acknowledged. We especially thank Mrs. Bettye Seal for her outstanding work as community coordinator. We also thank the children of Bogalusa especially thank Mrs. Bettye Seal for her outstanding work as community coordinator. We also thank the children of Bogalusa and their parents, without whom this study would not be possible.

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