Blood Pressure, Electrolytes, and Body Size: Their Relationships in Young Relatives of Men with Essential Hypertension

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SUMMARY In 154 white children aged 8 to 18 years from four large kindreds, relationships among blood pressure (BP), age, sex, body size, and electrolyte excretion were studied. Each kindred was ascertained through one male aged 35-58 years with essential hypertension, namely, a diastolic blood pressure (DBP) over 95 mm Hg. Weight, relative weight (relative to NCHS median for age, sex, and stature), subcutaneous fat-folds, various indices of obesity, and other measures of body size were significantly correlated with systolic blood pressure (SBP) and DBP in each sex (r = 0.3 to 0.7). Sodium and potassium excretion in 24-hour urine was also positively correlated with some measures of body size, and tended to increase with body size at a slightly more rapid rate in boys than in girls. In addition, there was a strong correlation between electrolyte excretion and BP in boys (r = 0.2 to 0.6); however, when the effects of age, body size and fatness were statistically removed, the correlations between BP and electrolyte excretion were not significant, except for 4th phase diastolic pressure (DBP 4). These data, therefore, while not strongly supporting a relationship between sodium excretion and BP in children, do not rule out such a relationship, especially in families with a history of hypertension. In addition, these data provide further evidence of a very strong association between BP and body size and fatness in boys and girls. (Hypertension 2 (suppl I): I-83-I-92, 1980)

KEY WORDS • Quetelet index • sodium • potassium • relative weight • hypertension • blood pressure • familial

ELEVATED BP in adulthood is an important risk factor for coronary heart disease. Evidence continues to accumulate that BP tends to “track” over time; that is, a BP at one age tends to be predictive of BP at a later age.3,4 This evidence supports the concept that adult BP is related to BP levels during childhood. Therefore, it is important to study BP in children and the variables that influence it. Although numerous variables are associated with BP in children, there are particularly strong associations with body size and fatness.10-17 Epidemiological studies have reported associations between electrolyte intake or excretion and BP,18-19 and increased salt intake can trigger hypertension in some animal models.20-22 The relationship between salt intake and BP in children, however, remains unclear and may differ depending on whether there is a family history of hypertension.23

Studies are needed of the variables that affect BP during childhood to identify genetic and environmental factors that can be used to predict later hypertension. This information could lead to methods for altering the time course of BP changes in certain individuals before established hypertension puts the individual at serious risk for coronary heart disease (CHD). The current paper examines the relationships among blood pressure, age, sex, measures of body size and fatness, and electrolyte excretion in children aged 8 to 18 years who are members of very large families.

Material and Methods

Sample and Ascertainment

The ultimate aim of this research project is to study genetic factors affecting BP. Since the planned genetic analytical approaches are most effective in large families (kindreds), five kindreds containing about 600 participating members are being studied in the overall project. In the present paper, data are analyzed from
154 children aged 8 to 18 years who are members of four white families each ascertained through one male with essential hypertension.

As part of the National Heart, Lung and Blood Institute's Multiple Risk Factor Intervention Trial (MRFIT), more than 20,000 men aged 35-58 years were screened in and near Dayton, Ohio. Part of this screening included three measurements of seated BP. Only about 3.5% of the screened men were selected for participation in the MRFIT program. They were in the upper 10% of risk of death from coronary heart disease (CHD) because of the presence of elevated serum cholesterol, DBP, and cigarette smoking. In addition, they did not have pre-existing CHD, diabetes, ECG abnormalities, and a variety of other exclusion criteria, including unwillingness to modify diet and smoking habits.

The 19,589 Dayton-area men who were screened, but not selected for participation in MRFIT, formed the pool from which probands of the present kindreds were obtained. About 10% of these men had a mean 5th phase diastolic blood pressure (DBP₅) greater than 95 mm Hg, the only initial criterion for inclusion in the present study. These men were sent questionnaires asking about local family size and interest in participating in this research study; 31% (644) returned the questionnaires, of which about one-third (206) indicated the respondent had 10 or more local relatives. After extensive telephone and home interviews with all 206 men, 16 men were identified who each had more than 50 local relatives; this was the number set as the minimum goal for family size. Subsequent to contact with relatives, 10 of these families were found to have sufficient individuals considered likely to participate.

The 10 probands were given extensive medical examinations to confirm the diagnosis of essential hypertension (DBP greater than 95 mm Hg, without apparent cause). After these examinations, seven men and their families were considered eligible for the study; budgetary restrictions limited enrollment to one black and four white families. The number of participating family members in the black kindred was 63; the four white kindreds included 60, 216, 48, and 205 members respectively.

Blood Pressure Measurement — Assessment Protocol

At the participant's first visit, seated BP was measured four times during one twenty-minute sitting period, in the right arm, to the nearest even mm Hg; 2 minutes elapsed between sequential measurements. The first and third measurements were assessed with a standard mercury sphygmomanometer (Baumanometer) and the second and fourth with a random zero sphygmomanometer. Cuff size was selected on the basis of arm dimensions. The cuff was applied only once and remained in place at least 10 minutes before the first BP was recorded. All measurements were made between 8:00 and 9:30 a.m. in the same room at a temperature of 21.5° ± 1.5°C. The first visit BP used in the reported analyses is the mean of the four measurements for each individual.

Blood Pressure Measurement — Observer Training and Variability

The seated BP was measured by observers trained and certified according to MRFIT procedures. In addition, observers were trained to accurately record DBP₄. The training and certification procedures developed by MRFIT were complemented by training using a special video cassette developed at Indiana University as part of the High Blood Pressure in the Young Program.

In addition to the training function, the video cassette was used to test for intra- and interobserver variation in detecting the first, fourth and fifth Korotkoff sounds (DBP₁, DBP₄, DBP₅). The results from these tests indicate that significant ($p < 0.05$) mean differences seldom occurred between replicates for an observer. When they did, the mean difference between replicates was less than 1.0 mm Hg. Likewise, there were few significant differences between the mean values obtained by an observer at viewings several days apart. None of these significant differences exceeded 1.5 mm Hg, but the differences tended to be higher for DBP₄ than for SBP or DBPₛ. While slightly more variation occurred from day to day with a single observer than occurred on any given day, in neither case was intraobserver replicability considered a problem.

Interobserver variation was assessed using the video cassette in addition to separate tests using double stethoscopes on test subjects. Statistically significant ($p < 0.05$) differences between observers were not uncommon, but the differences were almost always less than 3.0 mm Hg. When among-observer significant differences exceeding 3.0 mm Hg were found, all observers were retrained and retested. Experiments with double stethoscopes testing interobserver variation provided data consistent with those from experiments with the video cassette.

Blood Pressure Measurement — Digit Preference

In the present study, digit preference was not observed with the random zero sphygmomanometer. With the standard mercury sphygmomanometer, all six observers used in this study showed some digit preference, despite the intensive training. The SBP and DBP₄ presented the least problem; only three of the six observers showed significant digit preference. The preferred digit (usually 0) occurred at frequencies higher than the expected 20%, but less than 30%. Five observers showed a significant digit preference for DBP₅, with preferred digit frequencies near 40% indicating that DBP₅ was less accurately assessed than the others.

Blood Pressure Measurement — Order Effects

Comparisons were made between first and third measurements (standard sphygmomanometer) and second and fourth measurements (random zero sphygmomanometer). There were no significant differences between measurements for either device or for any BP
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Phase \( p \leq 0.05 \). In other words, the BP of participants did not show evidence of change during the measurement session.

24-Hour Urine Collection and Electrolyte Measurements

Urine collections were made from each participant for an exact 24-hour period beginning in the morning between 8:00 and 10:30 a.m. The 24-hour urine sodium and potassium levels (mEq/ml) were measured with an International Laboratories Model 143 flame photometer; creatinine excretion (mg/dl) was measured with a Gilford System 3500 Computer Directed Analyzer. In 10 children, the creatinine values fell outside the approximate 80% confidence interval of the sex-specific linear regression of creatinine on weight \( (W) \); these samples were judged invalid and not used in the analyses. The acceptable range was:

\[-0.208 + 0.0215 \ (W) \pm 0.461 \] for boys and \[0.044 + 0.0107 \ (W) \pm 0.327 \] for girls, where \( W \) is weight in kg.

Anthropometric Measures

Measures of body size and fatness recorded include weight \((kg)\), stature \((cm)\), triceps, subscapular, and suprailliac skinfolds \((mm)\); Hultain caliper), and bicristal and biacromial breadths \((cm)\); Hultain anthropometer). Each measurement was made by two observers following a rigorous and standardized protocol developed at the Fels Research Institute for the Fels Longitudinal Growth Study. The participant was weighed while wearing only a gown and/or shorts on a beam balance scale; and stature was measured with the participants not wearing shoes.

Indices of Body Size or Adiposity

Numerous indices of body size or obesity have been used in relation to BP or electrolytes. They include: body build or Quetelet index \((100 \times W/S^2)\); body bulk, ponderal, or Rohrer index \((100,000 \times W/S^3)\); surface area \((W^{0.43} \times S^{0.73} \times 0.007184)\); and relative weight, where \( W \) is weight in kilograms and \( S \) is stature in centimeters. Relative weight is defined as 100 times the child's weight divided by the National Center for Health Statistics median weight for the child's race, age, sex, and stature.

Results

Age and Sex Trends

The means and standard deviations of the variables discussed in this paper are given for each 2-year age group in table 1 (boys) and table 2 (girls). The number of children in each age group and sex is about 15. Significant \((0.05 \text{ level})\) sex differences within age groups occurred for some variables primarily in the older, post-pubertal age groups. Without exception, mean skinfold thicknesses for girls were larger than the corresponding thicknesses for boys; these differences were significant at 8.0–9.9 years for all three sites and at 14.0–15.9 years for the triceps and subscapular sites. Boys in the 14.0–15.9 and 16.0–17.9 year groups were significantly taller and had greater biacromial breadths and larger surface area than girls of corresponding age. In addition, boys in the 16.0–17.9 year group were significantly heavier and had a higher SBP than the girls.

Significant sex differences for the electrolytes and creatinine paralleled those for the body size variables, that is, boys in the 14.0–15.9 and 16.0–17.9 age groups excreted more sodium, potassium, and creatinine than girls. Boys in the 10.0–11.9 age groups also excreted significantly more sodium and creatinine than girls of the same age. There was a much steeper increase in electrolyte and creatinine excretion over age in boys than in girls.

Body Size and Blood Pressure

Sex-specific correlations between BP and measures of body size and fatness are given in table 3. Significant correlations between BP and body size variables were found in almost all cases. Generally, the relationships are consistent across sex; however, some sex differences may exist. Correlations between SBP and variables other than subcutaneous fatness tend to be slightly higher in boys than in girls. The corresponding correlations 

The first-order partial correlations controlled for age effects (table 3) show that the statistically significant correlations between BP and body size are not simply reflections of age effects. While there is some reduction in many of the correlation coefficients as a result of removing age effects, age alone has relatively little effect independent of body size or fatness.

The measures of body size that best explain the observed relationships with BP were identified using sex-specific multiple regression models. A three-part approach was employed: 1) equations using all of the body size and fatness variables were developed, and these necessarily accounted for the maximum amount of variation \( (R^2) \) in the dependent BP variable; 2) multiple stepwise regression procedures were used to find the “best” equation accounting for the most variation with a small number of variables, and 3) sets of a few selected variables were entered in equations to determine if an equation using independent variables common to both sexes and all BP phases could be found without appreciably decreasing the \( R^2 \). Table 4 reports the results of these procedures.

Equations using stature, weight, and triceps skinfold thickness were sufficient to account for virtually all of the variation resulting from age and body size differences. After the effects of these three variables were removed, no significant regression was found with the remaining variables in a multiple stepwise procedure. In the “best” equations resulting from forward stepwise regression for each BP phase in boys and girls, the variables listed in table 4 were significant. The proportion of variation \( (R^2) \) accounted for...
TABLE 1. Means and Standard Deviations of Variables for Boys in Each 2-Year Age Group Between 8 and 18 Years

<table>
<thead>
<tr>
<th>Boys</th>
<th>8.0-9.9 yrs</th>
<th>10.0-11.9 yrs</th>
<th>12.0-13.9 yrs</th>
<th>14.0-15.9 yrs</th>
<th>16.0-17.9 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 18)</td>
<td>(n = 18)</td>
<td>(n = 14)</td>
<td>(n = 16)</td>
<td>(n = 13)</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>8.57 ± 0.61</td>
<td>10.08 ± 0.55</td>
<td>10.11 ± 0.58</td>
<td>10.25 ± 0.55</td>
<td>10.36 ± 0.58</td>
</tr>
<tr>
<td>Blood pressure (mm Hg)</td>
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</tr>
<tr>
<td>Systolic</td>
<td>94.51 ± 9.18</td>
<td>106.88 ± 11.82</td>
<td>101.11 ± 10.25</td>
<td>109.36 ± 9.83</td>
<td>114.27* ± 11.03</td>
</tr>
<tr>
<td>4th phase diastolic</td>
<td>67.43 ± 8.07</td>
<td>76.03 ± 6.79</td>
<td>72.48 ± 11.32</td>
<td>78.77 ± 10.63</td>
<td>83.02 ± 9.96</td>
</tr>
<tr>
<td>5th phase diastolic</td>
<td>62.06 ± 9.49</td>
<td>68.36 ± 8.52</td>
<td>60.14 ± 8.57</td>
<td>60.32 ± 7.13</td>
<td>70.58 ± 8.07</td>
</tr>
<tr>
<td>Body size and indices of obesity</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>134.92 ± 5.14</td>
<td>149.87 ± 6.95</td>
<td>156.10 ± 13.43</td>
<td>171.89* ± 6.66</td>
<td>176.96* ± 4.06</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>28.92 ± 3.62</td>
<td>43.54 ± 10.50</td>
<td>44.66 ± 14.75</td>
<td>60.54 ± 13.49</td>
<td>74.43 ± 24.20</td>
</tr>
<tr>
<td>Quetelet index (kg × 10²/cm²)</td>
<td>15.99 ± 1.92</td>
<td>1.09 ± 0.36</td>
<td>1.79 ± 0.36</td>
<td>2.03 ± 0.35</td>
<td>2.37 ± 0.73</td>
</tr>
<tr>
<td>Rohrer index (kg × 10²/cm²)</td>
<td>1.18 ± 0.18</td>
<td>1.28 ± 0.22</td>
<td>1.15 ± 0.18</td>
<td>1.18 ± 0.18</td>
<td>1.34 ± 0.41</td>
</tr>
<tr>
<td>Surface area (m²)</td>
<td>1.06 ± 0.07</td>
<td>1.40 ± 0.27</td>
<td>1.71* ± 0.19</td>
<td>1.19 ± 0.08</td>
<td>1.89* ± 0.25</td>
</tr>
<tr>
<td>Relative weight (%)</td>
<td>98.09 ± 11.34</td>
<td>110.54 ± 19.78</td>
<td>97.10 ± 15.99</td>
<td>101.68 ± 16.38</td>
<td>113.85 ± 34.69</td>
</tr>
<tr>
<td>Subcutaneous fatness (mm)</td>
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</tr>
<tr>
<td>Triceps skinfold</td>
<td>8.79* ± 2.24</td>
<td>12.57 ± 9.07</td>
<td>10.11 ± 7.56</td>
<td>6.65* ± 1.39</td>
<td>11.97 ± 10.03</td>
</tr>
<tr>
<td>Subscapular skinfold</td>
<td>6.24* ± 1.65</td>
<td>10.16 ± 7.50</td>
<td>7.32 ± 4.49</td>
<td>7.61* ± 1.91</td>
<td>12.13 ± 9.11</td>
</tr>
<tr>
<td>Suprailiac skinfold</td>
<td>8.88* ± 4.07</td>
<td>10.95 ± 7.10</td>
<td>9.74 ± 7.42</td>
<td>11.29 ± 4.78</td>
<td>15.50 ± 9.10</td>
</tr>
<tr>
<td>Breadths (cm)</td>
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<td></td>
</tr>
<tr>
<td>Biacromial breadth</td>
<td>27.82 ± 2.84</td>
<td>32.13 ± 2.85</td>
<td>32.37 ± 3.01</td>
<td>36.61* ± 2.99</td>
<td>38.99* ± 2.10</td>
</tr>
<tr>
<td>Bicristal breadth</td>
<td>20.68 ± 2.52</td>
<td>22.23 ± 1.57</td>
<td>22.88 ± 2.95</td>
<td>26.47 ± 2.79</td>
<td>26.57 ± 1.58</td>
</tr>
<tr>
<td>Electrolytes and creatinine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium (mEq/24 hr)</td>
<td>104.29 ± 57.22</td>
<td>165.36* ± 71.22</td>
<td>165.77 ± 95.01</td>
<td>218.79* ± 118.94</td>
<td>198.83* ± 87.44</td>
</tr>
<tr>
<td>Potassium (mEq/24 hr)</td>
<td>36.06 ± 19.26</td>
<td>47.89 ± 16.19</td>
<td>59.37 ± 35.38</td>
<td>74.05* ± 28.33</td>
<td>70.58* ± 30.35</td>
</tr>
<tr>
<td>Sodium/potassium ratio</td>
<td>3.00 ± 0.95</td>
<td>3.51 ± 1.15</td>
<td>3.01 ± 0.84</td>
<td>2.99 ± 1.13</td>
<td>3.08 ± 1.14</td>
</tr>
<tr>
<td>Creatinine (g/24 hr)</td>
<td>0.43 ± 0.16</td>
<td>0.82* ± 0.32</td>
<td>0.67 ± 0.32</td>
<td>1.03* ± 0.37</td>
<td>1.46* ± 0.79</td>
</tr>
</tbody>
</table>

*Significant sex difference (p < 0.05).

by any equation using stature, weight, and triceps skinfold was very similar to that accounted for by the corresponding "best" equation. The implication is that, at least in this sample, anthropometry beyond the commonly measured stature, weight, and triceps skinfold thickness adds little in terms of explaining body size and fatness effects on BP.

Body Size and Electrolytes

Sex differences were observed in the correlations between age or the body size and fatness variables and electrolytes. Sodium and potassium excretion was more strongly related to age and body size and fatness in boys than in girls (table 5). Table 5 also presents the first-order partial correlations between electrolyte and body size variables with age removed. Age alone did not account for the significant relationships observed.

The relationship between sodium or potassium excretion and body size (weight or surface area, for example) is linear in boys and girls in the present study. There is no significant (p < 0.05) sex difference in the intercepts or slopes of the regression lines of sodium or potassium excretion on weight, for example; however, boys tend to have a steeper slope for both electrolytes.

Blood Pressure and Electrolytes

Table 6 shows that only in boys was there a significant positive correlation between BP and electrolyte excretion. Statistically significant positive cor-
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TABLE 2. Means and Standard Deviations of Variables for Girls in Each 2-Year Age Group Between 8 and 18 Years

<table>
<thead>
<tr>
<th>Age Group</th>
<th>8.0–9.9 yrs</th>
<th>10.0–11.9 yrs</th>
<th>12.0–13.9 yrs</th>
<th>14.0–15.9 yrs</th>
<th>16.0–17.9 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>sd</td>
<td>X</td>
<td>sd</td>
<td>X</td>
</tr>
<tr>
<td>Age</td>
<td>8.66</td>
<td>0.84</td>
<td>11.03</td>
<td>0.54</td>
<td>13.11</td>
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<tr>
<td>Blood pressure</td>
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<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>96.00</td>
<td>9.15</td>
<td>101.10</td>
<td>9.28</td>
<td>105.55</td>
</tr>
<tr>
<td>4th phase diastolic</td>
<td>66.49</td>
<td>11.25</td>
<td>71.37</td>
<td>6.87</td>
<td>75.75</td>
</tr>
<tr>
<td>5th phase diastolic</td>
<td>60.93</td>
<td>9.96</td>
<td>66.50</td>
<td>12.47</td>
<td>66.75</td>
</tr>
<tr>
<td>Body size and indices of obesity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stature</td>
<td>134.60</td>
<td>7.75</td>
<td>145.39</td>
<td>7.68</td>
<td>154.86</td>
</tr>
<tr>
<td>Weight</td>
<td>30.57</td>
<td>7.74</td>
<td>41.31</td>
<td>15.28</td>
<td>46.35</td>
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<tr>
<td>Quetelet index</td>
<td>1.09</td>
<td>0.34</td>
<td>1.92</td>
<td>0.56</td>
<td>1.93</td>
</tr>
<tr>
<td>Rohrer index</td>
<td>1.26</td>
<td>0.25</td>
<td>1.31</td>
<td>0.34</td>
<td>1.26</td>
</tr>
<tr>
<td>Surface area</td>
<td>1.07</td>
<td>0.14</td>
<td>1.28</td>
<td>0.23</td>
<td>1.41</td>
</tr>
<tr>
<td>Relative weight</td>
<td>105.71</td>
<td>22.12</td>
<td>111.02</td>
<td>29.75</td>
<td>104.82</td>
</tr>
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<td>Subcutaneous fatness</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Triceps skinfold</td>
<td>11.41*</td>
<td>3.58</td>
<td>14.71</td>
<td>7.74</td>
<td>12.60</td>
</tr>
<tr>
<td>Subscapular skinfold</td>
<td>8.35*</td>
<td>2.65</td>
<td>10.72</td>
<td>5.84</td>
<td>8.51</td>
</tr>
<tr>
<td>Suprailiac skinfold</td>
<td>11.90*</td>
<td>3.03</td>
<td>16.03</td>
<td>8.43</td>
<td>13.74</td>
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<tr>
<td>Breadths</td>
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<tr>
<td>Biacromial breadth</td>
<td>27.84</td>
<td>3.11</td>
<td>30.50</td>
<td>2.61</td>
<td>32.42</td>
</tr>
<tr>
<td>Bicristal breadth</td>
<td>20.16</td>
<td>1.42</td>
<td>22.58</td>
<td>2.19</td>
<td>24.52</td>
</tr>
<tr>
<td>Electrolytes and creatinine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>91.63</td>
<td>42.71</td>
<td>101.12*</td>
<td>57.19</td>
<td>123.25*</td>
</tr>
<tr>
<td>Potassium</td>
<td>32.98</td>
<td>16.66</td>
<td>40.89</td>
<td>26.09</td>
<td>48.31</td>
</tr>
<tr>
<td>Sodium/potassium ratio</td>
<td>2.88</td>
<td>1.16</td>
<td>2.86</td>
<td>1.20</td>
<td>3.07</td>
</tr>
<tr>
<td>Creatinine</td>
<td>0.31</td>
<td>0.17</td>
<td>0.56*</td>
<td>0.29</td>
<td>0.52</td>
</tr>
</tbody>
</table>

*Significant sex difference (p ≤ 0.05).
See table 1 for units of measurement.

relations from 0.24 to 0.59 were observed between every BP-electrolyte pair in boys; however, in girls no significant correlations were found.

Because electrolyte excretion is highly correlated with many measures of body size and because the same measures of body size are highly correlated with BP, perhaps it is not surprising to find that BP and electrolyte excretion are correlated. To determine if the BP and electrolyte association was simply a reflection of their individual relationships to body size, the effects of body size and fatness were statistically removed (using multiple linear regression) from BP and electrolyte variables. The relationships between the residual BP and residual electrolyte excretions are given as partial correlations in table 7. In girls there are no significant correlations; however, in boys, DBP, is positively and significantly correlated with sodium and potassium excretion. Significant correlations between BP and sodium/potassium ratio were not found in boys or girls.

**Discussion**

**Blood Pressure, Age, and Sex Trends**

The young relatives of hypertensive men in the present study do not have elevated BP compared to the general population. Unfortunately, the "norms," which are based on larger population surveys, are representative of more casual BP recordings than those assessed in the present study. The level of each BP phase across age in both boys and girls in the
### Table 3. Correlations (r) of Blood Pressure with Age and Measures of Body Size, Proportion, and Fatness in Boys and Girls Aged 8 to 18 Years and First Order Partial Correlations (r') with the Effects of Age Removed

<table>
<thead>
<tr>
<th>Measure</th>
<th>Boys Systolic (n = 70 to 79)</th>
<th>4th phase diastolic (n = 65 to 74)</th>
<th>5th phase diastolic (n = 70 to 79)</th>
<th>Girls Systolic (n = 70 to 75)</th>
<th>4th phase diastolic (n = 61 to 65)</th>
<th>5th phase diastolic (n = 70 to 75)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>r</td>
<td>r'</td>
<td>r'</td>
<td>r</td>
<td>r'</td>
<td>r'</td>
</tr>
<tr>
<td>Body size and indices of obesity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stature</td>
<td>0.64† 0.47† 0.54† 0.35† 0.38† 0.27*</td>
<td></td>
<td></td>
<td>0.33† 0.10 0.47† 0.24 0.28* 0.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>0.74† 0.62† 0.43† 0.16 0.41† 0.29*</td>
<td></td>
<td></td>
<td>0.60† 0.54† 0.53† 0.36† 0.45† 0.34†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quetelet index</td>
<td>0.68† 0.56† 0.29* 0.08 0.37† 0.26*</td>
<td></td>
<td></td>
<td>0.61† 0.55† 0.44† 0.29* 0.43† 0.35†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rohrer index</td>
<td>0.47† 0.47† 0.07 0.01 0.25* 0.22</td>
<td></td>
<td></td>
<td>0.52† 0.52† 0.27* 0.22 0.35† 0.33†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface area</td>
<td>0.74† 0.67† 0.50† 0.25* 0.42† 0.34†</td>
<td></td>
<td></td>
<td>0.53† 0.47† 0.54† 0.39† 0.41† 0.30*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative weight</td>
<td>0.53† 0.52† 0.15 0.08 0.30† 0.27*</td>
<td></td>
<td></td>
<td>0.48† 0.52† 0.24 0.27 0.31† 0.34†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subcutaneous fatness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triceps skinfold</td>
<td>0.28* 0.30* 0.06 0.05 0.16 0.16</td>
<td></td>
<td></td>
<td>0.42† 0.38† 0.25* 0.13 0.40† 0.36†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subscapular skinfold</td>
<td>0.35† 0.29* 0.13 0.04 0.23 0.18</td>
<td></td>
<td></td>
<td>0.35† 0.26* 0.33† 0.16 0.39† 0.31*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suprailiac skinfold</td>
<td>0.33† 0.22 0.20 0.09 0.06 0.03</td>
<td></td>
<td></td>
<td>0.23 0.16 0.29* 0.15 0.30* 0.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breadths</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicromial breadth</td>
<td>0.66† 0.47† 0.52† 0.30* 0.37† 0.22</td>
<td></td>
<td></td>
<td>0.31† 0.07 0.48† 0.25 0.23 – 0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicristal breadth</td>
<td>0.62† 0.44† 0.44† 0.20 0.35† 0.21</td>
<td></td>
<td></td>
<td>0.52† 0.43† 0.50† 0.30* 0.35† 0.18</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*0.01 < p ≤ 0.05.
†p ≤ 0.01.
See table 1 for units of measurement.

### Table 4. The Proportion of Variation (R²) in Blood Pressure Levels Accounted for by Various Combinations of Age, Body Size, and Fatness Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Boys SBP (R²)</th>
<th>Boys DBP₄ (R²)</th>
<th>Boys DBP₅ (R²)</th>
<th>Girls SBP (R²)</th>
<th>Girls DBP₄ (R²)</th>
<th>Girls DBP₅ (R²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All independent variables*</td>
<td>0.61</td>
<td>0.38</td>
<td>0.23</td>
<td>0.37</td>
<td>0.35</td>
<td>0.25</td>
</tr>
<tr>
<td>Stature, weight and triceps skinfold only</td>
<td>0.54</td>
<td>0.30</td>
<td>0.18</td>
<td>0.30</td>
<td>0.28</td>
<td>0.18</td>
</tr>
<tr>
<td>&quot;Best&quot; forward stepwise equation (variables entered)*</td>
<td>0.57</td>
<td>0.30</td>
<td>0.17</td>
<td>0.32</td>
<td>0.28</td>
<td>0.19</td>
</tr>
</tbody>
</table>

*Independent variables considered were: 1) age, 2) stature, 3) weight, 4) Quetelet index, 5) ponderal index, 6) surface area, 7) relative weight, 8) triceps skinfold, 9) subscapular skinfold, 10) suprailiac skinfold, 11) bicromial breadth, and 12) bicristal breadth.

SBP = systolic blood pressure; DBP₄ = diastolic blood pressure 4th phase; DBP₅ = diastolic blood pressure 5th phase.
present sample closely parallels normative data; however, the values for SBP are 8 to 10 mm Hg below the norms and those for DBP, are 5 to 6 mm Hg below the norms. There is a corresponding difference between the present means of SBP and DBP, as evidenced by slightly higher intra- and interobserver variability in the present study demonstrated that DBP4 could be measured satisfactorily if considerable attention were given to the training and retraining of observers. However, DBP4 was more difficult to measure reliably than SBP or DBP5, as evidenced by slightly higher intra- and in-
terobservervariabilityandincreaseddigitpreference
associated with DBP, measured with the standard
sphygmomanometer.

The absence of an order effect in the present series
of four measurements and the fact that the observed
BP in these children was substantially below published
norms suggest that the BP measured in these children
tended toward basal levels, as in the Bogalusa Study.9

**Blood Pressure and Body Size**

The positive association of body weight with hyper-
tension and general cardiovascular disease mortality is
well established in adults.9-43 Weight and stature have
been shown to be major BP determinants in chil-
dren.14-16 Almost 40% of the BP variability in children
aged 5 to 14 years from Bogalusa, Louisiana, can be
explained by factors such as stature, weight, triceps
skinfold thickness, and arm circumference.14 Voors
and his colleagues14 suggest that the effect of body size
on BP is sufficiently large that normative data should
include adjustments for these body dimensions. Data
from the present study are in complete agreement with
this notion; stature, weight, and triceps skinfold
thickness account for 20% to 30% of BP variation in
children aged 5 to 14 years. Age can account for
only a relatively small proportion of the BP variation
when compared to that which can be explained by
stature, weight, and triceps skinfold thickness.

Measures of body size such as weight and stature
are highly correlated with age in children; however, of
two children of similar age and weight, one may be
obese and the other thin because of differences in
stature. Numerous indices have been developed to
address the problem of "overweight" or "obesity"; those
examined in the current study include: Quetelet body
build index (W/S²), Rohrer body bulk index (W/S³),
and relative weight.24 These indices supply informa-
tion relevant to body size and whether mass is propor-
tional to size. In our current study, BP is correlated
with these indices, but somewhat higher with W/S²
than with W/S³. Voors and associates24 found that
log₁₀ W/S² was a major determinant of BP in children
aged 5 to 14 years.

Use of relative weight approaches the problem of
obesity from a slightly different perspective. Here,
each individual's weight is compared to the mean
weight of other individuals of approximately the same
stature who are in the same race, sex, and age group.
A systematic increment in BP with relative body
weight was found for adult males and females in the
Alameda study44 and for children in the Muscatine
study.45-48 Similarly, in the current study, relative
weight is positively correlated with BP, most strongly
with SBP. This indicates that increased weight (most
often fat) for a given stature, sex, and race is
associated with increased BP.

Thickness of the subcutaneous fat layer may be
used as another measure of obesity. Significant
differences between low BP and high BP groups in
their subscapular skinfold thickness and weight, but
not in stature were found by Tibblin and associates.47

Significant positive correlations between DBP and
skinfold thickness in children aged 8 to 12 years have
been reported also.14 In the current study, the cor-
relations between skinfold thickness and BP, while
significant, were considerably lower than those for the
obesity indices or other measures of size such as
stature, and the body breadths. However, sub-
cutaneous fat thickness did appear as a significant
variable in several regression equations of BP on body
size variables.

Excess weight and excess subcutaneous fat thick-
ness have been reported not to significantly increase
the risk of CHD in association with hypertension un-
less there is a high level of cholesterol, or gross
obesity.44 Because BP is correlated positively with
body weight, it is not surprising that essential
hypertension is correlated strongly with obesity, not
only in adults,60-63 but in children,40-44 The causa-
tive effect, if any, of overweight on BP in children
remains a matter of conjecture.

**Blood Pressure and Electrolytes**

Increased sodium intake is perhaps the most widely
discussed environmental variable relating to hyper-
tension. A good deal of evidence exists that increased salt
intake is etiologically involved in hypertension. In-
creased BP levels or increased prevalence of hyper-
tension has been noted in numerous populations with
high levels of salt in their drinking water.57, 66 Con-
versely, groups like the Yanomamo Indians, who do
not use salt in their diet, have low BP levels and show
little or no BP increase with age.64 An almost linear
relationship exists between average salt (NaCl) intake
and the prevalence of hypertension in several different
geographical and racial groups.18-21 In epidemi-
ological studies of the types cited, however, it is vir-
tually impossible to allow for all possible covariables
when making cross-cultural or cross-geographical
comparisons.

In many cases, salt restriction has proven effective
in preventing or treating essential hypertension.52-54 In
certain hypertension-prone strains of rats, the causal
effect of salt intake in producing hypertension is direct
and unequivocal.25, 60, 66

The role of electrolytes other than sodium in hyper-
tension has also been investigated. The prevalence of
hypertension is considered not only a direct function
of net sodium intake, but also, an inverse function of
calcium and potassium intake.57-70 The ratio of
sodium-to-potassium excretion has been reported to
show an association with BP57, 71 and to be involved in
the etiology of hypertension.72 No association between
BP and the sodium/potassium ratio exists in the pres-
cent study. While a positive correlation between age
and electrolyte excretion is observed, the age effect
alone does not account for the relationship between
electrolyte excretion and body size.

A genetic susceptibility to a BP increase with a high
sodium intake has been suggested to occur in some
"salt-sensitive" individuals.73 The recent study of
Pietinen and associates74 indicates that a relationship
between sodium excretion and BP occurs only in families with essential hypertension. A very definite, positive association of BP with electrolyte excretion, weight, and W/SS was observed in young adults with a family history of hypertension, but none in those without a family history of hypertension. This would be consistent with the concept of a genetically-based salt sensitivity of BP. However, there are many problems with this study that could decrease the possibility of finding a true relationship if one existed, and increase the chance of a spurious association. For example, in the study of Pietinen and coworkers, there was a relatively small sample size, mixed races, reported as opposed to measured family history of hypertension, differing methods of BP assessment during the study, use of an aneroid sphygmomanometer, and failure to adjust for size differences among subjects. In the present study, BP is positively associated with sodium or potassium in boys; however, when a correction is made for the relationship of BP and size, the BP relationship with the electrolytes is substantially decreased. Only for DBP, did the association remain significant.

Conclusions

This study of white children aged 8 to 18 years, who are members of four large kindreds each ascertained through one male with essential hypertension, has provided further evidence of a strong positive relationship between BP and measures of body size. The children with the higher relative weights or other indices of obesity tend to have higher BP. There is equivocal evidence of a relationship between BP and sodium or potassium excretion after adjusting for differences in body size. The relationship of body size and fatness to electrolyte excretion accounts for the observed relationships between BP and electrolytes except in boys for DBP. While the current study should not be interpreted as providing strong support for the notion of a BP-electrolyte relationship in families with positive history of hypertension, they are not inconsistent with that hypothesis.

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