Observations On Blood Pressure Measurements In High-School Athletes

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Abstract: The purpose of this study is to identify possible evidence of hypertension in athletic adolescents. In addition to sex and age, the effects of various physical factors that may influence blood pressure are measured. The data were collected from the annual screening physicals of local high-school athletic program participants. Nine of the 11 measured physical factors account for 10 percent to 20 percent of the variability in blood pressure measurements. These include age, weight, height, pulse, quadriceps girth, heel cord flexibility, jump reach, hang time, and grip strength. These variables are incorporated into formulae that adjust the range of "normal" values of systolic and diastolic blood pressure to reduce the effects of these confounding factors, thereby increasing the accuracy of the "normal" or "hypertensive" determination for each individual. (JABFP 1988; 1:81-6.)

During the last 20 years, the medical definition of hypertension has continually changed and has never been specifically and acceptably defined for any population. Hypertension continues to be based primarily on medical opinion and not on controlled epidemiological studies of normal populations. The difficulty lies with identifying blood pressure values that define a normal population. In the past, age and sex have been the most commonly used variables. What has been even more difficult is identifying the hypertensive child and adolescent. The purpose of the present study is to create a schema for identifying possible hypertension in athletic adolescents through the correlation of various physical variables, including age and sex.

The value of this determination emanates from the significance of hypertension. In the adult population, epidemiological studies have demonstrated the increasing risk of coronary artery disease as the blood pressure rises. In addition, the effectiveness of blood pressure control in reducing cardiovascular morbidity has been demonstrated[1]; yet, similar correlations have yet to be proved in an asymptomatic population of children or adolescents. In a study of 6,622 schoolchildren aged 5 to 18 years, 885 (13.4 percent) had elevated blood pressure on initial screening (systolic greater than 140 millimeters of mercury [mmHg] [95th percentile], diastolic 90 mmHg [95th percentile]).[2] Only 41 (0.6 percent) had persistent hypertension throughout four screenings. Will these children become hypertensive adults?

Before treatment can be established, hypertension in the adolescent population first must be defined. A 1977 task force on blood pressure control in children defined hypertension as a resting systolic and/or diastolic pressure exceeding the 95th percentile on at least three occasions according to sex and age.[3] In persons 18 years and older, a diastolic reading of 90 mmHg or above was considered abnormal.[4] Repeat recordings are essential because many individuals who have initial high readings have normal blood pressure by the third observation. This phenomenon is known as "regression towards the mean."

Londe proposed a definition based on the normal standards established for his office practice for boys and girls between the ages of 4 and 15 years.[5] Children are considered hypertensive when their systolic and/or diastolic pressures are repeatedly above the 90th percentile and occasionally above the 95th percentile for age and sex for 1 year or more.

In 1976, Fixler, et al. screened more than 10,000 eighth-grade students (average age, 14 years) for high blood pressure. Elevated blood pressure was defined according to age as greater

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than the 95th percentile.[6] On initial screening, 947 (approximately 8.9 percent) had elevated blood pressures; after three exams, only 167 (1.8 percent) continued to have elevated readings.

Some authors have defined the normal range of blood pressure as that above which there is an increase in morbidity. In accord with this, life insurance mortality investigations have shown an increase in morbidity and mortality at and beyond a reading of 140/90 mmHg. Master, et al. have incorporated a statistical definition based on the distribution of blood pressure readings around the mean, according to sex and age.[7] This assumes that the frequency distribution of blood pressure yields a fairly normal curve, i.e., two-thirds of the readings fall within the range of the mean plus or minus one standard deviation, and 95 percent fall within the range of the mean plus or minus two standard deviations. A reading within one standard deviation of the mean is considered "normal," and it is not unreasonable to extend this normal range to cover 80 percent of the observations, that is, 40 percent on either side of the mean. Readings departing two standard deviations or more from the mean are probably "abnormal" and constitute the 5 percent at the upper and lower ends of the curve.

We attempt here to sharpen the boundaries of "normal" and "abnormal" blood pressure values in high-school athletic participants. This study is not an effort to define hypertension in the athletic adolescent or any other sample population. Our premise is that sex and age are not the only confounding factors affecting blood pressure: weight and other physical variables that contribute to fitness level must also be considered. Our data support this premise and provide the basis for determining a more specific "normal" range for each individual.

Materials and Methods

The 1985 annual screening physicals for area high-school athletes in all sports provided a vehicle for this study. There were 990 boys and 647 girls whose ages ranged from 11 to 20 years. All testing was monitored and controlled to a reliable standard of performance. Two nurses and two nursing students recorded blood pressures. Eleven fitness and flexibility variables were measured in a station-to-station manner and recorded by physicians, physical therapists, trainers, and physiologists. These specific variables were selected as useful physical data for the coaches and trainers of these athletes in order to evaluate performance and athletic potential. These variables were not originally selected for a study of adolescent hypertension.

Blood pressure was measured before any of the fitness and flexibility variables. The recordings spanned the entire day as the students arrived from the respective schools. The recordings were taken in an air-conditioned room after a 30-minute rest period. Each student was in a seated position with an appropriately sized blood pressure cuff covering at least two-thirds of the upper arm. The pressures were recorded in millimeters of mercury (mmHg) in one arm. If the initial measurement was greater than 140/90 mmHg, it was repeated in the same or other arm, and the lowest value was recorded.

Standing height was measured with students in stocking feet and recorded in inches. Body weight was measured with the students clothed and shoeless using a beam-type balance scale and recorded in pounds.

Passive measurements were then recorded. Quadriceps girth was determined bilaterally by circumferential reading at 7 inches above the joint line. With the athlete supine, a goniometer was used to measure hamstring flexibility (angle of knee extension with hip flexed and held at 90 degrees) and heel cord flexibility (degrees of active dorsiflexion of the ankle with the leg extended).

Skinfold measurements were taken with Skyndex™ calipers at the subscapularis and mid-anterior thigh for the boys and the triceps and superior iliac crest for the girls. These were applied to a standard Sloan formula to give the body fat scores. Grip strength was measured with a JAMAR™ hand dynamometer, which measured absolute strength by applying force to an immovable object.

For boys, reverse hand chin-ups and parallel bar dips graded relative strength in moving body weight. Girls were required to do parallel bar dips and bent arm-hangs instead of chin-ups. Relative muscular endurance was tested by timed situps where the athlete was given 60 seconds to do as many situps as possible. These were done with hands behind the head and knees flexed, with the feet fixed or held by another student. Vertical jump measured explosive muscle function or relative power.

Table 1. *Correlation Matrix for Male Athletes.**

	Systolic	Diastolic
Age	0.22907	0.15340
Height	0.26768	0.17077
Weight	0.40958	0.18268
Pulse	0.14012	0.19827
Quad (L)	0.35848	0.19556
Quad (R)	0.35288	0.19914
Hams (L)	−0.05911	−0.01779
Hams (R)	−0.09631	−0.02497
Heel (L)	0.01923	0.09807
Heel (R)	0.00842	0.08095
Body fat	0.21844	0.07292
Grip (L)	0.20971	0.08313
Grip (R)	0.26605	0.12452
Chin-ups	−0.01714	−0.03348
Jump	0.14837	0.03751
Dips	0.08657	0.09692
Situps	−0.07555	−0.02977

*Critical value (one-tail, 0.5) = ±0.06061, critical value (two-tail, 0.5) = ±0.07218, n = 738.

Results

Measurements from the 11 examinations were plotted for frequency distribution. All but heel cord flexibility measurements show a normal distribution. The skewed distribution in the heel cord flexibility measurements results from rounding numbers to the nearest 5-degree mark. Measurements recorded in 1-degree increments would show a more normal distribution. A more exact procedure needs to be applied to this measurement. Overall, the recorded data appear to be normally distributed and conducive to meaningful statistical analysis.

The data were divided by sex and then analyzed for correlation of variables to blood pressure. Complete data for a correlation matrix were obtained for 738 boys and 353 girls. The others were excluded because of incomplete recordings. For boys, weight has the strongest correlation with systolic measurements. This is followed by quadriceps girth, height, grip strength, age, and percent of body fat (Table 1). Diastolic blood pressure measurements are correlated most highly with quadriceps girth, followed by pulse, weight, height, age, and grip strength (Table 1). Corresponding data for girls are presented in Table 2. Weight has the strongest correlation with systolic measurements, followed by quadriceps girth, age, height, body fat, and pulse. Diastolic measurements are correlated most highly with weight, followed by quadriceps girth, age, body fat, height, and pulse.

Because of the strong correlations noted in some of the variables, we employed a step-wise regression analysis to isolate the effects of each variable. Variables were singularly tested for variance and influence on both systolic and diastolic measurements. The R^2 statistic was computed for each regression and interpreted as the proportion of variance that the regression model and the blood pressure data have in common or as the percent of the variance in the regression model.[8] This statistic is a quantitative estimate of the influence of those various factors on the blood pressure measurement.

The variables that emerged as possible predictors for boys are shown in Table 3. For systolic measurements, height, grip strength, and age are so strongly correlated with weight that it was unnecessary to include them in the regression analysis. In determining diastolic blood pressure variability, weight and grip strength are strongly correlated with quadriceps girth and height and, so, did not appear to function as independent variables.

Table 4 presents predictor variables for the girls. Unlike boys, girls have nearly the same predictor

Table 2. *Correlation Matrix for Female Athletes.**

	Systolic	Diastolic
Age	0.22074	0.19198
Height	0.20984	0.17890
Weight	0.31324	0.29343
Pulse	0.18456	0.17761
Quad (L)	0.30887	0.27650
Quad (R)	0.28074	0.26151
Hams (L)	0.06336	0.08899
Hams (R)	0.04242	0.04975
Heel (L)	−0.08844	−0.06580
Heel (R)	−0.04514	−0.02172
Body fat	0.19067	0.18780
Grip (L)	0.07144	0.07799
Grip (R)	0.11834	0.11476
Hang	−0.03257	−0.12559
Jump	0.03474	0.05131
Dips	0.00051	0.00411
Situps	−0.02280	−0.02331

*Critical value (one-tail, 0.5) = ±0.08771, critical value (two-tail, 0.5) = ±0.10441, n = 353.

Table 3. *Blood Pressure Regression Coefficients for Male Athletes.*

	Systolic	Diastolic
Age		0.8568
Height		0.3589
Weight	0.1695	
Pulse	0.1640	0.1541
Quad	0.9453	0.8351
Heel	0.2193	0.2694
Jump	0.4761	
Constant	54.2392	2.9738
R^2	0.2025	0.0979
Average	121.8119	70.0827
Standard Deviation	15.2665	11.4859

variables for both systolic and diastolic measurements.

Discussion

Normal Blood Pressure Definition/Variables That Affect Blood Pressure

In an attempt to flag the students with higher than "normal" blood pressure, it was necessary to define normal. Some studies have set the upper limits at 140 mmHg systolic and 90 mmHg diastolic.[9] Other studies have based their threshold on the ages of students, assuming one standard deviation from the average to be a normal range.[10]

Analysis of our data reveals that age, considered independently, is not a sufficient standard by which to judge a blood pressure reading as "normal" or "abnormal." For boys, weight, quadriceps girth, and height for both systolic and diastolic measurements correlate better than does age. This reconfirms the importance of weight as a factor in blood pressure variability but does not necessarily take into consideration actual body structure or build. Similar inferences exist for girls.

The regression analysis for boys' systolic blood pressure suggests that weight, pulse, heel cord flexibility, vertical jump, and quadriceps girth are all more influential than age. Weight alone accounts for 17 percent of the variability, while weight and pulse account for 18 percent. All five variables combined account for 20 percent.

For diastolic blood pressure, age is a stronger factor than weight. Quadriceps girth and pulse continue to be important variables: the former accounts for 4 percent, and both combined account for 7 percent of the variability. However, we are only able to account for 10 percent of the variability in the boys.

Girls' blood pressure measurements and their confounding factors demonstrate a similar pattern. Predictor variables account for 15 percent of systolic blood pressure variability and 12 percent of the diastolic blood pressure variability. Age emerges as a slightly more important factor than it does with boys. For our data, a simple regression with age as the only predictor yields a maximum R^2 of only about 5 percent.

Our study supports data presented at the 1985 symposium on children's blood pressure.[11] The conclusions drawn there were: (1) blood pressure increases with age, (2) larger (increased weight and height) children have higher blood pressure than smaller children of the same age, and (3) obese children (increased body fat) have higher blood pressure than lean children.

Our derived significant predictor value of quadriceps girth is probably due to its high correlation to two of these causative factors—weight (0.7402) and body fat (0.5489). Because grip strength is also significant, at least for boys, perhaps another interaction factor, such as body density or height per unit of weight, may more accurately predict blood pressure than the individual variables of weight, height, and body fat.

Heel cord flexibility in boys, however, is an unexpected predictor. It may be explained by the nature of our population: most aerobically fit runners normally have a decreased blood pressure secondary to their exercise, and they also have very tight heel cords, which yields a positive correlation.

Table 4. *Blood Pressure Regression Coefficients for Female Athletes.*

	Systolic	Diastolic
Age	1.0443	0.6598
Weight	0.1975	0.1152
Pulse	0.1514	0.1099
Grip	−0.1325	−0.0712
Hang	0.1501	
Constant	62.7638	40.7036
R^2	0.1577	0.1258
Average	106.0057	67.8357
Standard Deviation	11.4152	8.3098

It is interesting to note the relationship of pulse rate to blood pressure in boys. This has been documented by Levy and associates who demonstrated the relative prognostic importance of transient tachycardia and transient hypertension with respect to the later development of sustained hypertension.[12] We believe that the secondary effects of the excitement of the examinee and the lack of repeated measurements do not diminish the value of this positive correlation.

Blood Pressure Prediction

The many predictive factors identified by statistical analyses seem to render the "normal" threshold reading of 140/90 mmHg imprecise. This prompted us to design a blood pressure determination method, with a view toward increasing the sensitivity, specificity, and repeatability of the test as well as toward automating the procedure for more efficient screening of large populations. The factors identified by the regression, along with their coefficients and constant values, were used to construct formulae for predicting a subject's systolic and diastolic blood pressure, given the other measurements. The four formulae thus identified were:

Boys

Systolic blood pressure =
Weight (0.1695) + Pulse (0.1640) + Quad (0.9453) + Heel (0.2193) + Jump (0.4761) + 54.2392

Diastolic blood pressure =
Age (0.8568) + Height (0.3589) + Pulse (0.1541) + Quad (0.8351) + Heel (0.2694) + 2.9738

Girls

Systolic blood pressure =
Age (1.0443) + Weight (.1975) + Pulse (.1514) − Grip (.1325) + Hang (.1501) + 62.7638

Diastolic blood pressure =
Age (0.6598) + Weight (0.1152) + Pulse (0.1099) − Grip (0.0712) + 40.7036.

For example, the predicted blood pressure for a 16-year-old boy was 119/70 mmHg and the observed blood pressure was 124/92 mmHg. To determine if the observed value was within normal range, the following equation for allowance was used:

$$\text{Allowance} = \pm 2S\,(1 - R^2),$$

where S is the standard deviation from the average of the population and R^2 is the percentage of variability when using the regression equation per variable of the population distribution.

Because one standard deviation was too restrictive, flagging over one-third of the students as abnormal, two standard deviations were chosen for maximum range. This was then adjusted by applying the percentage of variability to narrow the range to as close to the predicted value as possible. Note these values in Tables 3 and 4.

For boys, the following was determined:

Systolic

$$\text{Allowance} = \pm 2(15.2665)(1 - 0.2025) = \pm 24.3501$$

Diastolic

$$\text{Allowance} = \pm 2(11.4859)(1 - 0.0979) = \pm 20.7228$$

Thus, the normal range of systolic measurement would be ±24 from the predicted value of 119 mmHg. In other words, the observed systolic measurement should be no lower than 94 mmHg and no higher than 142 mmHg. The observed systolic measurement was 124 mmHg and so fell well within the normal range. The normal range for diastolic measurement would be ±21 from the predicted value of 70 mmHg, or no lower than 49 mmHg and no higher than 91 mmHg. The observed diastolic was 92 mmHg and so fell outside the normal range for this example. This student would be flagged as having higher than normal diastolic measurement.

These allowances are significantly less than the two standard deviations allowed in some studies. The formula for the allowance is only for illustrative purposes and is presented in this form purely as a basis for repetition of the experiment.

Study Pitfalls

By incorporating these variables into formulae, we have adjusted the range of "normal" values for systolic and diastolic blood pressure to reduce their confounding effects. We believe that this method has specified the boundaries of "normal" blood pressure values somewhat, although we realize that there are the following problems inherent in our study:

1. We have a small sample of adolescent athletes who come from the same geographic location and participate primarily in football.

2. Our blood pressure measurements were taken by four different people with some repeat measurements (about 5 percent), which tend to change the distribution slightly more towards the mean. We did not repeat any measurements over time.
3. We have incomplete data from some of the athletes. This occurred when a physician arbitrarily allowed students to bypass recording stations because previous recordings seemed normal. Other reasons could be a neglect to record data or simply data entry errors.
4. We have no long-term follow-up data that track these values for persistent hypertension and various cardiovascular sequelae.
5. The estimates obtained here should be applied only to the sample population from which they were derived. This initial study is presented simply to demonstrate the possibility of multiple confounding factors influencing blood pressure. Other independent samples could suggest different factors.

Conclusion

We conclude that more than age and sex must be considered when determining "normal" blood pressure for an individual. By including age, weight, height, quadriceps girth, pulse, heel cord flexibility, jump reach, hang time, and grip strength, the determination can be narrowed to a more correct norm for an individual. With 9 of the 11 variables from the physical examination identified as significant factors, about 15 percent of blood pressure variability was accounted for in the girls and 20 percent in the boys. Age alone accounted for only 5 percent or less of the variance in blood pressure in either group.

Ultimately, we hope to identify the child or adolescent with blood pressure significantly outside the normal distribution. Future investigations should be directed towards tracking the adolescents, considering other interaction factors such as height per unit of weight, and sampling a more general population. In addition, other variables that were not considered, but which are probably significant factors, are race, socioeconomic group, family history of hypertension, somatotype, diet, smoking history, sexual maturity, medications, and medical history.

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