Body Size, Composition, and Fitness in Adolescents with Elevated Blood Pressures

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SUMMARY Increased body size is often found in children with elevated blood pressures, but it is not clear whether this is a result of obesity or early maturity. Similarly, levels of activity and fitness have marked effects on blood pressure and body composition. To study these interrelated factors, we measured height, weight, and body composition (skinfold thickness and total body water) as well as heart rate, blood pressure, and oxygen consumption at rest and during exercise in 192 ninth grade boys and girls, 102 with persistently elevated blood pressures at or above the 95th percentile and 90 matched controls with blood pressures below the 50th percentile for the entire population of 10,641 Dallas County ninth graders tested. Differences in resting blood pressures also were present during maximal exercise and recovery periods. Boys with persistently elevated blood pressures were characterized by increased supine and recovery heart rates, normal fitness, excess size for age in the absence of obesity, and early maturation. Girls with persistently elevated blood pressures had increased heart rates, decreased fitness, and obesity. (Hypertension 7: 417–422, 1985)

KEY WORDS • adolescent hypertension • body composition • fitness

The interrelationships of body size, physical fitness, as measured by maximal oxygen consumption, and persistently elevated blood pressure in adolescents are of interest because (1) obesity is frequently associated with hypertension in this age group, (2) total body fat is inversely related to fitness, and (3) exercise training affects fatness, fitness, and blood pressure.1–11 Overweight, commonly defined as weight 10 to 30% above desired weight, may be due to excess musculature or bony structure rather than excess fat, while obesity is defined as excess body fatness estimated by methods such as densitometry, measurement of subcutaneous skinfolds, and soft-tissue x-ray films.1,2,6–15 A major problem with previous studies of the association of body size with hypertension has been the failure to differentiate between overweight and obesity.8 This study addresses this issue by examining body size and composition, physical fitness, and persistently elevated blood pressure in a large group of adolescents.

Materials and Methods

Subjects

Subjects were a group of 102 adolescents (34 girls; 68 boys) with persistently elevated blood pressure and a group of 90 control adolescents (34 girls; 56 boys). The mean age for both groups was 14 years. All were students attending ninth grade public school classes in Dallas County, Texas. Girls were postmenarcheal. All elevated blood pressure subjects were tested on three separate occasions and had persistently elevated blood pressures at or above the 95th percentile for this population of 10,641 students. Controls had blood pressures at or below the 50th percentile tested on three separate occasions over the same 1-year period. A random zero sphygmomanometer was used during all screening measurements. Of the students specifying race, 40.1% were white; 46.0% were black, and 13.9% were Mexican-American. As no differences in blood pressures were found between the ethnic groups, all were combined for analysis. Details have been published elsewhere.16,17

To reduce the influence of confounding variables, students were matched for age (within ± 1 year), race, sex, and ponderal index. Ponderal index has the capa-
The ability of separating body build types in a somatotypical sense, especially at the extreme low (endomorph) and high (ectomorph) end of the scale, but does not separate bigger individuals from those who are smaller but proportionally similar. Furthermore, the ponderal index is not a measure of adiposity. This matching resulted in a control group whose average heights and weights were larger than those of the total population of 10,641 students.

Definitions

Total body fatness was defined as the percent of body weight estimated to be fat or estimated kilograms of total body fat. Total body fat was determined by subtracting estimated lean body mass from weight. Lean body mass was estimated through multiple regression analysis of skinfolds and with deuterium oxide (D2O) measurements of total body water. Fitness was defined as maximal oxygen consumption expressed in milliliters per kilogram, either of total body weight or of estimated lean body mass.

Methods

Blood pressure readings were recorded by two examiners who participated in special training sessions. Subsequently, a test film was shown to determine interobserver and intraobserver variability as reported elsewhere. Diastolic pressures were recorded at the point of disappearance (K2) of the Korotkoff sounds because of smaller observer variability. Blood pressure readings at rest and during exercise were taken by auscultation with an appropriate size cuff. A random zero device was not used when the students performed exercise. Readings were made on each subject with an automated cuff system (Electro-Sphygmomanometer, Model PE-300, Narco Bio-Systems, Inc., Houston, TX) after 15 minutes of supine rest, after 10 minutes of zero device was not used when the students performed exercise. Readings were made on each subject with an automated cuff system (Electro-Sphygmomanometer, Model PE-300, Narco Bio-Systems, Inc., Houston, TX) after 15 minutes of supine rest, after 10 minutes of sitting on the bicycle, and after 3 minutes of exercise at each workload.

Oxygen consumption (Vo2) was measured with a Servomex O2 Analyzer, Type OA 250 (Servomex Control, Ltd., Sussex, England). Expired air was collected continuously from the subject by a large plastic bubble secured over the subject’s head and connected by tubing to a vacuum pump that drew the expired air across the Servomex Analyzer. A continuous tracing of Vo2 was provided by a pen recorder attached to the Servomex Analyzer. Values for Vo2 were expressed in liters per minute (STPD).

A modified Frank lead electrocardiogram (ECG) was displayed continuously on an oscilloscope and recorded on paper and magnetic tape for subsequent review. Postexercise blood pressures were obtained at 1, 3, and 5 minutes following cessation of the exercise test with the subject seated on the bicycle. The oxygen consumption monitoring system was removed three minutes after exercise and was not in place for the 5-minute postexercise blood pressure reading.

Height and weight were measured with a standard clinical vertical scale and beam balance. Height was measured with the subject standing barefooted and was recorded in centimeters to the nearest tenth. Weight was taken with the subject dressed in shorts and recorded in kilograms to the nearest tenth. Subcutaneous fat was measured using a Harpenden skinfold caliper, and the average of the three measurements at each site was recorded to the nearest 0.5 mm. Triceps skinfolds were taken on the dorsal aspect of the upper arm parallel to the mid-sagittal plane (MSP) at the midpoint of the humerus. Biceps skinfolds were taken on the ventral aspect of the upper arm at the same level as the triceps skinfold. All lateral measurements were made on the left side. Body composition was measured by the D2O dilution method of Schloerb et al. Subjects drank 1 gm of D2O per kilogram of body weight.

Experimental Protocol

The study was approved by the Institutional Review Board, and written informed consent was obtained from the subjects and parents for testing as follows: Blood pressures were measured following at least 5 minutes rest to verify that the subject was correctly classified as either persistently elevated or control. Five subjects who evidenced labile elevations were excluded from the study.

The first 47 consecutive subjects were administered D2O for determination of total body water and estimates of body composition. The cost of deuterium and laboratory analysis precluded further determinations in the entire study population.

The ECG leads were attached to the subject, who then rested in a supine position in a quiet, dimly lighted room for approximately 15 minutes. Supine blood pressures and heart rates were then measured. A general physical examination then was performed by a physician to determine the health status of the subject and to exclude any subjects with signs suggesting a secondary cause of elevated blood pressure. Two subjects were excluded from the study: one was pregnant and the other had a familial history of malignant hypertension.

In preparation for the exercise study, subjects were connected to the oxygen monitoring system and remained seated on the bicycle ergometer until stable rest measurements were obtained. Subjects exercised initially at 300 kpm for 3 minutes. The workload was then increased by either 150 or 300 kpm every 3 minutes until the subject reached maximal work capacity, defined as an extended plateau in the oxygen consumption curve. The criteria for cessation of the stress test included systolic blood pressure greater than 220 mm Hg, diastolic blood pressure greater than 120 mm Hg, or electrocardiographic evidence of ischemia. No tests were stopped due to these criteria. Blood pressure, heart rate, workload level, and duration were recorded for each step of exercise and the postexercise period as noted.

Data Analysis

The Statistical Package for the Social Sciences (SPSS 8.0), was used for all statistical tests performed except paired t tests. Interactive statistical pro-
grams were used for paired t tests. A random effects model was used in the analysis of variance after all distributions were determined to be normal. Factors were considered simultaneously for analysis of variance procedures. A P value of < 0.001 was considered to be highly significant; P < 0.01 was considered significant. The more conservative estimate of relevance was chosen because of the large number of statistical tests performed.

Results

Anthropometry

There were highly significant differences (P < 0.001) in height and weight among boys, but not among girls (Table 1). There were no significant differences between elevated pressure and control groups in triceps and biceps skinfolds for boys or girls.

Body Composition and Fitness

Differences in total body water and lean body mass were highly significant (P < 0.001) among boys, but not among girls (see Table 1). There were no differences among any of the groups with respect to lean body mass or total body fat.

Boys with elevated pressures had significantly higher resting oxygen consumption measured in absolute terms (P < 0.001), but these differences disappeared when adjusted for body weight (see Table 1). Differences in resting oxygen consumption, whether indexed or not, were not significant among girls.

Maximal oxygen consumption (Vo2 max) was significantly higher in boys compared with the girls (P < 0.001), but no significant differences were found between elevated blood pressure and control boys when indexed per kilogram of weight or per kilogram of lean body mass. Among girls, the elevated blood pressure group had a significantly lower Vo2 max than controls whether indexed by weight or lean body mass (P < 0.01).

Blood Pressure and Heart Rates

Systolic blood pressures (Figure 1) were significantly higher in the elevated groups for both boys and girls not only at rest but throughout exercise and recovery (P < 0.001). Among boys, diastolic blood pressures were significantly higher than controls at all levels except at maximal exercise and the 1-minute recovery level (P < 0.001). Among girls, diastolic blood pressures were significantly higher at all levels except at maximal exercise (P < 0.001). Boys with elevated pressures also had significantly higher rest and recovery heart rates (P < 0.001; Figure 2). Girls with elevated pressures had significantly higher heart rates at all levels except at the 1-minute recovery level (P < 0.001).

Comparative Growth Data

Table 2 gives mean heights and weights 1 year before and 1 year after the test year. Added to the study sample are data from elevated and normal pressure groups. Growth curves over this 3-year period are shown in Figure 3. Boys and girls with persistently elevated pressures were significantly taller and heavier than students with normal pressures (P < 0.001).

Table 1. Characteristics of Study Subjects Classified by Sex and Blood Pressure Groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Elevated pressure</th>
<th>Controls</th>
<th>Elevated pressure</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>(68) 172.7 ± 5.4</td>
<td>(56) 167.1 ± 6.4</td>
<td>(34) 162.2 ± 6.4</td>
<td>(34) 160.6 ± 5.6</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>(68) 78.9 ± 18.3</td>
<td>(36) 64.8 ± 12.8</td>
<td>(31) 25.8 ± 17.3</td>
<td>(29) 19.8 ± 7.2</td>
</tr>
<tr>
<td>Triceps skinfold (mm)</td>
<td>(57) 16.4 ± 11.1</td>
<td>(47) 13.7 ± 9.1</td>
<td>(31) 14.9 ± 9.8</td>
<td>(29) 12.5 ± 6.5</td>
</tr>
<tr>
<td>Biceps skinfold (mm)</td>
<td>(57) 10.7 ± 8.8</td>
<td>(47) 8.8 ± 7.3</td>
<td>(31) 14.4 ± 6.0</td>
<td>(29) 42.2 ± 5.3</td>
</tr>
<tr>
<td>Total body water (L)</td>
<td>(17) 44.1 ± 5.7</td>
<td>(14) 36.8 ± 4.8</td>
<td>(9) 36.0 ± 5.3</td>
<td>(7) 32.5 ± 3.6</td>
</tr>
<tr>
<td>Lean body mass (kg)</td>
<td>(57) 59.8 ± 10.7</td>
<td>(47) 50.5 ± 7.0</td>
<td>(31) 44.4 ± 6.0</td>
<td>(29) 42.2 ± 5.3</td>
</tr>
<tr>
<td>Total body water (% wt)</td>
<td>(57) 79.0 ± 14.8</td>
<td>(47) 80.2 ± 13.0</td>
<td>(31) 64.9 ± 8.9</td>
<td>(29) 66.7 ± 7.2</td>
</tr>
<tr>
<td>Total body fat (kg)</td>
<td>(57) 17.8 ± 14.7</td>
<td>(47) 14.2 ± 12.2</td>
<td>(31) 26.2 ± 13.0</td>
<td>(29) 22.1 ± 8.5</td>
</tr>
<tr>
<td>Total body fat (% wt)</td>
<td>(57) 21.0 ± 14.8</td>
<td>(47) 19.8 ± 13.0</td>
<td>(31) 35.1 ± 8.9</td>
<td>(29) 33.3 ± 7.2</td>
</tr>
<tr>
<td>Vo2 rest (L)</td>
<td>(56) 0.35 ± 0.13</td>
<td>(50) 0.28 ± 0.11</td>
<td>(29) 0.25 ± 0.14</td>
<td>(31) 0.25 ± 0.09</td>
</tr>
<tr>
<td>Vo2 rest/kg wt (ml)</td>
<td>(56) 4.69 ± 1.76</td>
<td>(50) 4.36 ± 1.77</td>
<td>(29) 3.16 ± 1.38</td>
<td>(31) 4.04 ± 1.62</td>
</tr>
<tr>
<td>Vo2 max (L)</td>
<td>(57) 2.72 ± 0.53</td>
<td>(53) 2.39 ± 0.52</td>
<td>(28) 1.65 ± 0.44</td>
<td>(31) 1.80 ± 0.34</td>
</tr>
<tr>
<td>Vo2 max/kg wt (ml)</td>
<td>(57) 36.2 ± 9.1</td>
<td>(53) 38.2 ± 9.2</td>
<td>(28) 22.7 ± 5.9</td>
<td>(31) 28.7 ± 5.4</td>
</tr>
</tbody>
</table>

Values are means ± SD.
Number of subjects in each group is in parentheses.

Vo2 = oxygen consumption per minute (STPD); Vo2 max = maximal oxygen consumption.

*p < 0.01; *p < 0.001, analysis of variance between groups.
FIGURE 1. Systolic and diastolic blood pressure (BP) during rest, exercise, and recovery in the four groups of subjects. Standard deviations, ranging from 7.5 to 19.0 for boys and 5.8 to 31.9 for girls, have been omitted.

Discussion

Blood Pressures

In assessing borderline values for resting blood pressure and early hypertension, it is often asked whether the pressure is elevated only at rest, or if blood pressure is also abnormal in response to physical work. If the blood pressure reaction is normal in connection with physical work, one ought to be able to dismiss the diagnosis of hypertension, at least temporarily, presumably because psychological stress factors are abolished during exercise. Exercise stress testing provided a means by which anxiety and other emotional or arousal related factors could be eliminated as potential causes of the differences in resting blood pressures found in the study subjects. Systolic and diastolic responses to exercise in this study are similar to the hypertensive pattern described by Astrand and Levy. The blood pressures of adolescents with persistently elevated pressures paralleled those of the controls during graded exercise, but at a higher level. Thus, these persistently elevated pressures are clearly not an artifactual response to the measurement situation.

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Height (cm)</td>
</tr>
<tr>
<td>Male EBP</td>
<td>75</td>
</tr>
<tr>
<td>Normal</td>
<td>315</td>
</tr>
<tr>
<td>Female EBP</td>
<td>52</td>
</tr>
<tr>
<td>Normal</td>
<td>249</td>
</tr>
</tbody>
</table>

Values are means ± SD.

EBP = elevated blood pressure.

*Values from approximately 500 students from the same population as the study subjects have been added for comparison.

†p < 0.001, paired t test between groups.
ELEVATED BLOOD PRESSURE IN ADOLESCENTS/Wilson et al.

FIGURE 3. Heights and weights in both elevated and normal blood pressure (BP) adolescents over a 3-year period compared with National Center for Health Statistics percentiles in children 10 to 18 years old. Values at age 14 are from the subgroup of children who underwent exercise testing in the present study.

Body Composition

Results of the present study indicate that increased body size and sex-specific body composition characteristics are associated with persistently elevated blood pressure among adolescents. Boys with elevated pressure were certainly bigger than controls, but were not significantly fatter. Although percentages of total body fat among the boys were slightly higher than reported elsewhere for similarly aged boys, neither group should be characterized as obese based on published criteria.

The larger size among elevated blood pressure boys is accounted for by an absolute excess of lean body mass. Larger size in the absence of obesity indicates advanced maturity among elevated blood pressure boys, as suggested by Katz et al. An examination of body size between elevated and normal pressure groups over a 3-year period found that boys with persistently elevated pressures were consistently out of phase with national norms (see Figure 3). Boys with elevated pressures demonstrated early maturity with growth patterns that did not show the sharp ascent characteristic of the adolescent growth spurt during these years. They also had less linear growth and less weight gain than normal boys. This finding suggests that they were earlier developers or had an earlier growth spurt that put them in higher percentiles for size at 14 years and hence higher percentiles of blood pressure at 14 years. This pattern is not so with girls because both groups had growth spurts before 14 years.

Regarding body composition among girls, the elevated pressure and control groups were not significantly different in body size or composition either absolutely or relatively. Both the elevated pressure and control groups, matched by ponderal index, should be characterized as obese based on percentages of total body fat in excess of 33%, although minimal triceps skinfold criteria were met only in the elevated pressure group. When compared with controls over a 3-year period, girls with persistently elevated pressures were consistently bigger than the total population. Data points used for Year 2 reflect the obese control group used for exercise testing only (see Figure 3).

It may be that persistent blood pressure elevation occurs in those obese girls who are genetically predisposed to hypertension. It is apparent that persistent blood pressure elevation does not accompany obesity in all adolescent girls, as shown by the data among obese adolescent girls who maintain normal blood pressures. If these data are indicative of the postpubertal female population in general, however, persistent blood pressure elevation would be uncommon in girls who are not obese. As all girls were postmenarcheal and growth slopes were approximately normal for height, it is unclear whether girls with persistently elevated blood pressure have advanced maturity with respect to controls.

Fitness

Greater absolute values for resting and VO₂max among boys with elevated pressures is due to their greater size; however, the functional capacity of the oxygen transport mechanism is most accurately reflected in maximal oxygen consumption per kilogram of weight or per kilogram of lean body mass. In this regard, elevated pressure and control boys were equally fit.

The analysis of cardiovascular fitness provided an unexpected result among girls. Girls with elevated pressures were significantly less fit than controls. The association between persistent blood pressure elevation and decreased oxygen consumption found among girls in this study has not been noted previously. The implications of finding decreased fitness associated with persistently elevated blood pressures are not clear. It is unlikely that these findings represent spurious correlations due to the similarities in body composition and size between elevated and normal groups. Naturally occurring differences in maximal oxygen uptake are often associated with differences in skeletal muscle fiber type composition. Whether training induced differences in fiber composition and skeletal muscle capillary density account for the lower pressures in the more fit normotensive girls is not known.

Normal levels of fitness and body size for age among boys with elevated pressures also correspond to observed differences in physical activities and cultural values between boys and girls in the population. In Dallas boys are more often involved in sports activities
than girls, which results in a higher level of activity and training among boys. In addition, bigger size is a selective advantage for boys playing the most popular high school sport in Dallas — football. The converse is true for girls, in that sports such as basketball, volleyball, and swimming use thinner, rather than overweight, individuals. It is possible that some boys involved in sports that require "bigness" as a prerequisite for participation have elevated blood pressures because of early maturity and growth of lean body mass.

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