Blood Pressure Trends With Aging

J. Morley Kotchen, M.D., M.P.H., Harley E. McKeain, Ph.D., and Theodore A. Kotchen, M.D.

SUMMARY In industrialized societies, blood pressure increases with age, and blood pressure at one age is related to blood pressure at an earlier age. Blood pressure is also related to weight, weight change, and maturation. This paper reviews the association of growth and maturation with blood pressure and the evidence for blood pressure “tracking” with age. Additional longitudinal studies are required to determine if blood pressures before puberty are related to blood pressures of sexually mature young adults. Adolescents with “gestational” hypertension also have relatively high blood pressures at long-term follow-up. Thus, it may be possible to identify young individuals who are at increased risk for cardiovascular disease. (Hypertension 4 (supp III): III-128—III-134, 1982)

KEY WORDS • blood pressure • gestational hypertension • hypertension • tracking

Both cross-sectional and longitudinal population-based studies describing the association between blood pressure and age provide information about the natural history of hypertension. Most studies suggest that blood pressure increases with age and that blood pressure at one age is related to blood pressure at an earlier age. This raises the possibility that “prehypertensive” individuals can be identified at young ages. For clinical purposes, a designation of hypertension is generally based on an arbitrary blood pressure level; however, relatively little information is available to define the risks of different blood pressure levels at different ages. The purpose of this presentation is to briefly review the associations between age and blood pressure and the evidence for blood pressure “tracking” with age.

Effect of Age on Blood Pressure

In industrialized societies, based on the results of cross-sectional studies, blood pressure increases with age. We observed this phenomenon in a survey of an entire rural Kentucky community (fig. 1). Both systolic and diastolic blood pressure tended to increase with age, and in addition we also observed a sex effect on blood pressure. Between ages 16 and 40 years, systolic blood pressure of males was higher than that of females, whereas above age 60, females had higher systolic blood pressures. Similar age-sex differences have been observed in other populations. One hypothesis to explain the sex difference in the older age group is that the males with higher blood pressures had died, and consequently the survivors have lower blood pressures. At the other age extreme, the age effect on blood pressure also extends to infancy. Between the ages of 2 days and 6 weeks, blood pressure rises sharply and then remains relatively constant until 4 years of age. Subsequently, a further rise begins and extends into adult life. Most studies do not demonstrate a sex blood pressure difference in prepubertal children.

The effect of age on blood pressure should be considered in a definition of hypertension, particularly in children. Indeed, one approach to defining hypertension in children is to relate blood pressure to age, as recently suggested by the National Heart, Lung and Blood Institute (NHLBI) Task Force on Blood Pressure Control in Children. Similar to plotting an individual’s height and weight in percentiles over time, charts may be constructed to follow blood pressure longitudinally (fig. 2). This approach depends on the availability of blood pressure norms by age and sex.
Blood Pressure Tracking

Several studies of children and adults demonstrate that blood pressure of an individual tends to maintain the same relative rank order over time within a population and that blood pressure at one age is predictive of blood pressure at a later age.\textsuperscript{6-20} This tracking phenomenon was clearly observed in the Framingham study in 30- to 59-year-old men, over seven examinations.\textsuperscript{21} Between examinations 1 and 2, blood pressure in the higher group decreased and those of the lower groups tended to increase, a well-recognized phenomenon of regression toward the mean (fig. 3). However, between examinations 2 and 7, the tracks were essentially parallel. Recent evidence from the Framingham study suggests that the rate of rise of blood pressure with age is accelerated in younger people with relatively higher blood pressures.\textsuperscript{22} Similarly, in 50-year-old Swedish males, Svardsudd et al. reported that the systolic blood pressure change during a 10-year follow-up was positively correlated with the blood pressure level at the start of the study.\textsuperscript{23}

To evaluate the tracking phenomenon at younger ages, we are obtaining longitudinal blood pressure information in young adults residing in Bourbon County, Kentucky, a rural, predominantly white county with a high prevalence of hypertension. In 1972, we obtained standardized measurements of blood pressure, height, and weight for all high school students in the County. We arbitrarily divided these students into 14- to 15-year-old and 16- to 19-year-old groups, because the

Figure 1. Mean systolic and diastolic blood pressures by age and sex in a rural population (n = 1029).

Figure 2. Percentiles of blood pressure measurement (right arm, seated), from NHLBI Task Force on Blood Pressure Control in Children (see ref. 1).
younger group was physically less mature and still growing. We are obtaining follow-up measurements in the entire original 14- to 15-year-old population and in selected subgroups of the 16- to 19-year-old population. Follow-up measurements were obtained at 5 years, and to date we have completed 8-year follow-up measurements in approximately 50% of the subjects in these populations.

Of the original 14- to 15-year-old group, among males, systolic and diastolic blood pressures increased significantly \( (p < 0.0006) \) between the initial and 5-year follow-up surveys, with no additional increase between the 5-year and 8-year surveys (table 1). In contrast, systolic blood pressure of females did not change between the initial and 5-year follow-up surveys, but increased \( (p < 0.004) \) between the 5-year and 8-year follow-up surveys; diastolic blood pressure increased between each of the surveys \( (p < 0.05) \). Between the original and 5-year follow-up surveys, height and weight increased significantly \( (p < 0.009) \) in males and females, and these increases were greater in males. Between the 5-year and 8-year follow-up, there was no additional increment of height, although weight increased \( (p < 0.01) \) in both males and females. There were highly significant correlations between repeated measurements of both systolic and diastolic blood pressure (table 2). Change in systolic blood pressure over time was positively correlated with change in relative weight, using \( \text{wt/ht}^2 \) as an index of relative weight.

Of the original 16- to 19-year-old population, follow-up measurements were obtained in individuals who, at the original survey, had systolic blood pressures \( \geq 95 \text{th percentile by sex (high),} \leq 5 \text{th percentile (low), and an intermediate group randomly selected from the remainder of the population. Among both males and females, between the initial and 5-year follow-up surveys, mean systolic blood pressure decreased in subjects selected as having "high" systolic blood pressure and increased in subjects selected as having "low" blood pressure (table 3). These changes are attributed to the phenomenon of regression toward

**TABLE 1. Original 14- to 15-Year-Old Bourbon County Population: Initial and Follow-up (FU) Measurements of Blood Pressure, Height, and Weight**

<table>
<thead>
<tr>
<th></th>
<th>Initial</th>
<th>5-year FU</th>
<th>8-year FU</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Males</strong></td>
<td>SBP (mm Hg)</td>
<td>118 ± 1 (n = 145)</td>
<td>123 ± 1 (n = 145)</td>
</tr>
<tr>
<td></td>
<td>DBP (mm Hg)</td>
<td>57 ± 1</td>
<td>75 ± 1</td>
</tr>
<tr>
<td></td>
<td>Ht (cm)</td>
<td>170.6 ± 1.6</td>
<td>176.4 ± 0.9</td>
</tr>
<tr>
<td></td>
<td>Wt (kg)</td>
<td>61.5 ± 1.1</td>
<td>75.3 ± 0.7</td>
</tr>
<tr>
<td></td>
<td>Wt/ht² (kg/m²)</td>
<td>21.2 ± 0.3</td>
<td>24.5 ± 0.7</td>
</tr>
<tr>
<td><strong>Females</strong></td>
<td>SBP (mm Hg)</td>
<td>111 ± 1 (n = 142)</td>
<td>110 ± 1</td>
</tr>
<tr>
<td></td>
<td>DBP (mm Hg)</td>
<td>63 ± 1</td>
<td>68 ± 1</td>
</tr>
<tr>
<td></td>
<td>Ht (cm)</td>
<td>161.8 ± 0.5</td>
<td>163.4 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>Wt (kg)</td>
<td>56.0 ± 1.0</td>
<td>61.9 ± 1.2</td>
</tr>
<tr>
<td></td>
<td>Wt/ht² (kg/m²)</td>
<td>21.3 ± 0.3</td>
<td>23.1 ± 0.4</td>
</tr>
</tbody>
</table>

**TABLE 2. Original 14- to 15-Year-Old Bourbon County Population: Correlations Between Initial and Follow-up (FU) Blood Pressures and Between Change in Relative Weight and Change in Blood Pressure Over Time (Males and Females Combined)**

<table>
<thead>
<tr>
<th></th>
<th>( r )</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic blood pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial vs 5-yr FU</td>
<td>0.47</td>
<td>0.0001</td>
</tr>
<tr>
<td>Initial vs 8-yr FU</td>
<td>0.45</td>
<td>0.0001</td>
</tr>
<tr>
<td>5-yr vs 8-yr FU</td>
<td>0.70</td>
<td>0.0001</td>
</tr>
<tr>
<td>Diastolic blood pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial vs 5-yr FU</td>
<td>0.16</td>
<td>0.0007</td>
</tr>
<tr>
<td>Initial vs 8-yr FU</td>
<td>0.21</td>
<td>0.01</td>
</tr>
<tr>
<td>5-yr vs 8-yr FU</td>
<td>0.34</td>
<td>0.0001</td>
</tr>
<tr>
<td>Change in relative weight vs change in systolic BP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between initial and 5-yr FU</td>
<td>0.19</td>
<td>0.0012</td>
</tr>
<tr>
<td>Between initial and 8-yr FU</td>
<td>0.39</td>
<td>0.0001</td>
</tr>
<tr>
<td>Between 5-yr and 8-yr FU</td>
<td>0.21</td>
<td>0.01</td>
</tr>
<tr>
<td>Change in relative weight vs change in diastolic BP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between initial and 5-yr FU</td>
<td>0.05</td>
<td>NS</td>
</tr>
<tr>
<td>Between initial and 8-yr FU</td>
<td>0.30</td>
<td>0.0003</td>
</tr>
<tr>
<td>Between 5-yr and 8-yr FU</td>
<td>0.13</td>
<td>NS</td>
</tr>
</tbody>
</table>
TABLE 3. Initial and follow-up (FU) Measurements of Blood Pressure, Height, and Weight in High, Intermediate, and Low Blood Pressure Groups of Original 16- to 19-Year Old Bourbon County Population

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Intermediate</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial (n = 32)</td>
<td>5-yr FU (n = 32)</td>
<td>8-yr FU (n = 16)</td>
</tr>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBP (mm Hg)</td>
<td>159 ± 2 SE</td>
<td>146 ± 3</td>
<td>144 ± 3</td>
</tr>
<tr>
<td>DBP (mm Hg)</td>
<td>73 ± 3</td>
<td>85 ± 3</td>
<td>84 ± 4</td>
</tr>
<tr>
<td>Ht (cm)</td>
<td>178.5 ± 1.1</td>
<td>179.1 ± 1.1</td>
<td>177.6 ± 1.7</td>
</tr>
<tr>
<td>Wt (kg)</td>
<td>90.4 ± 4.1</td>
<td>95.2 ± 3.9</td>
<td>94.7 ± 4.5</td>
</tr>
<tr>
<td>Wt/ht² (kg/m²)</td>
<td>28.3 ± 1.3</td>
<td>29.6 ± 1.2</td>
<td>30.0 ± 1.4</td>
</tr>
<tr>
<td>Females</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBP (mm Hg)</td>
<td>141 ± 2</td>
<td>131 ± 2</td>
<td>130 ± 5</td>
</tr>
<tr>
<td>DBP (mm Hg)</td>
<td>77 ± 3</td>
<td>76 ± 3</td>
<td>80 ± 4</td>
</tr>
<tr>
<td>Ht (cm)</td>
<td>164.6 ± 1.2</td>
<td>164.6 ± 1.2</td>
<td>164.0 ± 1.5</td>
</tr>
<tr>
<td>Wt (kg)</td>
<td>73.0 ± 4.2</td>
<td>74.2 ± 4.1</td>
<td>83.4 ± 7.3</td>
</tr>
<tr>
<td>Wt/ht² (kg/m²)</td>
<td>26.9 ± 1.5</td>
<td>27.3 ± 1.5</td>
<td>30.9 ± 2.6</td>
</tr>
</tbody>
</table>

the mean. At each of the two follow-up surveys, systolic blood pressure differences, by sex (p < 0.0001), were maintained among groups defined as having relatively "high," "intermediate," or "low" systolic pressure on the basis of the original blood pressure distribution. Group differences of diastolic blood pressure were also maintained over time. Weight, but not height, increased in all groups over the 8-year period. Relative weight was highly correlated with blood pressure at all three surveys (p < 0.0001), and groups defined on the basis of blood pressure also differed in relative weight (p < 0.0001). Correlation coefficients between initial and follow-up blood pressure measurements were highly significant (table 4). Additionally, there were highly significant correlations between change in relative weight and change in blood pressure over time. Comparable correlation coefficients were noted for both males and females.

Similar to these results, in a 17-year follow-up study of high school students, Kuller et al. also observed a significant correlation between repeated blood pressure measurements over time and a relationship between increase in blood pressure and weight gain. Other investigators have described weak but significant correlations between repeated blood pressure measurements obtained during infancy. 4, 12, 13

Effect of Growth and Maturation in Blood Pressure

At all ages, blood pressure is related to body size. In children and adolescents, blood pressure is also highly correlated with various indices of growth and maturaiton, including height, Tanner's staging of sexual maturity, and radiographic determination of bone age. 26, 25

Indeed, to define normal or elevated blood pressure in children, it has been suggested that blood pressures be

TABLE 4. High, Intermediate, and Low Blood Pressure Groups in Original 16- to 19-Year-Old Bourbon County Population: Correlations Between Initial and Follow-up (FU) Blood Pressures and Between Change in Relative Weight and Change in Blood Pressure Over Time (Males and Females Combined)

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Systolic</td>
<td>Diastolic</td>
</tr>
<tr>
<td></td>
<td>blood pressure</td>
<td>blood pressure</td>
</tr>
<tr>
<td>Initial vs 5-yr FU</td>
<td>0.67</td>
<td>0.32</td>
</tr>
<tr>
<td>Initial vs 8-yr FU</td>
<td>0.70</td>
<td>0.48</td>
</tr>
<tr>
<td>5-yr vs 8-yr FU</td>
<td>0.78</td>
<td>0.60</td>
</tr>
<tr>
<td>Change in relative weight vs change in systolic BP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between initial and 5-yr FU</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Between initial and 8-yr FU</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Between 5-yr and 8-yr FU</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Change in relative weight vs change in diastolic BP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between initial and 5-yr FU</td>
<td>0.39</td>
<td>0.39</td>
</tr>
<tr>
<td>Between initial and 8-yr FU</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>Between 5-yr and 8-yr FU</td>
<td>0.13</td>
<td>NS</td>
</tr>
</tbody>
</table>
related to height or weight rather than to chronologic age.26-28 Although most studies have found significant correlations between repeated blood pressure measurements in children and adolescents, several investigators have reported that correlations between repeated blood pressure measurements tend to decrease during puberty, probably because of the confounding effects of growth and maturation on blood pressure. For example, Katz et al.24 obtained follow-up blood pressure measurements of 7-year olds, and divided the population on the basis of blood pressure percentiles at age 7. Group systolic blood pressure differences of those with relatively high, intermediate, and low blood pressures at age 7 persisted until age 15 in males and until 13 in females (fig. 4). However, in both sexes, the tracking relationship tended to disappear after puberty. This apparent loss of tracking may be related to the fact that the pubertal growth spurt tended to occur later in smaller children, and consequently these late maturers had "catch-up" blood pressure at a later age. Additional longitudinal studies are required to determine if blood pressures before puberty are related to blood pressures of sexually mature young adults.

Long-Term Significance of Hypertension in Pregnancy

In normal pregnancy, arterial pressure tends to decrease during the midtrimester. Hypertension of pregnancy is defined as the presence of any one of the following:29 1) a sustained rise of at least 30 mm Hg over the usual level of systolic blood pressure; 2) a sustained rise of at least 15 mm Hg over the usual level of diastolic blood pressure; 3) a sustained systolic blood pressure of at least 140 mm Hg; and 4) a sustained diastolic blood pressure of at least 90 mm Hg.

We are conducting a longitudinal study to determine if hypertension during nulliparous adolescent pregnancy is associated with subsequent hypertension.30 Our initial study population consisted of 409 pregnant ado-

![Figure 4. Systolic blood pressures, by chronologic age in black males found to have relatively high (> 85th % ile), intermediate (15–85th % ile), and relatively low blood pressures (< 15th % ile) at age 7 years. (Reproduced with permission from the Philadelphia Blood Pressure Project, Katz et al., see ref. 24.)](image)

Table 5. Blood Pressures of Young Mothers with Normotensive Pregnancy (NP) and Hypertensive Pregnancy (HP)

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>3- to 6-year follow-up</th>
<th>6- to 9-year follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NP (n = 54)</td>
<td>HP (n = 70)</td>
</tr>
<tr>
<td>SBP (mm Hg)</td>
<td>111.1</td>
<td>117.1*</td>
</tr>
<tr>
<td>DBP (mm Hg)</td>
<td>64.4</td>
<td>70.1*</td>
</tr>
<tr>
<td>Rel wt (kg/m²)</td>
<td>22.4</td>
<td>25.4*</td>
</tr>
</tbody>
</table>

*p < 0.01 compared to NP.
edema. 29, 31 Gestational hypertension tends to recur in a high proportion of later pregnancies and is associated with an increased prevalence of chronic hypertension and cardiovascular disease mortality at long-term follow-up. Consistent with our results, in a prospective study of black women, Langford and Watson32 recently reported that blood pressures and weights of women who developed "mild pre-eclampsia" (gestational hypertension) during a first pregnancy were also higher before pregnancy and at 6 weeks after delivery than respective levels in women who did not develop hypertension in pregnancy. In contrast to gestational hypertension, most evidence suggests that "true" pre-eclampsia is not associated with an increased incidence of subsequent hypertension.31

Conclusions

Blood pressure at one age is predictive of blood pressure at a later age. In young women, mild hypertension during pregnancy is also predictive of higher blood pressures at a later age. However, some investigators report that correlations of repeat blood pressure measurements are of a low order of magnitude and tend to decrease over time.25, 33 Repeated blood pressure measurements over time may be required to evaluate the "tracking" hypothesis, and correlation coefficients may achieve greater statistical significance after adjustment for the phenomenon of regression toward the mean.24 Blood pressure is closely related to growth and maturation, and it has not yet been demonstrated that blood pressure in the prepubertal child is predictive of blood pressure in the young adult. Nevertheless, blood pressure at one age is generally regarded as the single most reliable predictor of blood pressure at a later age.

One clinical implication of the tracking phenomenon is that adolescents and young adults with relatively high blood pressures are at increased risk for developing hypertension as blood pressure increases with age. In young adults, even modest elevations of blood pressure are associated with an increased incidence of cardiovascular disease. For example, Paffenbarger et al.7, 35 have reported that a difference of a few millimeters of mercury in the blood pressure of college students is associated with significant increases in later mortality from both stroke and coronary heart disease. In male college entrants with a single systolic blood pressure above 130 mm Hg, death from coronary heart disease in middle-aged years was 1.6 times greater than that of males whose blood pressure were less than 130 mm Hg at college entrance.36 We have recently observed that young adults in our Bourbon County population with relatively high blood pressure sustained over 5 years have echocardiographic evidence of increased cardiac work and left ventricular wall stress.37 Thus, identification of adolescents and young adults with relatively high blood pressures defines a high risk group, and innovative strategies for interventions in this group may have important implications for the primary prevention of cardiovascular disease.

References


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