Correlates of Adolescent Blood Pressure at Five-Year Follow-Up

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SUMMARY In 1973, standardized measurements of blood pressure (BP), height, and weight were obtained on all adolescents attending high school in a rural Kentucky county. In 1978, a 5-year follow-up BP study was undertaken of all adolescents who were 14–15 years old at the time of the initial survey (n = 310), and of selected 16–19 year olds who were in the high, intermediate, and low ranges of the initial sex-specific BP distributions (n = 198). Follow-up measurements included height, weight, and BP on all subjects and, in addition, overnight sodium (Na) excretion, serum cholesterol, glucose, triglyceride, and uric acid concentrations on the older group. Our findings indicate that BP in young adults is related to BP in adolescence, change in relative weight since adolescence, and current relative weight. Relative rank order of initial BP levels were maintained over the 5-year period in both the younger and older groups. Additional cardiovascular disease risk factors were found to cluster in young adults with high BP, and clustering of risk factors may, in part, be related to high relative weight. (Hypertension 2 (suppl 1): I-124-I-129, 1980)

KEY WORDS • blood pressure • cardiovascular disease risk factors • weight • adolescence

COMPARED to other states, Kentucky has a relatively high cardiovascular disease mortality rate. To determine if risk factors for cardiovascular diseases could be identified at a young age, in 1973 we surveyed the blood pressure (BP) in all high school seniors in Bourbon County, Kentucky, a rural community. In these adolescents, aged 14–19 years, we found that BP was higher in males than females and that in both sexes BP was related to body size. We had previously observed that the BP of black adolescents in Washington, D.C., was higher than in whites. In this rural Kentucky county we found no racial BP difference, however, but did find that BP was higher in both white and black Bourbon County adolescents than in black adolescents residing in Washington, D.C.

Several longitudinal studies of children and young adults suggest that an individual tends to maintain BP in the same relative rank order within the peer group and that BP at one age may be predictive of BP at a later age. Two conflicting studies report impressive variability rather than stability of BP measurements over time, however. If the probability of developing cardiovascular disease is affected by only small differences of BP, and if BP “tracking” begins at a young age, it is important to identify factors associated with BP in young people.

In 1978, we undertook a 5-year follow-up study of the original Bourbon County population to identify BP changes in young people over time. One purpose was to determine whether correlates of subsequent BP are the same among young, more immature adolescents as among older, more fully grown individuals. For this reason, at the time of follow-up, the original population was divided into an older and younger age group. In addition, serum lipids, uric acid, and glucose were measured to determine if these risk factors for cardiovascular disease are associated with BP.

Methods

One follow-up group consists of individuals who were 14–15 years old at the time of the initial survey (n = 310). The relative immaturity of the males in this group is suggested by their light body weight, short stature, and low BP compared with older males. Differences between younger and older females were not striking. Of these previously 14–15 year old adolescents, 95% have been seen at home for standardized measurements of height, weight and BP.

In older adolescents, 16–19 years, we have been concerned with correlates associated with relatively high BP compared with intermediate and low BP dur-
ing adolescence. In this older age group, based on the original BP distribution, we selected all persons with the highest and lowest systolic blood pressure (SBP), namely, those in the 95th and 5th percentiles for whites and 90th and 10th percentiles for blacks, and also studied a random sample of persons in the middle BP ranges (85 of 709). Follow-up studies among this group have consisted of home measurements of height, weight, and BP, and a clinic visit for additional laboratory studies. Of the 198 young adults selected for follow-up from this population, 94% were seen at home and 125 (63%) were also seen in clinic.

All measurements of height, weight, and BP during both the original and follow-up surveys were obtained by the same two observers under the same standardized conditions. After the subject had been sitting quietly for at least 5 minutes, BP was measured with a mercury manometer and a standard-sized metal lock cuff. Consecutive BP measurements were obtained until SBP could be reproduced within 2 mm Hg. Weights and heights were measured while subjects were clothed but without shoes. Body mass was computed for each subject using Quetelet's index $^{18}$ (wt/ht$^4 \times 100$). A relatively small proportion (15%) of the original population was black. Because no racial BP differences had been analyzed separately.

For follow-up study of the older adolescent group, blood was drawn from nonfasting subjects originally identified in the “high,” “intermediate,” and “low” BP groups for measurement of serum cholesterol, triglyceride, glucose, uric acid, and creatinine concentrations. Time since the last food consumption among these three groups of subjects did not differ. A timed overnight urine collection was also obtained for measurement of sodium (Na), potassium (K), and creatinine (Cr) excretion. All serum and urine chemistries were determined with an autoanalyzer.

Statistical methods include the determination of simple statistics, analysis of variance, multiple regression analyses, computation of simple (Pearson product-moment) correlation coefficients, the paired $t$ test, and chi-square contingency analyses.

Because individuals with the highest and lowest SBP in the original 16–19 year-old population were deliberately oversampled, the appropriateness of using parametric statistical methods that assume normal distributions was evaluated. Among both males and females selected for follow-up study, the SBP, relative weight, serum glucose, uric acid, cholesterol, and triglycerides were tested for normality. With the exception of triglyceride measurements, these overall distributions did not deviate significantly from normal. Analysis of serum triglyceride measurements indicated that for females ($p < 0.05$) and males ($p < 0.01$), the distributions tended to be positively skewed compared to a strictly normal frequency distribution. Nevertheless, there is the potential for correlation and regression coefficients to be distorted in this select population.

### Results

**Five-year Follow-Up of 14-15 Year-Old Adolescents**

Over the 5-year period, height and weight increased significantly ($p < 0.009$) in males and females (table 1), and these increases were greater in males ($p < 0.0001$). Height increased by 7.6 ± 0.7 cm in males and by only 2.4 ± 1.8 cm in females, suggesting that females had passed their adolescent growth spurt whereas males had not. In both males and females, the increase in body weight was relatively greater over time than was the increase in height, so that Quetelet’s index of relative weight increased.

Among males, mean SBP increased significantly ($p < 0.0001$), from 118.1 ± 1.1 mm Hg at the initial survey to 123.2 ± 0.9 mm Hg at the time of follow-up; among females SBP did not change significantly ($p > 0.1$). The mean DBP of both males and females increased ($p < 0.0001$), and the increase was greater in males than females ($p < 0.0001$). Among females, initial SBP was inversely related to age of menarche ($r = -0.23, p < 0.005$), although age of menarche did not correlate with SBP at the time of follow-up. Follow-up SBP was also highly correlated with SBP at the time of the initial survey in both males ($r = 0.48, p < 0.0001$) and females ($r = 0.29, p < 0.0004$). Correlations between follow-up and initial diastolic blood pressures, though smaller, were also significant in both males ($r = 0.30, p < 0.0002$) and females ($r = 0.17, p < 0.05$).

### Table 1. Mean ($\pm$SE) Systolic and Diastolic Blood Pressures and Relative Weight at the Initial Survey of 14-15 Year-Old Adolescents and at 5-Year Follow-up

<table>
<thead>
<tr>
<th>Factor</th>
<th>Males (n = 144)</th>
<th>Females (n = 142)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>169.2 ± 0.7SE</td>
<td>176.8 ± 0.7</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>61.6 ± 1.1</td>
<td>75.4 ± 1.2</td>
</tr>
<tr>
<td>Quetelet's index of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>relative weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(wt/ht$^4 \times 100$)</td>
<td>0.21 ± 0.003</td>
<td>0.24 ± 0.003</td>
</tr>
<tr>
<td>SBP (mm Hg)</td>
<td>118.1 ± 1.1</td>
<td>123.2 ± 0.9</td>
</tr>
<tr>
<td>DBP (mm Hg)</td>
<td>57.0 ± 1.2</td>
<td>74.7 ± 0.8</td>
</tr>
</tbody>
</table>
To determine whether individuals maintain their relative BP rank over time within the population, individuals were assigned to three ranked groups based on their initial SBP (fig. 1). Those in the upper quartile for initial SBP make up the initial "high" category. The "low" category consists of those individuals who fell within the lower quartile for SBP. All other individuals in the mid-range for SBP are included in the intermediate category. Approximately 50% of individuals who previously fell within the upper quartile range maintained SBP within the upper quartile range at follow-up. Relatively few subjects in the previously high range had made the transition to the low SBP range at the time of follow-up. Approximately 60% of the subjects who were originally categorized in the low range maintained their relatively low SBP status over time, and relatively few were ranked high at the time of follow-up. Overall, there was a significant association ($x^2 = 54.1, p < 0.0001$) between initial and follow-up rank for SBP.

Over the 5-year period, change in SBP was significantly correlated with change in relative weight for both males ($r = 0.25, p < 0.002$) and females ($r = 0.33, p < 0.0001$). Correlation between change in DBP and change in Quetelet's index of relative weight was not significant in either males or females ($p < 0.2$).

A multiple regression analysis was used to identify major predictors of follow-up SBP among these adolescents. The following independent variables were introduced into the model: current relative weight, previous relative weight, change in relative weight, and previous SBP. Among males, previous SBP accounted for 23% of the variability of current SBP, and previous SBP and current relative weight combined accounted for 27% of the SBP variability. Among females, differences in current relative weight accounted for 29% of the SBP variability, and current relative weight plus previous SBP explained 31% of the SBP variation.

Five-year Follow-up of Selected Groups of 16–19 Year-Old Adolescents

Over the follow-up period, males had a small but significant increment in height (2.1 cm ± 0.4 se, $p < 0.0001$), and height did not change in females ($p < 0.2$), indicating that these people had reached their mature height at the time of the initial survey. Weight increased significantly among males (8.1 ± 1.1 kg, $p < 0.0001$), but not females ($p < 0.2$). At the time of follow-up, Quetelet's index of relative weight differed significantly ($p < 0.0001$) among the three groups identified on the basis of their original BP (table 2). The BP differences among the three groups were also maintained. Multiple regression analysis was used to adjust for differences due to sex, and least squares means procedures to test for intergroup BP differences. The groups initially selected for high SBP had high mean SBP compared to the intermediate and low BP groups ($p < 0.001$). The intermediate group consisting of individuals selected at random from the middle range of SBP continued to have BP intermediate between the other two groups ($p < 0.0001$). Similar group differences were also observed for DBP ($p < 0.007$). Similar to the results in the younger population, rank order for follow-up SBP was associated with initial SBP rank ($x^2 = 77.4, p < 0.0001$). For both males and females, there was a significant correlation between BP and relative weight ($p < 0.0001$). There was a significant correlation between change in relative weight and change in SBP among males ($r = 0.26, p < 0.009$) and females ($r = 0.44, p < 0.0001$). Change in DBP was also related to change in relative weight ($p < 0.003$).

To determine if higher BP is associated with other cardiovascular disease risk factors, plasma concentrations of cholesterol, triglycerides, uric acid, and glucose were measured in these subjects. After multiple regression techniques were used to adjust for differences due to sex, least squares means procedures were used to compare intergroup values. The group originally selected in the upper percentiles of the BP distribution had higher values for serum cholesterol ($p < 0.01$), glucose ($p < 0.003$), triglyceride ($p < 0.002$), and uric acid ($p < 0.002$) than the low BP group. Mean values of the intermediate BP group were intermediate between the values of the other two groups. However, only two significant intergroup differences were observed between the intermediate group and the others. Mean serum triglyceride level was significantly higher in the intermediate BP group than in the low group ($p < 0.05$), and mean serum glucose was significantly lower than the mean value for the high BP group ($p < 0.03$).

After adjusting for sex differences, SBP was significantly correlated with serum triglyceride ($p < 0.0001$), cholesterol ($p < 0.03$), uric acid ($p < 0.04$), and glucose ($p < 0.02$). These variables were also correlated with relative weight (table 3); after adjusting for relative weight, however, only the correlation between SBP and serum triglyceride concentrations remained significant ($p < 0.009$). This
suggests that several cardiovascular risk factors are related to body size.

To further evaluate clustering of cardiovascular disease risk factors, the 90th percentile level by sex for SBP, serum glucose, cholesterol, triglycerides, and uric acid concentrations were identified. An individual was arbitrarily determined to have a cardiovascular disease risk factor present if his or her value fell within the upper decile for that factor. An individual was arbitrarily determined to be free of the cardiovascular disease risk factor if the value fell below the 90th percentile level. We tabulated the number of persons having zero, one, two, three, or more factors present and compared them to the number expected on the basis of expected probabilities of occurrence if, in fact, these risk factors occur randomly and independently of one another (table 4). We found that the greater number of individuals than expected had either no risk factors or three or more risk factors present. Six times as many individuals as expected had three or more risk factors. However, fewer individuals than expected had one or two cardiovascular disease risk factors. These data indicate that individuals tend to have either no risk factor present or multiple risk factors. The chi square value is highly significant ($p < 0.0002$), indicating that risk factors are not independent of one another.

To determine whether additional cardiovascular disease risk factors cluster in individuals with high SBP, we compared individuals whose SBP fell within the highest decile to the remainder of the study group. For this analysis, we defined the presence of a risk factor as a serum glucose, cholesterol, triglyceride, or uric acid concentration within the highest decile for each sex separately. As indicated in figure 2, more individuals in the lower BP range were free of these selected risk factors, compared with individuals in the high range, while more individuals with high BP had either one or two of these selected risk factors present. Chi square analysis indicated that these risk factors were not independently distributed between the two groups ($x^2 = 7.59$, $p < 0.03$), suggesting that other risk factors for cardiovascular disease cluster in young adults with high BP.

A timed overnight urine collection was obtained for measurement of Na, K, and Cr concentrations. Sodium excretion did not differ among BP groups and, overall, BP was not related to Na excretion, urine Na/K ratio, or urine Na/Cr ratio. Creatinine clearance did not differ among the various BP groups.
Our results demonstrate that the BP of young adults is related to previous BP levels measured during adolescence. Several long-term population-based studies indicate that hypertension in adulthood is related to preceding BP levels during adolescence. Furthermore, although clinical criteria for the designation of hypertension in young people have not been established, the association of even modest BP elevations with cardiovascular disease is becoming increasingly apparent. Several population-based studies clearly demonstrate a direct association between BP and the risk of cardiovascular disease. Paffenbarger and Williams have shown that a difference of a few millimeters of mercury in BP among college students was associated with significant increases in later mortality from both stroke and coronary heart disease. In a cohort of 3983 young men observed over 26 years, the SBP change over time was more strongly associated with ischemic heart disease than the entry BP. These observations provide a rationale for the long-term surveillance of young individuals with relatively high BP.

In adults, clustering of multiple cardiovascular risk factors has been observed in individuals with a family history of coronary artery disease. Stamler et al. recently reported that postprandial serum glucose, serum uric acid, and, in white males, serum cholesterol are independently related to BP, although it is unclear whether glucose and uric acid contribute independently to cardiovascular disease risk when other variables such as age, body size, BP, serum cholesterol, and smoking status are taken into account. In this population of young adults we also found that risk factors for cardiovascular disease tended to cluster. Furthermore, serum cholesterol, triglyceride, uric acid, and glucose concentrations were related to body weight as well as to BP, raising the possibility that a reduction of body weight might also be associated with a reduction of other risk factors in addition to BP.

Summary

Our 5-year follow-up studies of previous 14-19 year-old adolescents indicate that adolescents tend to maintain their rank order within a BP distribution. We found that BP at the time of follow-up was related to BP during adolescence, changes in relative weight since adolescence, and current relative weight. Our findings also suggest that other cardiovascular disease risk factors tend to cluster in young adults with high BP and that the clustering of risk factors may, in part, be related to high relative weight.

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CORRELATES OF ADOLESCENT BLOOD PRESSURE/Kotchen et al.

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