Can Pediatric Hypertension Criteria Be Simplified?

A Prediction Analysis of Subclinical Cardiovascular Outcomes From the Bogalusa Heart Study

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See Editorial Commentary, pp 587–588

Abstract**—**Prehypertension and hypertension in childhood are defined by sex-, age-, and height-specific 90th (or ≥120/80 mm Hg) and 95th percentiles of blood pressure, respectively, by the 2004 Fourth Report. However, these cutoffs are complex and cumbersome for use. This study assessed the performance of a simplified blood pressure definition to predict adult hypertension and subclinical cardiovascular disease. The cohort consisted of 1225 adults (530 men; aged 26.3–47.7 years) from the Bogalusa Heart Study with 27.1-year follow-up since childhood. We used 110/70 and 120/80 mm Hg for children (age, 6–11 years), and 120/80 and 130/85 mm Hg for adolescents (age, 12–17 years) as the simplified definition of childhood prehypertension and hypertension, respectively, to compare with the 2004 Fourth Report (the complex definition). Adult carotid intima-media thickness, pulse wave velocity, and left ventricular mass were measured using digital ultrasound instruments. Compared with normal blood pressure, childhood hypertensives diagnosed by the simplified definition and the complex definition were both at higher risk of adult hypertension with hazard ratio of 3.1 (95% confidence interval, 1.8–5.3) by the simplified definition and 3.2 (2.0–5.0) by the complex definition, high pulse wave velocity with 3.5 (1.7–7.1) and 2.2 (1.2–4.1), high carotid intima-media thickness with 3.1 (1.7–5.6) and 2.0 (1.2–3.6), and left ventricular hypertrophy with 3.4 (1.7–6.8) and 3.0 (1.6–5.6). The results were confirmed by reclassification or receiver operating curve analyses. The simplified childhood blood pressure definition predicts the risk of adult hypertension and subclinical cardiovascular disease equally as the complex definition does, which could be useful for screening hypertensive children to reduce risk of adult cardiovascular disease. **(*Hypertension*. 2017;69:691-696. DOI: 10.1161/HYPERTENSIONAHA.116.08782.)** • **Online Data Supplement**

Key Words: blood pressure ■ cardiovascular diseases ■ child ■ hypertension ■ longitudinal studies

Childhood elevated blood pressure (BP) is a public health problem worldwide.[1] Elevated BP has been associated with risk of target organ damage in children.[2] In addition, BP in childhood is moderately correlated with BP in adulthood.[3] Children with elevated BP are more likely to develop subclinical atherosclerosis[4] and premature mortality,[5] compared with those with normal BP although the absolute number developing adult cardiovascular disease (CVD) events for elevated BP children are much less than normal BP ones. It is important to identify children with elevated BP early to prevent target organ damage and identify secondary hypertension in childhood, and lower the risk of CVD in adulthood.

Currently, BP measurements are recommended in clinical practice for children aged ≥3 years by both the American Academy of Pediatrics[6] and the European Society of Hypertension.[7] Prehypertension and hypertension in childhood are defined based on sex-, age-, and height-specific 90th and 95th BP percentiles, respectively, on 3 different occasions by the National High Blood Pressure Education Program (the Fourth Report).[6] However, these reference criteria lead to as many as 476 cutoff points for children and adolescents aged 1 to 17 years, which are complex and cumbersome to use in clinical practice. Elevated BP is infrequently diagnosed in children even when routinely measured BP is available, partially because of the complexity of the BP percentile reference criteria.[8] Recently, several researchers have developed simplified tools to screen for elevated BP in children,[9] including the use of simplified mathematical formulas,[10,11] simplified tables by age and sex,[12,13] and height-specific simplified tables,[14] and BP to height ratio.[15,16] However, these simplified methods are either still difficult to use or have low positive predictive values compared with the complex definition specific for sex, age, and height percentiles.[17–19]

The International Diabetes Federation has recommended that systolic/diastolic BP (SBP/DBP) ≥130/85 mm Hg should be used to define hypertension for adolescents.[20] We feel that ≥120/80 mm Hg might be suitable to define hypertension for

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children aged 6 to 11 years based on the complex BP percentile tables (the Fourth Report). Most recently, the SPRINT (Systolic Blood Pressure Intervention Trial) suggested that reduction of SBP to <120 mm Hg decreases the risk of CVD and related mortality compared with the traditional reduction goal of <140 mm Hg in adults.[21] Falkner and Gidding[22] suggested normal (optimal) BP cutoff could be <120/80 mm Hg for adolescents aged ≥12 years and <110/70 mm Hg for children aged <12 years for primordial prevention in pediatric population. It is clear that these 4 cutoffs are much easier to remember and more user-friendly in clinical practice than the complex definition based on sex-, age-, and height-specific percentiles. To our knowledge, no study has validated the performance of this simplified criterion in predicting cardiovascular risk in adulthood compared with the complex references.

We aimed to assess the performance of these simplified BP cutoffs in childhood to predict hypertension and subclinical CVD in adulthood utilizing the longitudinal cohort of the Bogalusa Heart Study.[23]

Methods

Subjects

The Bogalusa Heart Study, a series of long-term studies in a semirural biracial (65% white and 35% black) community in Bogalusa, Louisiana, was funded by Berenson et al[23] in 1973. This study focuses on the early natural history of CVD since childhood. The study cohort profile has been described in detail elsewhere.[23] In brief, between 1973 and 1988, 8 cross-sectional surveys of children aged 4 to 17 years were conducted in Bogalusa, Louisiana. Children aged 4 and 5 years (n=57) were excluded as the sample size was small. A total of 1225 adults (43.3% men; age range, 26.3–47.7 years) who participated in previous children surveys were examined between 2000 and 2010. The mean follow-up period was 27.1 years (range, 19.1–36.5 years).This longitudinal cohort had data on cardiovascular risk factors from childhood to adulthood, and subclinical CVD including carotid intima-media thickness (CIMT), aorta–femoral pulse wave velocity (afPWV), and left ventricular hypertrophy (LVH) in adulthood.

The number of children (number of visits) during the follow-up period in this longitudinal cohort was 236 (1), 333 (2), 310 (3), 197 (4), and 149 (≥5). The definitions of childhood prehypertension and hypertension were based on the Fourth Report and our simplified method cutoffs. For children experiencing ≥1 visits, BP value in the first visit was chosen to classify children as normotensives if BP values in all visits were below the cutoffs of both definitions; the first visit was chosen to classify children as prehypertensives or hypertensives if BP values in ≥1 visits during childhood were above the cutoffs of either definition. This sample selection strategy maximized the number of children with prehypertension and hypertension. For instance, using our selection approach, the number of children with hypertension was 59 based on the Fourth Report, and 50 according to our simplified method (Table 1). This approach is superior to the methods of choosing the first visit, choosing the last visit and random selection because a substantial proportion of hypertensive children were misclassified using these 3 selection methods, with only 25, 29, and 28 for the Fourth Report and 15, 33, and 23 for our simplified definition.

All subjects in this study gave informed consent for each survey, and for those under 18 years of age, consent of a parent/guardian was obtained in all children surveys. The protocol was approved by the Institutional Review Board of the Tulane University Health Sciences Center.

General Examinations

All examinations in both childhood and adulthood followed essentially the same protocols.[23] Height was measured twice with 0.1 cm accuracy, and weight was measured twice with 0.1 kg accuracy. The average values were used to calculate body mass index as weight/height^2 (kg/m^2). Overweight and obesity was defined according to 85th and 95th percentile of CDC 2000 growth charts by sex and age.[24]

BP levels in both childhood and adulthood were measured on the right arm with appropriate cuff after at least 5 minutes resting for each participant using calibrated mercury sphygmomanometers between 8:00 AM and 10:00 AM. BP measurements were obtained with subjects sitting with back supported and feet on the floor. SBP was measured at the first Korotkoff phase and DBP at the fifth Korotkoff (K5) phase for both children and adults. DBP at the fourth Korotkoff phase (K4) was also recorded for all children. For children with the K5 being very low (<20 mm Hg),[25] the K4 was used as DBP recommended by the Fourth Report.[6] For each participant, BP levels were measured by 2 trained observers (3 replicates each). The mean values of the 6 readings were used for analysis. This is far more measurements than that would be obtained in a routine child health examination, but the mean of 6 BP readings would be more stable and accurate. Adult hypertension was defined as ≥140/90 mm Hg or taking antihypertensive medicine.

Subclinical CV Structure and Function

CIMT, afPWV, and LVH in adulthood were measured using a Toshiba digital ultrasound instrument (Xario SSA-660A; Toshiba America Medical Systems, Tustin, CA) following American Society of Echocardiography recommendations.[26] Details of CIMT, afPWV, and LVH measurements have been described elsewhere.[27–29] In brief, the mean value of 3 sites of CIMT (the far walls of the right and left common carotid artery, carotid bulb, and internal carotid artery) was determined using a 7.5-MHz linear array transducer.[27] Subclinical atherosclerosis was defined as values equal to or greater than the age-, sex-, and race-specific 80th percentile of CIMT.[30]

For afPWV, a 2.5-MHz nondirectional transcutaneous Doppler flow probe was positioned at the suprasternal notch, and another 7.5-MHz probe was positioned at the left femoral artery with the subject lying in a supine position. After the collection of the waveform data, the distance between the suprasternal notch and femoral arteries was measured with a caliper instrument to reduce the influence of body contours on the distance measured. afPWV was calculated by dividing the distance traveled by the time differential between the 2 waveforms. Results from 3 data collection runs were averaged for each participant.[28] Arterial stiffness was defined as values at or above the age-, gender-, race-, and heart-rate-specific 80th percentile of afPWV.[31]

LV dimensions were assessed by 2-dimensional–guided M-mode echocardiography with 2.25- and 3.5-MHz transducers. Parasternal long- and short-axis views were used for measuring LV end-diastolic and end-systolic measurements in duplicate, and the mean was calculated. LV mass was calculated from a necropsy-validated formula on the basis of a thick-wall prolate ellipsoidal geometry.[29] LV mass index was calculated as LV mass/height$^{2.7}$ (g/m$^{2.7}$) to account for body size. The presence of LVH was defined by sex-specific cutoffs of LV mass index >46.7 g/m$^{2.7}$ in women and >49.2 g/m$^{2.7}$ in men.[32]

Definition of Elevated BP in Childhood

Simplified BP Definition

Prehypertension was defined as SBP≥110 and <120 mm Hg and/or DBP≥70 and <80 mm Hg for children aged 6 to 11 years, and SBP≥120 and <130 mm Hg and/or DBP≥80 and <85 mm Hg for adolescents aged 12 to 17 years. Hypertension was defined as SBP≥120 and/or DBP≥80 mm Hg for children, and SBP≥130 and/or DBP≥85 mm Hg for adolescents. There was no child at baseline using antihypertensive drugs.

Complex BP Definition

Prehypertension and hypertension were defined as ≥90th percentiles (or ≥120/80 mm Hg) and <95th percentiles, and ≥95th percentiles by sex, age, and height based on BP references of the Fourth Report, respectively.[6]

Statistical Analysis

The differences in baseline and follow-up variables between children and adolescents were tested using generalized linear model (for

Table 1. Baseline and Follow-Up Characteristics of Study Participants by Age Group

Variable	Total	Children (6–11 y)	Adolescents (12–17 y)	*P* Value*
No. of subjects	1225	737	488	
Whites, n (%)	849 (69.3)	508 (68.9)	341 (69.9)	0.772
Males, n (%)	531 (43.4)	305 (41.4)	226 (46.3)	0.100
Baseline				
Age, y	10.9±3.3	8.6±1.7	14.4±1.6	<0.001
Height, cm	142.9±19.3	130.1±11.8	162.2±10.3	<0.001
BMI, kg/m^2	18.4±4.0	16.9±3.0	20.6±4.2	<0.001
SBP, mm Hg	103.0±13.1	97.1±10.1	111.8±12.2	<0.001
DBP-K4, mm Hg	63.8±9.8	59.7±8.3	69.9±8.6	<0.001
DBP-K5, mm Hg	48.6±12.4	44.8±10.5	54.3±13.0	<0.001
Overweight, n (%)	127 (10.4)	81 (11.0)	46 (9.4)	
Obesity, n (%)	105 (8.6)	62 (8.4)	43 (8.8)	0.671
Simplified definition, n (%)				
Prehypertension	225 (18.4)	83 (11.3)	142 (29.1)	
Hypertension	50 (4.1)	20 (2.7)	30 (6.2)	<0.001
Complex definition, n (%)				
Prehypertension	168 (13.7)	27 (3.7)	141 (29.0)	
Hypertension	59 (4.8)	26 (3.5)	33 (6.8)	<0.001
Follow-up				
Age, y	37.3±4.5	34.9±3.8	40.8±2.7	<0.001
Height, cm	169.5±9.5	169.0±9.3	170.3±9.7	0.009
BMI, kg/m^2	29.5±7.1	29.3±7.2	29.8±6.8	0.202
SBP, mm Hg	117.4±14.6	115.3±13.8	120.5±15.3	<0.001
DBP, mm Hg	79.2±10.2	77.8±10.0	81.2±10.2	<0.001
afPWV, m/s	5.4±1.3	5.3±1.3	5.7±1.4	<0.001
CIMT, mm	0.82±0.17	0.79±0.13	0.87±0.20	<0.001
LVMI, g/m$^{2.7}$	35.6±11.2	35.1±11.0	36.2±11.4	0.107
Hypertension, n (%)	271 (22.1)	131 (17.8)	140 (28.7)	<0.001
High PWV, n (%)	213 (20.0)	129 (20.0)	84 (20.0)	1.000
High CIMT, n (%)	228 (20.0)	124 (18.2)	104 (22.8)	0.065
LVH, n (%)	138 (12.4)	75 (11.2)	63 (14.3)	0.144
Any of high PWV, CIMT, or LVH, n (%)	452 (44.1)	262 (42.5)	190 (46.5)	0.231

Continuous variables are expressed as mean±SD. afPWV indicates aorta–femoral pulse wave velocity; BMI, body mass index; CIMT, carotid intima-media thickness; DBP-K4, diastolic blood pressure at the fourth Korotkoff; DBP-K5, diastolic blood pressure at the fifth Korotkoff; LVH, left ventricular hypertrophy; LVMI, left ventricular mass index; PWV, pulse wave velocity; and SBP, systolic blood pressure.

*Difference between children and adolescents.

continuous) or χ^2 test (for categorical). Multivariable-adjusted Cox regression analyses were conducted to examine the performance of the childhood simplified definition as compared with the traditional complex definition in predicting adult hypertension, subclinical atherosclerosis, arterial stiffness, and LVH, with adjustment for sex, age, race, and childhood body mass index. We also performed sensitivity analyses according to sex, age group, body mass index categories, categories, and height categories. We calculated net reclassification improvement to determine the extent to which the simplified definition (versus the complex definition) improves the predictive ability.[33,34] In addition, we used receiver operating characteristic curve analysis to calculate the sensitivity, specificity, positive predictive value, negative predictive value, and area under curve of 2 definitions of pediatric elevated BP (including prehypertension and hypertension) in predicting adult hypertension and subclinical CVD outcomes. All data analyses were performed using R 3.1.3. Two-tailed $P<0.05$ were considered statistically significant.

Results

Participant Characteristics

Table 1 shows the baseline and follow-up characteristics of study participants by age group. The number (percentage) of children with normal BP, prehypertension, and hypertension was 998 (81.5%), 168 (13.7%), and 59 (4.8%), respectively, based on the complex definition and 950 (77.5%), 225 (18.4%), and 50 (4.1%), respectively, based on the simplified method. At baseline, adolescents aged 12 to 17 years were more likely to have elevated BP than children aged 6 to 11 years. In adulthood, older participants had higher CIMT and afPWV and had higher prevalence of hypertension than younger participants.

Consistence of 2 BP Definitions in Childhood

The κ correlation coefficient between the simplified definition and complex definition was 0.86 (95% confidence interval, 0.89–0.91), with only 77 subjects being nonoverlapping using 2 definitions (complex definition: n=52 for normal BP, n=10 for prehypertension, and n=15 for hypertension; simplified definition: the corresponding figures were 4, 67, and 6, respectively).

Association Between Elevated BP Defined by 2 Criteria in Childhood and Risk of Adult Outcomes

Participants with prehypertension or hypertension in childhood defined using either definition were at higher risk of adult hypertension and subclinical CVD outcomes including arterial stiffness, subclinical atherosclerosis, and LVH compared with children with normal BP (Table 2). The strengths of the associations were similar using either the simplified definition or the complex definition. For instance, for the outcome of any subclinical CVD in adulthood, the hazard ratio was 3.21 (95% confidence interval, 2.07–4.96) and 2.20 (95% confidence interval, 1.47–3.30) for children with hypertension compared with those with normal BP, using 2 definitions, respectively (Table 2).

We performed sensitivity analyses to test the robustness of our findings. First, we used K4 for DBP, and the results were much similar to those using K5 (Table S1 in the online-only Data Supplement). In addition, because K5<20 mm Hg might be too low for us to decide the use of K4, we performed a sensitivity analysis using K4 to replace K5 when K5<30 mm Hg. The results were similar (data not shown). Second, we examined the association in subgroups by sex, age (6–11 versus 12–17 years), body mass index categories (normal weight versus overweight), and height categories (<50th percentile versus ≥50th percentile specific for age and sex). The performance of the simplified BP definition was similar to that of the complex definition in predicting adult hypertension, high afPWV, high CIMT, and LVH in each subgroup (Tables S2–S6). Third, we further adjusted for other covariates in adulthood (eg, physical activity, smoking, and alcohol consumption) in Cox regression models, and the results did not change substantially (data not shown). Fourth, when examining association with subclinical CV risk, we performed a sensitivity analysis after exclusion of adults taking antihypertensive (n=115) or lipid-lowering drugs (n=44) and obtained similar results.

Performance of 2 Criteria in Childhood for Predicting Adult Outcomes Using Reclassification Method and Receiver Operating Characteristic Curve Analysis

The simplified BP definition also performed equally well when compared with the complex BP definition in predicting hypertension and subclinical CVD in adulthood using reclassification method (Table S7) or receiver operating characteristic curve analysis (Table S8). There was no significant difference in net reclassification improvement (all $P>0.05$) or area under curve (all $P>0.05$) between the 2 definitions.

Discussion

Currently, prehypertension and hypertension are usually defined by sex-, age-, and height-specific 90th and 95th percentile of BP in children and adolescents.[6,35] However, these percentile cutoffs are difficult to remember and use in practice. Simplifying these percentiles would allow convenient and effective screening and identification of elevated BP in

Table 2. HR and 95% CI for Adult Hypertension and Subclinical CVD Outcomes Associated With Childhood Prehypertension and Hypertension as Predictors by the 2 Definitions

	Simplified Definition			Complex Definition		
	HR	95% CI	*P* Value	HR	95% CI	*P* Value
Childhood prehypertension						
Adult hypertension	2.82	2.04–3.89	<0.001	2.91	1.99–4.26	<0.001
High PWV	2.66	1.82–3.89	<0.001	2.55	1.58–4.12	<0.001
High CIMT	2.79	1.96–3.97	<0.001	3.03	1.99–4.61	<0.001
LVH	1.92	1.19–3.10	0.007	2.45	1.40–4.28	0.002
Any subclinical CVD	2.55	1.97–3.31	<0.001	3.03	2.20–4.18	<0.001
Childhood hypertension						
Adult hypertension	3.11	1.83–5.26	<0.001	3.17	1.99–5.04	<0.001
High PWV	3.51	1.74–7.07	<0.001	2.22	1.21–4.07	0.010
High CIMT	3.07	1.70–5.56	<0.001	2.03	1.15–3.58	0.015
LVH	3.41	1.70–6.84	0.001	2.97	1.57–5.61	0.001
Any subclinical CVD	3.21	2.07–4.96	<0.001	2.20	1.47–3.30	<0.001

Sex, age, race, and childhood body mass index were included in the models for adjustment. CI indicates confidence interval; CIMT, carotid intima-media thickness; CVD, cardiovascular disease; HR, hazard ratio; LVH, left ventricular hypertrophy; and PWV, pulse wave velocity.

childhood, which might be useful for early prevention of CVD in adulthood. In the present study, the κ correlation coefficient was 0.86, which confirmed that when compared with the complex definition, our choices of simplified cutoffs of elevated BP were reasonable. In addition, we demonstrated that a simplified definition (110/70 and 120/80 mm Hg for children, and 120/80 and 130/85 mm Hg for adolescents, to define prehypertension and hypertension, respectively) performed similarly when compared with the traditional complex BP references (the Fourth Report) in predicting adult hypertension and subclinical CVD outcomes measured as arterial stiffness, subclinical atherosclerosis, and LVH. With a similar predictive power, the simplified definition can be more convenient and useful for screening high-risk subjects in practice.

In adults, 120/80 and 140/90 mm Hg are widely accepted as the optimal cutoffs of prehypertension and hypertension, respectively. The choice of these cutoffs is mainly based on the predictive value of BP for CVD outcomes. However, data are limited linking specific BP levels in children or adolescents to CVD outcomes in later life. The definition of pediatric elevated BP is mainly based on the distribution of BP levels using statistical methods, as well as the assumption that the upper limits of BP ranges in general children are probably not ideal.[22,36] In addition, age and height are considered in establishing childhood BP percentiles because BP changes with 2 variables during normal growth and development. However, these childhood BP percentiles are arbitrary to some extent as they were established using the statistical method rather than linking BP levels in childhood to health outcomes in childhood or adulthood.

In 1977, the first US BP percentiles were established with only sex and age factored in the study by Blumenthal et al.[37] In 1996 and 2004, besides sex and age, height was introduced into BP percentiles[6,38] because height is an important factor influencing childhood BP.[39] However, the introduction of height into childhood BP percentiles made it more complex and difficult to use for health professionals in clinical practice. Although our proposed simplified definition does not take into account sex and height, they performed equally well (if not better) in predicting adult hypertension and subclinical CVD outcomes compared with the traditional complex BP references. Our findings suggest that the complex definition might be unnecessary to adjust for height.

The current longitudinal study cohort followed from childhood to adulthood provided an opportunity to assess the performance of pediatric BP cutoffs by prediction analyses. However, this study has certain limitations. First, the small number of blacks did not allow us to perform subgroup analysis by race. Second, the cohort is still too young (mean age, 37.3 years) to have clinical CVD events such as coronary heart disease and stroke. Thus, we used surrogate end points of PWV, CIMT, and LVH for prediction analysis. Other subclinical indices such as endothelial function may be a more mechanistically related surrogate index of CVD. Unfortunately, endothelial function data were not available in this cohort. Third, many medical organizations recommend that children aged ≥3 years should be included, but we provided simplified BP cutoffs for children aged 6 to 17 years only. Further studies are necessary to bridge this gap. Fourth, in children aged 6 to 11 years, a big discrepancy in the prevalence rates of prehypertension (11.3% versus 3.7%) was seen by using the 2 definitions in the present study. Further studies with sufficient sample size are necessary to determine the optimal cutoff for this age group.

Perspectives

The present study suggests that compared with the much more complex definition of the Fourth Report, our simplified BP cutoffs performed equally well to predict hypertension and subclinical CVD in adulthood. Our findings support the use of the simplified definitions to screen and identify children and adolescents with elevated BP to prevent CVD risk in adulthood. Further future cohort studies are needed to confirm our findings in different populations.

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Disclosures

None.

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Novelty and Significance

What Is New?

- To our knowledge, this is the first study using 110/70 and 120/80 mm Hg for children (age 6–11 years) and 120/80 and 130/85 mm Hg for adolescents (age 12–17 years) as the simplified definitions of childhood prehypertension and hypertension, respectively, to compare with the complex definitions in predicting adult hypertension and cardiovascular outcomes.

What Is Relevant?

- The simplified childhood blood pressure definition predicts the risk of adult hypertension and subclinical cardiovascular disease equally as the complex definition does. The simplified pediatric blood pressure cutoffs could be convenient and useful for screening children at high risk and for targeting early life interventions to reduce the risk of developing cardiovascular disease in later life.

Summary

The present study suggests that compared with the much more complex definition of the Fourth Report, our simplified blood pressure cutoffs performed equally well to predict hypertension and subclinical cardiovascular disease in adulthood. Our findings support the use of the simplified definitions to screen and identify children and adolescents with elevated blood pressure to prevent cardiovascular disease risk in adulthood.

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Can Pediatric Hypertension Criteria Be Simplified? A Prediction Analysis of Subclinical Cardiovascular Outcomes from the Bogalusa Heart Study

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Table S1. Hazards ratios and 95% confidence intervals for adult hypertension and subclinical CVD outcomes according to the two definitions for pediatric elevated BP (Using K4 for DBP)

Outcome	Childhood Pre-hypertension					
	Simplified definition			Complex definition		
	HR	95% CI	*P* value	HR	95% CI	*P* value
Adult hypertension	2.83	2.10-3.83	<0.001	2.91	2.03-4.17	<0.001
High PWV	2.70	1.92-3.80	<0.001	2.82	1.84-4.31	<0.001
High CIMT	2.35	1.70-3.25	<0.001	2.49	1.68-3.71	<0.001
LVH	2.59	1.69-3.96	<0.001	2.44	1.42-4.21	0.001
Any subclinical CVD	2.47	1.96-3.12	<0.001	2.83	2.12-3.79	<0.001
	Childhood Hypertension					
	Simplified definition			Complex definition		
	HR	95% CI	*P* value	HR	95% CI	*P* value
Adult hypertension	3.94	2.55-6.07	<0.001	3.44	2.27-5.23	<0.001
High PWV	3.03	1.65-5.58	<0.001	2.14	1.25-3.67	0.006
High CIMT	2.80	1.67-4.71	<0.001	2.21	1.35-3.61	0.002
LVH	3.58	1.88-6.81	<0.001	3.21	1.81-5.69	<0.001
Any subclinical CVD	2.94	2.00-4.31	<0.001	2.19	1.54-3.12	<0.001

CVD, cardiovascular disease; PWV, pulse wave velocity; CIMT, carotid intima-media thickness; LVH, left ventricular hypertrophy

Sex, age, race, and childhood BMI were included in the models for adjustment.

Table S2. Hazards ratios and 95% confidence intervals for adult hypertension according to the two definitions

Childhood characteristics	Childhood Pre-hypertension					
	Simplified definition			Complex definition		
	HR	95% CI	*P* value	HR	95% CI	*P* value
All	2.82	2.04-3.89	<0.001	2.91	1.99-4.26	<0.001
Sex						
Males	2.74	1.77-4.24	<0.001	2.75	1.68-4.50	<0.001
Females	3.33	2.04-5.43	<0.001	4.00	2.17-7.38	<0.001
Age group						
6-11 years	2.97	1.83-4.80	<0.001	3.61	1.80-7.24	<0.001
12-17 years	2.25	1.36-3.74	0.002	2.08	1.25-3.46	0.005
BMI categories						
Normal weight	3.38	2.27-5.03	<0.001	3.25	2.01-5.26	<0.001
Overweight and obese	2.55	1.42-4.57	0.002	2.88	1.49-5.57	0.002
Height categories						
<P50	2.85	1.66-4.91	<0.001	2.36	1.31-4.27	0.004
≥P50	2.56	1.70-3.86	<0.001	2.95	1.73-5.03	<0.001
	Childhood Hypertension					
	Simplified definition			Complex definition		
	HR	95% CI	*P* value	HR	95% CI	*P* value
All	3.11	1.83-5.26	<0.001	3.17	1.99-5.04	<0.001
Sex						
Males	2.43	1.23-4.80	0.011	2.45	1.26-4.76	0.008
Females	5.86	2.54-13.52	<0.001	4.99	2.51-9.91	<0.001
Age group						
6-11 years	2.37	0.91-6.17	0.076	2.62	1.28-5.38	0.008
12-17 years	2.20	1.04-4.65	0.039	2.78	1.38-5.6	0.004
BMI categories						
Normal weight	3.92	1.90-8.09	<0.001	3.82	1.97-7.41	<0.001
Overweight and obese	2.49	1.14-5.46	0.023	2.60	1.31-5.16	0.006
Height categories						
<P50	5.63	2.13-14.85	<0.001	4.61	2.18-9.76	<0.001
≥P50	2.23	1.06-4.71	0.035	2.16	1.07-4.36	0.031

Sex, age, race, and childhood BMI were included in the models for adjustment.

Table S3. Hazards ratios and 95% confidence intervals for adult high PWV according to the two definitions

Childhood characteristics	Childhood Pre-hypertension					
	Simplified definition			Complex definition		
	HR	95% CI	*P* value	HR	95% CI	*P* value
All	2.66	1.82-3.89	<0.001	2.55	1.58-4.12	<0.001
Sex						
Males	2.89	1.52-5.48	0.001	3.15	1.48-6.69	0.003
Females	2.48	1.54-4.00	<0.001	2.37	1.25-4.49	0.008
Age group						
6-11 years	2.04	1.18-3.54	0.011	1.55	0.61-3.92	0.355
12-17 years	3.34	1.83-6.11	<0.001	2.82	1.48-5.38	0.002
BMI categories						
Normal weight	3.05	1.87-4.99	<0.001	3.30	1.80-6.06	<0.001
Overweight and obese	2.51	1.32-4.77	0.005	1.74	0.82-3.68	0.148
Height categories						
<P50	3.46	1.86-6.41	<0.001	2.18	1.08-4.40	0.030
≥P50	2.13	1.29-3.54	0.003	2.77	1.41-5.42	0.003
	Childhood Hypertension					
	Simplified definition			Complex definition		
	HR	95% CI	*P* value	HR	95% CI	*P* value
All	3.51	1.74-7.07	<0.001	2.22	1.21-4.07	0.010
Sex						
Males	3.60	1.32-9.79	0.012	1.99	0.65-6.08	0.224
Females	3.47	1.25-9.62	0.017	2.31	1.12-4.76	0.023
Age group						
6-11 years	3.55	1.22-10.33	0.02	1.05	0.37-2.98	0.934
12-17 years	4.81	1.5-15.41	0.008	7.10	2.78-18.12	<0.001
BMI categories						
Normal weight	3.60	1.42-9.17	0.007	3.17	1.36-7.35	0.007
Overweight and obese	3.25	1.02-10.37	0.046	1.25	0.48-3.29	0.649
Height categories						
<P50	5.16	1.41-18.92	0.013	3.10	1.16-8.29	0.024
≥P50	2.58	0.99-6.68	0.051	1.38	0.54-3.54	0.503

Sex, age, race, and childhood BMI were included in the models for adjustment.

Table S4. Hazards ratios and 95% confidence intervals for adult high CIMT according to the two definitions

Childhood characteristics	Childhood Pre-hypertension					
	Simplified definition			Complex definition		
	HR	95% CI	*P* value	HR	95% CI	*P* value
All	2.79	1.96-3.97	<0.001	3.03	1.99-4.61	<0.001
Sex						
Males	2.35	1.35-4.10	0.003	2.27	1.24-4.17	0.008
Females	3.12	1.95-5.00	<0.001	3.78	2.08-6.86	<0.001
Age group						
6-11 years	2.37	1.42-3.96	0.001	3.19	1.54-6.61	0.002
12-17 years	2.99	1.71-5.21	<0.001	2.73	1.57-4.74	<0.001
BMI categories						
Normal weight	3.38	2.21-5.17	<0.001	3.16	1.90-5.27	<0.001
Overweight and obese	2.16	1.16-4.02	0.015	2.96	1.47-5.94	0.002
Height categories						
<P50	2.07	1.03-4.16	0.041	2.02	0.96-4.22	0.063
≥P50	3.06	2.00-4.67	<0.001	3.56	2.08-6.08	<0.001
	Childhood Hypertension					
	Simplified definition			Complex definition		
	HR	95% CI	*P* value	HR	95% CI	*P* value
All	3.07	1.70-5.56	<0.001	2.03	1.15-3.58	0.015
Sex						
Males	2.40	1.00-5.72	0.049	1.69	0.68-4.18	0.260
Females	4.21	1.73-10.25	0.002	2.30	1.06-4.96	0.034
Age group						
6-11 years	1.58	0.52-4.81	0.417	0.83	0.29-2.36	0.722
12-17 years	4.18	1.71-10.25	0.002	4.69	2.02-10.90	<0.001
BMI categories						
Normal weight	6.07	2.92-12.63	<0.001	3.37	1.62-7.02	0.001
Overweight and obese	1.37	0.51-3.67	0.537	1.19	0.47-2.99	0.713
Height categories						
<P50	16.59	5.16-53.31	<0.001	5.46	2.39-12.46	<0.001
≥P50	1.59	0.68-3.74	0.284	0.95	0.39-2.32	0.916

Sex, age, race, and childhood BMI were included in the models for adjustment.

Table S5. Hazards ratios and 95% confidence intervals for adult LVH according to the two definitions

Childhood characteristics	Childhood Pre-hypertension					
	Simplified definition			Complex definition		
	HR	95% CI	*P* value	HR	95% CI	*P* value
All	1.92	1.19-3.10	0.007	2.45	1.40-4.28	0.002
Sex						
Males	1.50	0.73-3.07	0.271	1.49	0.67-3.30	0.323
Females	2.76	1.43-5.31	0.002	4.84	2.22-10.54	<0.001
Age group						
6-11 years	1.47	0.69-3.14	0.317	3.74	1.52-9.20	0.004
12-17 years	1.63	0.75-3.54	0.218	1.71	0.77-3.78	0.187
BMI categories						
Normal weight	1.33	0.64-2.76	0.438	1.02	0.43-2.41	0.958
Overweight and obese	3.22	1.53-6.80	0.002	6.40	2.85-14.34	<0.001
Height categories						
<P50	1.37	0.55-3.41	0.495	1.76	0.70-4.45	0.228
≥P50	2.13	1.17-3.85	0.013	3.12	1.44-6.72	0.004
	Childhood Hypertension					
	Simplified definition			Complex definition		
	HR	95% CI	*P* value	HR	95% CI	*P* value
All	3.41	1.70-6.84	0.001	2.97	1.57-5.61	0.001
Sex						
Males	3.77	1.62-8.78	0.002	3.16	1.34-7.47	0.009
Females	1.78	0.40-7.98	0.449	2.22	0.80-6.19	0.125
Age group						
6-11 years	1.67	0.54-5.19	0.372	1.90	0.71-5.05	0.200
12-17 years	1.54	0.47-5.04	0.475	2.50	0.85-7.40	0.098
BMI categories						
Normal weight	2.91	0.98-8.69	0.055	2.50	0.88-7.10	0.087
Overweight and obese	2.25	0.79-6.48	0.131	2.17	0.84-5.61	0.108
Height categories						
<P50	2.16	0.48-9.61	0.314	1.67	0.47-5.86	0.424
≥P50	3.51	1.42-8.66	0.007	3.19	1.35-7.54	0.008

Sex, age, race, and childhood BMI were included in the models for adjustment.

Table S6. Hazards ratios and 95% confidence intervals for adult any subclinical CVD according to the two definitions

Childhood characteristics	Childhood Pre-hypertension					
	Simplified definition			Complex definition		
	HR	95% CI	*P* value	HR	95% CI	*P* value
All	2.55	1.97-3.31	<0.001	3.03	2.2-4.18	<0.001
Sex						
Males	2.53	1.68-3.80	<0.001	2.54	1.56-4.13	<0.001
Females	2.54	1.8-3.58	<0.001	3.41	2.21-5.26	<0.001
Age group						
6-11 years	2.17	1.48-3.17	<0.001	2.73	1.54-4.84	0.001
12-17 years	2.74	1.79-4.19	<0.001	2.77	1.78-4.29	<0.001
BMI categories						
Normal weight	2.88	2.07-4.01	<0.001	3.16	2.08-4.80	<0.001
Overweight and obese	2.43	1.56-3.79	<0.001	2.76	1.69-4.49	<0.001
Height categories						
<P50	3.17	1.92-5.23	<0.001	2.87	1.67-4.95	<0.001
≥P50	2.34	1.71-3.21	<0.001	2.94	1.95-4.42	<0.001
	Childhood Hypertension					
	Simplified definition			Complex definition		
	HR	95% CI	*P* value	HR	95% CI	*P* value
All	3.21	2.07-4.96	<0.001	2.20	1.47-3.30	<0.001
Sex						
Males	3.15	1.71-5.83	<0.001	2.02	1.08-3.81	0.029
Females	3.11	1.56-6.21	0.001	2.27	1.31-3.96	0.004
Age group						
6-11 years	2.27	1.07-4.84	0.033	1.20	0.61-2.34	0.594
12-17 years	3.41	1.67-6.93	0.001	4.25	2.26-8.00	<0.001
BMI categories						
Normal weight	4.06	2.25-7.32	<0.001	3.06	1.73-5.40	<0.001
Overweight and obese	2.38	1.13-5.00	0.022	1.59	0.83-3.04	0.163
Height categories						
<P50	7.98	3.39-18.79	<0.001	3.97	2.01-7.82	<0.001
≥P50	2.20	1.23-3.95	0.008	1.47	0.82-2.63	0.194

Sex, age, race, and childhood BMI were included in the models for adjustment.

Table S7. Performance of the simplified definition (vs. the complex definition) to predict adult hypertension and subclinical CVD based on the reclassification method

Outcome	Childhood elevated BP [*]
	Simplified definition vs. Complex definition
Hypertension	
NRI, %	1.13
P value	0.441
High PWV	
NRI, %	2.70
P value	0.129
High CIMT	
NRI, %	2.41
P value	0.150
LVH	
NRI, %	-0.70
P value	0.743
Any subclinical CVD	
NRI, %	2.17
P value	0.115

CVD, cardiovascular disease; PWV, pulse wave velocity; CIMT, carotid intima-media thickness; LVH, left ventricular hypertrophy; NRI, net reclassification improvement

[*] Elevated BP includes pre-hypertension and hypertension

Table S8. Performance of the two definitions for pediatric elevated BP (including hypertension and pre-hypertension) to predict hypertension and subclinical CVD in adulthood based on ROC curve analysis

Outcome	Childhood elevated BP *	
	Simplified definition	Complex definition
Hypertension		
Sensitivity,%	36.9	32.1
Specificity,%	81.7	85.3
PPV,%	36.4	38.3
NPV,%	82.0	81.6
AUC(95% CI)	0.59 (0.56-0.62)	0.59 (0.56-0.62)
P value for AUC difference	0.442	
High PWV		
Sensitivity,%	26.8	20.7
Specificity,%	78.6	82.0
PPV,%	23.9	22.3
NPV,%	81.1	80.5
AUC(95% CI)	0.53 (0.49-0.56)	0.51 (0.48-0.54)
P value for AUC difference	0.130	
High CIMT		
Sensitivity,%	31.6	25.9
Specificity,%	80.1	83.4
PPV,%	28.5	28.1
NPV,%	82.4	81.8
AUC(95% CI)	0.56 (0.53-0.59)	0.55 (0.52-0.58)
P value for AUC difference	0.151	
LVH		
Sensitivity,%	33.3	30.4
Specificity,%	80.2	83.8
PPV,%	19.3	21.0
NPV,%	89.5	89.5
AUC(95% CI)	0.57 (0.53-0.61)	0.57 (0.53-0.61)
P value for AUC difference	0.744	
Any subclinical CVD		
Sensitivity,%	28.8	23.5
Specificity,%	81.9	85.0
PPV,%	55.6	55.2
NPV,%	59.3	58.5
AUC(95% CI)	0.55 (0.53-0.58)	0.54 (0.52-0.57)
P value for AUC difference	0.115	

PPV, positive predictive value; NPV, negative predictive value; AUC, area under curve; CVD, cardiovascular disease; PWV, pulse wave velocity; CIMT, carotid intima-media thickness; LVH, left ventricular hypertrophy

* Elevated BP includes pre-hypertension and hypertension