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Original Article

Blood pressure-to-height ratio for diagnosing hypertension in adolescents

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Abstract

Background Diagnosing hypertension in children and adolescents is not always straightforward. The blood pressure-to-height ratio (BPHR) has been reported as a screening tool for diagnosing hypertension.

Objective To evaluate the diagnostic value of blood pressure-to-height ratio for evaluating hypertension in adolescents.

Methods A cross-sectional study was conducted among 432 healthy adolescents aged 12-17 years in Singkuang, North Sumatera from April to May 2016. Blood pressure tables from the National High Blood Pressure Education Program (NHBPEP) Working Group on High Blood Pressure in Children and Adolescents were used as our standard of comparison. Sex-specific systolic and diastolic blood pressure-to-height ratios (SBPHR and DBPHR) were calculated. ROC curve analyses were performed to assess the accuracy of BPHR for discriminating between hypertensive and non-hypertensive adolescents. Optimal thresholds of BPHR were determined and validated using 2x2 table analyses.

Results The accuracies of BPHR for diagnosing hypertension were > 90% (P<0.001), for both males and females. Optimal SBPHR and DBPHR thresholds for defining hypertension were 0.787 and 0.507 in boys, respectively, and 0.836 and 0.541 in girls, respectively. The sensitivities of SBPHR and DBPHR in both sexes were all >93%, and specificities in both sexes were all >81%. Positive predictive values for SBPHR and DBPHR were 38.7% and 45.2% in boys, respectively; and 55.9% and 42.4% in girls, respectively; negative predictive values in both sexes were all >97%, positive likelihood ratios in both sexes were all >5, and negative likelihood ratios in both sexes were all <1.

Conclusion Blood pressure-to-height ratio is a simple screening tool with high sensitivity and specificity for diagnosing hypertension in adolescents. **[Paediatr Indones. 2017;57:84-90. doi: http://dx.doi.org/10.14238/pi57.2.2017.84-90]**.

Keywords: *adolescents; blood pressure to height ratio; hypertension*

The prevalence of adolescent hypertension in developing countries is rising steeply.[1,2] Examination of the national childhood blood pressure data from several epidemiological studies in adolescents aged 13 to 15 years, according to the criteria of the *2004 Fourth Report from the National High Blood Pressure Education Program (NHBPEP) Working Group on Children and Adolescents*, indicated that 20% of adolescent boys and 13% of adolescent girls met the criteria for prehypertension. In adolescent subjects with BP measurements taken 2 years apart, the rate of progression from prehypertension to hypertension was 7% per year.[3,4] In 2013, the *Indonesian Ministry of Health* reported a 5.3% prevalence of hypertension in youth aged 15 to 17 years (6% for boys and 4.7% for girls), according to the JNC VII 2003 criteria.[5,6] However, a study found that 45.2% of 200 children with

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a family history of hypertension were hypertensive, in a study of high school students in Soposorung, North Sumatera.[7]

Hypertension in children and adolescents can lead to adult hypertension. Hypertension is a known risk factor for coronary artery disease in adults, and its presence in children and adolescents may contribute to the early development of coronary artery disease. Appropriate early-stage diagnosis and intervention in children and adolescents are important for reducing the risk of hypertension-related disorders in adults.[8,9] Identifying hypertension in children and adolescents is more complicated than in adults.[1,2] Diagnosis of hypertension in children and adolescents, according to the *NHBPEP Working Group on Children and Adolescents*, is influenced by age, sex, and height.[3] As a result, the threshold values of hypertension in children and adolescents vary according to these parameters. Hence, alternative, less cumbersome, diagnostic tools for adolescent high blood pressure are under evaluation.[1,2]

Several studies reported associations between blood pressure and weight, height, and age.[10,11] Height has an especially important role in determining blood pressure because body size affects blood pressure.[12-14] The hydrostatic paradox, first described by Stevin *et al.*, stipulates that fluid pressure generated at the bottom of a tube can be measured from the vertical height of the tube. Fluid can flow from the top to the bottom of the tube when the pressure at the bottom of the tube exceeds the hydrostatic pressure that is defined by its height.[15] Kahn *et al.* then applied this principle to a child's blood pressure, naming it the hydrostatic column of blood hypothesis. Adequate perfusion to the child's brain can be achieved when the blood pressure in the heart exceeds the hydrostatic pressure defined by the vertical distance between the heart and vertex.[12]

High blood pressure indirectly identified through anthropometric indicators may be an efficient strategy for detection and control.[16] In 2010, Lu *et al.* evaluated, for the first time, the feasibility and accuracy of the blood pressure-to-height ratio (BPHR) for identifying hypertension in Chinese adolescents.[2] The study was replicated in Nigerian adolescents by Ejike.[1] Both studies concluded that the BPHR is a simple method for diagnosing hypertension in children and adolescents.[1,2] Therefore, we evaluated the diagnostic value of BPHR for diagnosing hypertension in Indonesian adolescents.

Methods

This prospective, diagnostic study with cross-sectional design was conducted in healthy adolescents aged 12 to 17 years in Singkuang, Mandailing Natal District, North Sumatra from April to May 2016. Adolescents who had overt signs of ill health on physical examination or who related a history of being on medications for any diseases/conditions were excluded from the study. Subjects' parents or legal guardians provided written informed consent.

Subjects were collected by consecutive sampling and their ages were obtained from school records. Subjects underwent height measurements, in a standing position without shoes, using a portable stadiometer, to the nearest 0.1 cm. Before blood pressures were measured, subjects were asked to rest for an initial 10 minutes, in a seated position and in a quiet room. Three separate blood pressure readings were taken per subject, at five-minute intervals, using a mercury sphygmomanometer. Appropriate cuff sizes were used for each subject. Systolic blood pressure (SBP) was determined by the onset of the 'tapping' Korotkoff sounds (K1); diastolic blood pressure (DBP) was determined by the fifth Korotkoff sound (K5). Systolic blood pressure-to-height ratio (SBPHR) was calculated as SBP (mm Hg)/height (cm), and diastolic blood pressure-to-height ratio (DBPHR) was calculated as DBP (mm Hg)/height (cm).[1,2]

Blood pressure tables from *The Fourth Report from the NHBPEP Working Group on Children and Adolescents* (2004) were used as our standard of comparison to determine the subjects' hypertensive status. Normal blood pressure was defined as systolic and diastolic blood pressure $< 90^{th}$ percentile for gender, age, and height. Prehypertension was defined as systolic or diastolic blood pressure $\geq 90^{th}$ percentile but $< 95^{th}$ percentile for gender, age, and height. Hypertension was defined as systolic or diastolic blood pressure $\geq 95^{th}$ percentile for gender, age, and height.[3]

Numerical variables were reported as median (minimum – maximum). Comparisons were performed between groups using Mann-Whitney test. Spearman's correlation coefficient was used to measure the strength of association between two variables. Results with P values < 0.05 were considered to be statistically significant.[17] A receiver operating characteristic (ROC) curve was used to assess the discriminatory ability/diagnostic accuracy of SBPHR and DBPHR (separately), with respect to normotensive and hypertensive subjects, as defined by the age-, gender-, and height-specific reference standards.[3] The ROC curves were plotted using measures of sensitivity and specificity for the various cut-off points. The area under the curve (AUC) is a measure of this discriminatory/diagnostic power of a test. An AUC value of 1.0 indicates a perfectly accurate test, whereas an AUC value of 0.5 indicates that the test performs worse than chance. Optimal cut-off points for both SBPHR and DBPHR were determined by specificity and sensitivity values that yielded the maximum sums from the ROC curves. Using the determined cut-off points as diagnostic tools, normotension and hypertension were defined in the population, and the sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood ratio, and negative likelihood ratio of the thresholds were calculated.[17] All data analyses were done using *SPSS 17.0* statistical software.

Results

A total of 450 adolescents, junior and senior high school students were initially screened for this study. Eleven adolescents were excluded because they did not meet the age criteria and 7 adolescents refused to participate. Of 432 subjects, 177 (40.9%) were boys and 255 (59.1%) were girls. All subjects were from the Batak Mandailings tribe, Mongoloid race.

The characteristics of study subjects are presented in **Table 1**. The age distribution of subjects was as follows: 28 (6.5%) adolescents aged 12 years, 88 (20.4%) adolescents aged 13 years, 79 (18.3%) adolescents aged 14 years, 96 (22.2%) adolescents aged 15 years, 82 (19%) adolescents aged 16 years, and 59 (13.7%) adolescents aged 17 years. Median heights in boys and girls increased by age and boys were significantly taller than girls (P<0.001). Median SBPs generally (not always) increased with age, but there was no significant difference between SBPs in boys and girls (P=0.212). However, DBP was significantly higher in girls than in boys (P=0.009) although the median were in the same range due to variations of number of subjects by age group. The SBPHR and DBPHR were also significantly higher in girls than in boys (P <0.001).

The SBPHR and DBPHR correlations to SBP, DBP, height, and age are shown in **Table 2**. Statistically significant correlations were found between SBPHR and SBP, height, and age (P<0.001). Likewise, DBPHR had significant correlations with DBP, height, and age (P<0.001 for DBP and height, P=0.008 for age). Strong, positive correlations were found between SBPHR and SBP (r = +0.876), as well as between DBPHR and DBP (r = +0.914). Weak, inverse correlations were found between SBPHR and

Table 1. The characteristics of study subjects based on age and sex

Age in years	Males Median (range)	Females Median (range)	P value*
Height, cm			
12 (n=28)	141.5 (133-151)	138.0 (99-151)	0.500
13 (n=88)	150.5 (127-161)	143.0 (99-155)	0.096
14 (n=79)	148.0 (127-161)	147.0 (133-160)	0.738
15 (n=96)	154.5 (136-168)	149.0 (135-161)	<0.001
16 (n=82)	158.5 (137-168)	150.0 (99-159)	<0.001
17 (n=59)	161.0 (150-172)	146.5 (129-161)	<0.001
Total (N=432)	151.0 (127-172)	146.0 (99-161)	<0.001
Systolic blood pressure, mmHg			
12 (n=28)	105.0 (85-130)	115.0 (90-130)	0.304
13 (n=88)	102.5 (80-130)	112.5 (85-140)	0.007
14 (n=79)	112.5 (90-130)	120.0 (90-135)	0.191
15 (n=96)	120.0 (90-135)	110.0 (85-130)	0.218
16 (n=82)	115.0 (90-155)	110.0 (80-140)	0.395
17 (n=59)	115.0 (100-135)	110.0 (85-130)	0.865
Total (N=432)	110.0 (80-155)	110.0 (80-140)	0.212
Diastolic blood pressure, mmHg			
2 (n=28)	60.0 (50-80)	75.0 (50-80)	0.043
13 (n=88)	62.5 (50-85)	70.0 (50-90)	0.005
14 (n=79)	65.0 (50-90)	75.0 (50-90)	0.045
15 (n=96)	70.0 (50-90)	70.0 (55-95)	0.710
16 (n=82)	70.0 (50-100)	70.0 (50-100)	0.826
17 (n=59)	70.0 (60-90)	70.0 (50-80)	0.516
Total (N=432)	70.0 (50-100)	70.0 (50-100)	0.009
Systolic blood pressure-to-height ratio, mmHg/cm			
12 (n=28)	0.753 (0.616-0.872)	0.849 (0.596-0.963)	0.079
13 (n=88)	0.746 (0.552-0.938)	0.815 (0.594-1.010)	0.015
14 (n=79)	0.751 (0.573-0.897)	0.816 (0.600-0.951)	0.109
15 (n=96)	0.752 (0.563-0.956)	0.738 (0.581-0.912)	0.971
16 (n=82)	0.728 (0.621-0.987)	0.731 (0.526-1.212)	0.601
17 (n=59)	0.697 (0.592-0.839)	0.788 (0.599-0.906)	0.009
Total (N=432)	0.741 (0.552-0.987)	0.769 (0.526-1.212)	<0.001
Diastolic blood pressure-to-height ratio, mmHg/cm			
12 (n=28)	0.449 (0.362-0.537)	0.549 (0.331-0.615)	0.007
13 (n=88)	0.464 (0.341-0.625)	0.519 (0.331-0.629)	0.011
14 (n=79)	0.444 (0.333-0.621)	0.510 (0.350-0.634)	0.024
15 (n=96)	0.479 (0.325-0.588)	0.467 (0.342-0.620)	0.522
16 (n=82)	0.449 (0.336-0.637)	0.469 (0.316-0.808)	0.233
17 (n=59)	0.429 (0.382-0.577)	0.486 (0.352-0.576)	0.005
Total (N=432)	0.446 (0.325-0.637)	0.489 (0.316-0.808)	<0.001

*Mann-Whitney test

Table 2. SBPHR and DBPHR correlations to SBP, DBP, height, and age

Variables		SBPHR	DBPHR
SBP	r (P)*	+0.876 (<0.001)	-
DBP	r (P)*	-	+0.914 (<0.001)
Height	r (P)*	-0.337 (<0.001)	-0.293 (<0.001)
Age	r (P)*	-0.170 (<0.001)	-0.128 (0.008)

*Spearman's correlation test

Table 3. The AUC of SBPHR and DBPHR for male and female adolescents

Variables	AUC	95%CI	P value
Males			
SBPHR	0.911	0.868 to 0.953	< 0.001
DBPHR	0.973	0.952 to 0.995	< 0.001
Females			
SBPHR	0.942	0.914 to 0.969	< 0.001
DBPHR	0.976	0.958 to 0.993	< 0.001

height, as well as DBPHR and height (r = -0.337 and r= -0.293, respectively). A very weak, inverse correlation was found between SBPHR and age, as well as DBPHR and age (r = -0.170 and r = -0.128, respectively). Hence, clinically significant correlations were not found between SBPHR or DBPHR and age or height, with r <0.4.

The ROC analysis resulted in accuracies of >90% for both SBPHR and DBPHR, in discriminating between hypertensive and non-hypertensive adolescents based on sex (P<0.001) (**Table 3**). (DBP ≥ 95th percentile) were 0.507 for boys and 0.541 for girls.

The diagnostic values of the SBPHR and DBPHR cut-off points for males and females are shown in **Table 5**. The sensitivities of SBPHR and DBPHR in boys and girls were > 93%. Specificities of SBPHR and DBPHR in boys and girls were > 80%. These values indicate that SBPHR and DBPHR have high sensitivities and specificities for detecting hypertension in adolescents. The positive predictive values of SBPHR and DBPHR in boys and girls were each <56%. However, as these tests are for screening purposes, some false positive results may be tolerated. The negative predictive values of SBPHR and DBPHR in boys and girls were very high, >97%, indicating that SBPHR and DBPHR may serve very well in distinguishing adolescents without hypertension.

Table 4. Various cut-off points of SBPHR and DBPHR for male and female adolescents

Variables	Cut-off points	Sensitivity (%)	Specificity (%)
SBPHR			
Males	0.782	100	79.7
	0.787	100	81
	0.794	100	82.4
Females	0.830	96	79.5
	0.836	94	82
	0.839	88	82
DBPHR			
Males	0.506	100	79.1
	0.507	100	81
	0.508	100	83.5
Females	0.540	100	78.6
	0.541	100	81.2
	0.543	100	81.6

Discussion

Our study subjects were adolescents aged 12 to 17 years in Singkuang, Mandailing Natal District of North Sumatera. Subjects' heights increased with age, with boys beyond 14 years old significantly taller than girls of the corresponding ages (P <0.001), similar to findings in a previous study.[1]

Biological sex affects blood pressure and arterial hemodynamics. Since females generally have smaller body size, their blood pressure is lower than that of boys.[14,18] We found no significant difference in SBP between boys and girls (P=0212), but DBP was significantly higher in girls than boys (P=0.009) although the median in the same range due to variations of number of subjects by age group. This discrepancy may be due to greater body mass index (BMI) in girls than boys, increasing with age, leading to higher DBP in girls than in boys.[1] Other studies also found that overweight/obese children had two to three times the risk of hypertension, than normoweight children.[19-21] However, we did not measure our subjects' weights, so their BMIs could not be determined. In addition to BMI, sex hormones are known to affect vascular function, influencing the production of endothelin-1 and nitric oxide, both of which affect contraction of the vascular endothelium. Decreased nitric oxide activity and increased endothelin-1 activity were found in adolescents with hypertension. Pubertal adolescents were prone to unstable nitric oxide levels and hypertension.[22]

Both SBPHR and DBPHR were significantly higher in girls than in boys (P<0.001), similar to previous studies.[1,2] Correlation analysis revealed an inverse relationship between SBPHR and DBPHR and height, with r = -0.337 (P<0.001), indicating that the higher the ratio, the shorter the subjects. In our study, boys were significantly taller than girls (P <0.001), so the BPHR in boys was lower than that in girls.

We found significant correlations between SBPHR/DBPHR and SBP/DBP, height, and age (P<0.05). Both SBPHR and SBP as well as DBPHR and DBP had strong, positive correlations. However, inverse correlations were found between SBPHR/DBPHR and height, as well as SBPHR/DBPHR and age. The greater the height and age, the smaller the BPHR. These correlations were weak, with r <0.4. From a clinical standpoint, SBPHR and DBPHR are not influenced by age, so BPHR cut-off points were not determined by age. As such, the BPHR can be used in both tall and short adolescents. These results are consistent with previous studies which stated that BPHR was not associated with age and height.[1,2,23,24] Thus, BPHR is simpler to use than the gold standard NHBPEP tables.

In this study, we found that the accuracy of SBPHR and DBPHR for the diagnosis of hypertension in adolescents was >90% (P <0.001). As such, BPHR had a strong ability to discriminate between hypertension and non-hypertension in adolescent boys and girls. Previous studies also found the accuracy of BPHR to be >90% in adolescent populations in China, Nigeria, and the United States.[1,2,23]

We found the optimal cut-off points of SBPHR and DBPHR to be 0.787 and 0.507 in boys, respectively, and 0.836 and 0.541 in girls, respectively, with sensitivities >90% and specificities >80%. The gold standard requires the use of *Centers for Disease Control and Prevention* (CDC) weight-to-height percentile graphics[25] and the NHBPEP normative blood pressure tables.[3] Hence, the BPHR is simpler to use, as it requires remembering only four cut-off points. Thus, the difficulty in detecting hypertension in adolescents can be reduced.

Our BPHR cut-off points for defining hypertension were different from previous studies. Lu *et al.* studied in adolescents in China and found SBPHR and DBPHR cut-off points of 0.75 and 0.48 in boys, respectively, and 0.78 and 0.51 in girls, respectively.[2] Ejike reported SBPHR and DBPHR cut-off points of 0.75 and 0.51 in boys, respectively, and 0.77 and 0.50 in girls, respectively, in a study of Nigerian adolescents.[1] Also, Galescu et al. found SBPHR and DBPHR cut-off points 0.75 and 0.46 in boys, respectively, and 0.75 and 0.48 in girls, respectively.[23] In Indian adolescents, such cut-off points were 0.76 and 0.50 in boys, respectively, and 0.80 and 0.52 in girls, respectively.[24] These variations in cut-off points may be due to racial differences. Our study subjects were all of Mongoloid race in Singkuang, North Sumatera. Although the Lu *et al.* study also had subjects of Mongoloid race, they had a much larger sample size (13,136 *vs.* 432 adolescents).[2] Moreover, socioeconomic and cultural differences could have affected the cut-off points. It is possible that in the less developed countries, the wealthy readily adopt unhealthy lifestyles, characterized by smoking, sedentarism, and diets high in energy and fats.[26]

The diagnostic value of SBPHR and DBPHR for discriminating hypertension in adolescents compared to the NHBPEP tables,[2] was very good, with sensitivities of >93% and specificities of >80% for SBPHR and DBPHR in boys and girls. Similarly, Lu *et al.* and Ejike reported sensitivity and specificity >90% using the BPHR method,[1,2] while Galescu *et al.* and Ahmed *et al.* reported sensitivity and specificity of >80%.[23,24] Hence, SBPHR and DBPHR had a high ability to detect hypertension and distinguish between hypertensive and non- hypertensive adolescents.

Our positive predictive values for SBPHR and DBPHR were 45.2% and 38.7% in boys, respectively, and 55.9% and 42.4% in girls, respectively. Albeit low, these values were consistent with results of a previous study that reported a PPV range from 28% to 60%.[24] The low PPVs indicate that a hypertension diagnosis using SBPHR and DBPHR should be confirmed by the gold standard. In contrast, the negative predictive values of SBPHR and DBPHR in boys and girls were very high (>97%), respectively, consistent with previous studies.[1,2,23,24] High NPVs for SBPHR and DBPHR indicate that the BPHR is very good in discriminating non-hypertensive adolescents. Hence, adolescents diagnosed as normotensive using SBPHR and DBPHR, are actually non-hypertensive and can be eliminated after screening, thereby, simplifying the steps in detecting hypertension in adolescents.

This study had several limitations. First, the small sample size led to differences in the cut-off points, even in subjects of the same race. Second, we examined the adolescent population of only the Batak Mandailing tribe, therefore, our findings cannot be necessarily be generalized to the population of Indonesia. However, previous studies stated that height does not depend on ethnic differences,[2] so it is likely that our findings can be used in different ethnic groups, until such time as more data becomes available.

In conclusion, the blood pressure-to-height ratio is a simple and easy diagnostic tool with high sensitivity, specificity, and negative predictive value for diagnosing hypertension in adolescents. Clinically, the BPHR can be used to screen for specific hypertensive adolescents, and to distinguish them from non-hypertensive adolescents. Adolescents diagnosed with hypertension using the BPHR method should undergo confirmation by the NHBPEP tables. However, those diagnosed as non-hypertensive can be eliminated. This method may be applicable to other ethnic groups, but should be validated in those groups.

Conflict of Interest

None declared.

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