SUMMARY

This report reviews the results of six large blood pressure surveys done on pediatric populations and points out factors responsible for differences in the blood pressure norms. The studies were selected on the basis of there being recent examinations of large numbers of children. Important differences in mean systolic pressures and 95th percentile values were found among the studies, which may be attributed to: 1) actual differences among the populations; 2) biases due to methodological differences; or 3) increased sampling variability with small sample sizes. Actual differences in pressures among the populations surveyed may be due to differences in geographic location, racial composition, or average body sizes. Discrepancies due to methodological biases may have occurred because of associated venipuncture or exercise stress on the day of the examination; differences in selection of blood pressure cuff sizes; differences in the number of measurements averaged. In several studies, small sample sizes for each age-race-sex subclass accounted for considerable variability of the 95th percentile value. The implication of this analysis is that before the 95th percentile norms for children of different ages, races, and sexes can be more firmly established, it is necessary to collect larger sample sizes controlling for known biasing factors and using a standardized methodology.

KEY WORDS • hypertension • epidemiology • childhood hypertension • blood pressure surveys

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N important step has been taken to establish blood pressure norms for children and adolescents. The Task Force on Blood Pressure Control in Children has recommended that sustained blood pressure levels (obtained at least on three separate occasions) above the 95th percentile for age should be considered abnormal.1 The Task Force has published standards of blood pressures for school age children based on data gathered mainly from two studies conducted in Muscatine, Iowa, and Rochester, Minnesota.2 Over the past few years, several other large pediatric surveys have been published reporting important differences in blood pressure values from those of the Task Force.3 These discrepancies may be attributed to: 1) actual differences among the populations; 2) biases due to methodological differences; or 3) increased sampling variability with small sample sizes. The purpose of this report is to review the findings of several large blood pressure surveys performed recently on pediatric populations in this country. We will take into consideration various factors that may have resulted in inconsistent findings among the studies.

The studies selected for this comparison were chosen arbitrarily on the basis of there having been recent examinations of large numbers of children and adolescents. Table 1 lists the individual studies and their sample sizes, age ranges, and racial composition. Although each survey made efforts to standardize the measurements of blood pressure, few of the studies used the same protocol. The National Health Survey5,6 recorded and averaged three sets of blood pressures, the first two at the beginning and end of the physical examination with the subjects recumbent, and the third with the subjects sitting. A venipuncture was done between the first two. The Bogalusa study8 recorded and averaged six sets of blood pressures with the subjects seated. The Rochester study9 measured one set of blood pressures with the subjects seated, prior to venipuncture. The Muscatine study10 measured one set of pressures with the subjects seated, several hours after venipuncture. The St. Louis study10 measured three sets of blood pressures (averaged the second and third measurements) with the subjects seated; no venipunctures were performed. The Dallas study10 measured one set of pressures with the subjects seated; no venipunctures were performed. All of the studies used mercury sphygmomanometers. The Rochester and Dallas studies used random zero models to reduce observer bias.7

Figure 1 displays the mean systolic pressure for boys from each study according to age. The heavy line represents the mean pressures published by the Task Force on Blood Pressure Control in Children.

Figure 1: Mean systolic blood pressure for boys from each study according to age. The heavy line represents the mean pressures published by the Task Force on Blood Pressure Control in Children.
Table 1. Recent Blood Pressure Surveys in Pediatric Populations

<table>
<thead>
<tr>
<th>Study</th>
<th>No. of subjects</th>
<th>Ages (yrs)</th>
<th>Racial makeup</th>
<th>No. of measurements</th>
<th>Associated procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Health Survey (NHS)</td>
<td>13387</td>
<td>6-17</td>
<td>86% white</td>
<td>3</td>
<td>venipuncture, exercise</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14% black</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bogalusa, La</td>
<td>3524</td>
<td>5-14</td>
<td>63% white</td>
<td>6</td>
<td>venipuncture</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>37% black</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rochester, Minn</td>
<td>3048</td>
<td>6-18</td>
<td>100% white</td>
<td>1</td>
<td>venipuncture</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscatine, Iowa</td>
<td>4783</td>
<td>5-18</td>
<td>90% white</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1% black</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>3% Mexican Am</td>
<td></td>
<td></td>
</tr>
<tr>
<td>St. Louis, Mo</td>
<td>6944</td>
<td>14-18</td>
<td>70% white</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30% black</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dallas, Tx</td>
<td>19658</td>
<td>13-17</td>
<td>40% white</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>48% black</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14% Mexican Am</td>
<td></td>
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</tr>
</tbody>
</table>

Reference numbers refer to those listed in the References.

Force. Diastolic pressures are not presented here, since some studies used the fourth and others the fifth Korotkoff phase criteria. The data shown here indicate that important differences exist among studies for systolic pressures. Similar differences are also found with girls. As mentioned earlier, the differences may be due to measurement biases or may reflect true blood pressure differences among pediatric populations from different geographic regions. The greatest discrepancy in mean systolic pressures among the studies occurs in adolescents, being as high as 22 mm Hg when the National Health Survey results are compared with those of the Bogalusa and Dallas studies.

It is well known that significant differences in blood pressures do exist among adult populations from various geographic regions within the United States. The National Health Survey has studied the differences in blood pressures among pediatric populations from different regions. Table 2 is an excerpt from their data that shows mean systolic blood pressure in 14-year-old youths according to sex, race, and region. Geographic differences are apparent; therefore, the discrepancies may reflect actual differences among the pediatric populations. This is an important issue that deserves further epidemiologic investigation.

The racial composition of the populations surveyed differed from study to study (table 1). In preadolescents, racial differences in mean systolic pressure are not significant. The National Health Survey found that in adolescents the mean systolic pressure of white youths was generally greater than that of black youths. The mean difference was small (4 mm Hg or less), and only at 15 and 17 years of age was it large enough to be statistically significant. Similar findings were reported in the St. Louis and Dallas studies where white adolescent males tended to have higher mean systolic pressures (approximately 2-4 mm Hg higher) than black males. Therefore, some of the discrepancies in mean systolic pressures among the surveys may be due in part to different proportions of blacks and other ethnic groups.

It is also well known that body mass is a strong correlate with blood pressure. Differences in mean systolic pressure among the surveys could be due to differences in the size of the children examined. Tables 3 and 4 show the mean weights and mean systolic pressures for male youths by age among selected studies. The heavy line represents the mean systolic blood pressure values reported by the Task Force on Blood Pressure Control in Children.
pressures in a subsample taken from each of the surveys, consisting of 14-year-old white youths. In general, those surveys having larger mean weights tended to have higher systolic blood pressures. However, a more detailed analysis of individual weight and pressure data would be necessary to more clearly evaluate how these differences in body size accounted for differences in mean systolic blood pressure among studies.

With regard to methodological biases, the instrumentation used by the various studies consisted of mercury sphygmomanometers. Probably the most important factor affecting blood pressure measurement in pediatric populations is the selection of cuff sizes for children of different body sizes. Although each of the studies attempted to standardize the selection of cuff size, the criteria for this selection was not reported in sufficient detail to allow comparisons among studies. Only the Bogalusa study\textsuperscript{4} reported the specific criteria used in the selection of cuff size based on arm size. It is recommended that future blood pressure surveys performed in children and adolescents establish and describe more specific criteria for selection of cuff size. Despite the influence of cuff sizes, it is unlikely that the rather large differences in mean systolic pressures can be explained entirely on this basis. The greatest discrepancy in mean systolic pressures among the studies occurred in late adolescence when an adult size cuff would have been used in most of the subjects.

Blood pressures may be affected by performing venipunctures or exercise stress tests on the day of examination. The prospect of having blood drawn may have produced apprehension and thereby elevated the blood pressure in children who were anxious. The
National Health Survey data suggest that mean systolic pressure prior to venipuncture is approximately 5 mm Hg higher than pressures measured after venipuncture. Physical activity is known to influence blood pressure, but the duration of the effect has not been well established in children. Submaximal exercise stress tests were performed as part of the National Health Survey in adolescents. The test consisted of a 5-minute walk on a treadmill surface, which was raised to a 10% grade after an initial period of zero grade. Among these adolescents, the mean systolic pressure measured within 20 minutes after exercise averaged 7 mm Hg higher than pressures measured either before the exercise or after a recovery period longer than 20 minutes. The subjects in the National Health Survey had blood pressures measured both before and after exercise, which were included in their average blood pressure calculation. This survey had the highest average systolic pressure, which may be explained in part by the influence of the stress test. It is also possible that differences among other studies may in part reflect differences in physical activity of the children on the day of examination.

Environmental factors at the location of the examination may affect blood pressure. Ambient temperature has been reported to influence blood pressures in adults, with a tendency toward decreased blood pressure with higher temperature (Rose, personal communication). However, the St. Louis authors failed to demonstrate a significant effect of temperature in their adolescent study (ambient temperature ranged from 70° to 75° F). They also found no significant correlation between blood pressure and time of day (pressures were measured in the morning and early afternoon hours). Recently, Prineas and co-workers reported that systolic pressures in children tended to be lower at warmer room temperatures, whereas diastolic pressure tended to be higher.

The 95th percentile values for systolic blood pressure varied considerably among the studies (fig. 2). A partial explanation for the observed differences is the bias introduced by regression to the mean effect in the studies that used multiple measurements to determine an individual’s blood pressure. The number of measurements taken on each child varied from a single measurement in the Rochester, Muscatine, and Dallas studies to an average of six measurements in the Bogalusa study. The concept of regression to the mean can be interpreted as the tendency for individuals with high readings on one blood pressure determination to show a decrease on the next reading and for those with low readings to show an increase. Consequently, those individuals experiencing blood pressure measurements in the extremes on the first measurement will have measurements closer to the overall mean on the second measurement. Using the mean of the two observations tends to reduce the variance of the distribution, since the extremes will be averaged. The variance close to the mean effect for multiple measurements would result in a blood pressure distribution with the same mean as the distribution for single measurements. As more and more measurements are taken in each subject and averaged, however, the extreme values will be eliminated from the distribution, thereby narrowing the range of reported blood pressures in a population. This effect is demonstrated by comparing the Bogalusa and Dallas data. The mean systolic blood pressures of 14-year-old males in the Bogalusa and Dallas studies were similar, 108.4 and 109.5 mm Hg respectively. In the Bogalusa study reporting the average of six blood pressures, systolic pressures ranged from 92 to 134 mm Hg, whereas in the Dallas study reporting a single blood pressure measurement, systolic pressures ranged from 70 to 170 mm Hg.

The effect of regression to the mean of multiple measurements, in addition to narrowing the range and reducing the variance, would also be to limit the extreme percentiles, causing the 95th percentile to be lower in value. This is because the 95th percentile is a function of the variance (95th percentile = mean plus 1.645 times the standard deviation). This may partially explain why the Bogalusa study reports a 95th percentile value of 122 mm Hg for systolic pressure in 14-year-old boys, whereas the Dallas study reports a value of 134 mm Hg.

Some of the variability in 95th percentile values for systolic blood pressure is probably due to small numbers in each age-sex class. This is apparent in the subsample from these populations shown in table 3. The sample size directly affects the results because it is related to the variability observed in the estimation of the parameters of the population, for example, the variability of the 95th percentile. The differences observed in the 95th percentile blood pressure values are a function of the variability in blood pressure in each study especially in the tails of the distribution.

![Figure 2. Comparisons of 95th percentile values for systolic pressure of male youths by age among selected studies. The heavy line represents the values reported by the Task Force on Blood Pressure Control in Children.](image-url)
The sample size affects the variability, which in turn affects the location of the 95th percentile.

We explored the relationship of sample size to the 95th percentile in terms of confidence limits for the 95th percentile. (See the Appendix.) As an example, in the Dallas data the 95% confidence interval for the true 95th percentile for systolic pressure of 14-year-old white males was between 132 and 136 mm Hg. This implies that, if this population of approximately 1400 white males (14 years of age) were resurveyed shortly after the initial survey, the newly established 95th percentile would probably lie between 132 and 136 mm Hg. The Muscatine study has reported values for three separate surveys in the same school system done biennially. The 95th percentile values for systolic pressure of 14-year-old boys were 146 mm Hg in 1971, 140 mm Hg in 1973, and 148 mm Hg in 1978. In each of these years, approximately 200 boys of this age were examined. The variability in the 95th percentile for the three surveys demonstrates the changes that may occur with relatively small sample sizes despite similar methodology and environment.

Since it is our desire to have as precise an estimate of the 95th percentile in the general population as possible, a calculation of sample size needed to generate a very tight confidence interval (implying a very small variability) can be computed. For example, if one wanted to be 95% confident that the sample estimate is within 1% of the true 95th percentile, the sample size needed would be 1825 in the case of 14-year-old white males. No pediatric surveys have been conducted on as large a sample.

The implication of our analyses is that, before the 95th percentile norms for children of different ages and sexes can be firmly established, it is necessary to collect more information. To control for other biasing factors and actual differences in the population, the study groups should be a representative sample of races and geographic regions and should be studied using a standardized methodology. The National Health Examination Survey will be conducted again within the next few years. It is our hope that the Task Force on Blood Pressure Control in Children will have input to the design of that survey so that the results can resolve many of the unanswered questions.

Appendix

Calculation for Size of Sample

The calculation of the sample size necessary to be confident that the sample estimate is within 1% of the true 95th percentile is based on Mood and Graybill, who give the following equation for the confidence intervals for the parameter of a binomial distribution for large samples:

\[ P \left( \hat{p} - 1.96 \sqrt{\frac{\hat{p}(1-\hat{p})}{n}} < p < \hat{p} + 1.96 \sqrt{\frac{\hat{p}(1-\hat{p})}{n}} \right) \approx 0.95. \]

For the 95th percentile, \( \hat{p} = 0.95 \), and \( 1-\hat{p} = 0.05 \).

It is desired to find \( n \) so that \( 1.96 \sqrt{\frac{\hat{p}(1-\hat{p})}{n}} \leq 0.01 \).

Solving for \( n \), we see that the necessary sample size is

\[ \left( \frac{1.96}{0.01} \right)^2 \leq n, \]

or \( n \geq 1825. \)

References

Systolic blood pressure differences among pediatric epidemiological studies.
D E Fixler, J A Kautz and K Dana

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