RESEARCH PAPER

Oscillometric Blood Pressure in Indian School Children: Simplified Percentile Tables and Charts

RAJIV NARANG, ANITA SAXENA, S RAMAKRISHNAN, [#]SN DWIVEDI AND [*]ARVIND BAGGA
From the Departments of Cardiology, [#]Biostatistics and [*]Pediatrics, All India Institute of Medical Sciences, New Delhi, India.
Correspondence to: Dr Anita Saxena, Professor, Department of Cardiology, All India Institute of Medical Sciences, New Delhi 110 029, India. anitasaxena@hotmail.com
Received: January 29, 2015; Initial review: April 30, 2015; Accepted: August 28, 2015.

Background: Data on blood pressure recorded by oscillometric method is limited.

Objective: To develop simplified tables and charts of blood pressure recorded by oscillometric method in children.

Design: Cross-sectional.

Setting:Ballabhgarh, Haryana.

Participants: Healthy school-children.

Main outcome measures: Blood pressure measured by oscillometric method.

Results: The study group included 7,761 children (58.4% males) with mean (SD) age of 10.5 (2.8) years. Age and gender were used to create simplified percentile tables and charts, as height was seen to explain very little variability of either systolic or diastolic blood pressure. Formulae for SBP and DBP thresholds for hypertension were derived as [110 + 1.6 x age] and [79 + 0.7 x age], respectively, with 1 mm Hg to be added for females. 95^{th} percentile values suggest simple levels indicating hypertension to be 120/80, 125/85 and 135/90 at ages of 5, 10 and 15 years, respectively.

Conclusions: Simplified reference tables and charts, formulae for SBP and DBP, and simple convenient thresholds may be useful for rapid screening of hypertension using oscillometric method.

Keywords: *Assessment, Hypertension, Oscillometry, Screening.*

In recent years, need for regular and accurate recording of blood pressure in children is being stressed upon, since hypertension is often under-diagnosed in them [1-3]. There have been a number of studies from different parts of the world to determine normal blood pressure values for children [4-6]. The complexity of current standard tables is mainly due to inclusion of height adjustment and height percentile needs to be known beforehand. This is in stark contrast to blood pressure reference level in adults, where one value has been given for all people, irrespective of age, gender, height, weight, waist circumference etc, although these factors affect the blood pressure in adults also.

Oscillometric measurement of blood pressure has the advantage of ease, accuracy, reliability, reproducibility and freedom from observer bias [8-10]. Moreover, it avoid the controversy regarding the use of phase 4 *versus* phase 5 Korotkoff sounds as indicator of diastolic blood pressure. Hence, this method is regarded as a promising approach for BP assessment in children. Although, oscillometry is now widely used for blood pressure measurement, data on its reference values in normal children is limited. In the present study, we aim to provide normal reference values for blood pressure in Indian children, measured using oscillometric method, and attempt to simplify these reference values so that they can be used more widely.

METHODS

This cross-sectional epidemiological study was conducted in a rural area in Ballabhgarh, Haryana, as part of a rheumatic heart disease screening program [12]. Twenty-eight villages with a total population of 85,000 are covered under a government-funded Comprehensive Rural Health Services Project (CRHSP) running in this area. The estimated number of children aged 5 to15 years attending the various schools under this project was approximately 20,000. For this study, we used a cluster sampling method. We randomly selected ten of these 28 villages and enrolled all the children studying in both government and private schools of these ten villages. A total of 8,445 children were enrolled during a 2-year period (enrollment rate of 42%). Consent to take part in the study was taken from the parents. Parents of only two children refused to take part in the study. Study was approved by the Institutional ethics committee of AIIMS. Children with known major hepatic, renal, cardiac or respiratory diseases were excluded. Children with heart rate below 50 or above 150 and those with any missing data were excluded. No child was excluded based on blood pressure reading. Finally, 7761 children were included in this analysis.

During the survey, paramedical staff documented demographic and anthropometric data, including height, weight and waist-circumference. Children sat and rested for 5 minutes before blood pressure measurement. Blood pressure was measured in sitting position by trained field investigators or research fellows using Omron HEM 7080 automatic oscillometric instruments. Field investigators were trained for BP measurements specifically for this study. Their measurement variability had to be less than 5 mm Hg to be satisfactory. The instruments were calibrated and regularly checked against mercury sphygmomanometer for accuracy. Cuff sizes of 10.5×18.5 and 13×30 cm provided by same company as instrument were used for younger and older children, respectively. Children with abnormal blood pressure readings underwent repeat blood pressure measurements by research physicians.

Method of defining hypertension and its stages was same as that used by the National High Blood Pressure Education Program Working Group [4]. Accordingly, ≥90th percentile is considered normal blood pressure, while values ≥90th and <95th percentile are taken as high normal or prehypertension. Values ≥95th percentile and <99th percentile plus 5 mm Hg indicate stage 1 hypertension, while those ≥99th percentile plus 5 mm Hg are stage 2 hypertension. Hence, 90th and 95th percentiles are thresholds for prehypertension and hypertension (stage 1), respectively, while 5 mm Hg above 99th percentile is threshold for stage 2 hypertension.

Statistical analysis: Univariate analysis between blood pressure and age, height, weight and waist-circumference was performed with Pearson's correlation method, and gender difference were tested with Student's *t*-test. P-values less than 0.05 were regarded as significant. Multiple regression analysis was performed to determine independent predictors. Age- and gender-specific percentile curves for systolic blood pressure (SBP) and diastolic blood pressure (DBP) were generated using LMS (Lamda-Mu-Sigma) method. Statistical package R version 3.1.2 was used for analyses (*http://www.r-project.org/*).

RESULTS

A total of 7761 children (58.4% males) with a mean (SD) age 10.5 (2.8) years were studied. The mean age did not differ between males and females. ***Table* I** shows anthropometric and blood pressure parameters of children grouped by age and gender. SBP and DBP progressively increased with age though increase was attenuated in males after 10 years of age. DBP was significantly higher in females after 10 years of age.

Univariate analysis showed a weak but statistically signficant correlation of height and weight with blood pressure. Multiple regression analysis was performed with age, gender, height, weight and waist-circumference as predictor variables. Age, gender, height and weight but not waist were found to be independent predictor of systolic blood pressure. Age, height and weight had a positive effect on SBP and female gender was associated with higher SBP. For DBP, gender, weight and waist circumference, but not age and height, were found to be independently predictors. DBP directly correlated with weight and waist circumference and was higher in females.

Addition of height to age and gender in multivariable regression model lead to only a minimal improvement in variance of SBP explained (R^2 of 0.136 *versus* 0.11). For DBP, the variance explained was much poorer. The R-squared was only 0.03 with age and gender in the model and 0.04 after addition of height. Similar conclusion was reached on comparing AIC and BIC values. Performing stepwise regression, polynomial regression and adding interactions did not improve the model for either SBP or DBP. Similar results were obtained when height percentile was used. Moreover, there was close and almost linear correlation between age and height (r=0.88, 0.88 and 0.87 for whole group, males and females, respectively, $p<0.00001$ for each). In view of these results and to simplify the tables, percentile were prepared for age and gender only, without incorporating height adjustment. ***Table* 2** and ***Figures* 1** & **2** shows these percentile values. Since definition of hypertension depends on 90th, 95th and 99th percentiles, annotated curves for these percentiles of SBP and DBP for boys and girls are shown (***Fig*. 3**). A review of 95th percentile values suggest levels indicating hypertension to be 120/80, 125/85 and 135/90 at ages of 5, 10 and 15 years, respectively.

Using coefficients obtained from regression analysis, formulae were derived for quick estimation of hypertension thresholds (i.e. 95th percentile) for a given age. For SBP, threshold for hypertension (in mm Hg) equaled [110 + 1.6 × age] while that for DBP was [79 + 0.7 × age]. Both values are to be incremented by 1 mm Hg for females. To derive other thresholds, means of the differences between percentiles at different ages for both genders was determined. For SBP, the mean (SD) difference between 90th and 95th percentile was 4(0) mm

TABLE I ANTHROPOMETRIC AND HEMODYNAMIC PARAMETERS OF CHILDREN BY AGE AND GENDER

Age (y)	N	Height	Weight	BMI	Waist	SBP	DBP
Girls							
5	68	110.5 (5.2)	17.9 (3.0)	14.6 (1.7)	45.3 (5.0)	99.8 (10.2)	66.9 (10.2)
6	237	113.7 (6.5)	18.6 (3.7)	14.6 (2.2)	45.4 (6.1)	102.6 (10.7)	67.4 (9.2)
7	292	117.0 (6.3)	19.8 (3.7)	14.4 (2.0)	44.9 (5.9)	103.0 (10.7)	67.8 (9.8)
8	334	123.5 (8.1)	23.0 (5.8)	15.0 (2.6)	47.3 (7.2)	105.4 (10.9)	69.6 (9.2)
9	358	128.1 (7.5)	25.5 (6.2)	15.5 (2.7)	48.0 (6.5)	106.8 (11.1)	69.9 (9.7)
10	353	132.6 (7.8)	27.8 (6.8)	15.6 (2.6)	49.6 (6.6)	107.2 (10.5)	69.8 (9.4)
11	310	139.2 (8.8)	32.2 (8.5)	16.4 (2.9)	51.8 (7.4)	110.6 (10.6)	71.5 (9.7)
12	352	144.5 (8.0)	34.57 (2.9)	16.5 (2.9)	52.5 (6.4)	111.5 (10.9)	71.6 (9.7)
13	358	149.8 (7.5)	39.9 (8.7)	17.7 (3.2)	55.7 (7.9)	114.0 (11.9)	72.7 (10.4)
14	293	152.5 (7.2)	43.2 (7.8)	18.5 (2.9)	57.0 (7.1)	114.3 (11.6)	74.1 (9.5)
15	275	153.7 (6.5)	44.6 (6.9)	18.9 (2.9)	57.8 (7.3)	115.0 (10.5)	74.8 (9.2)
Boys							
5	132	110.9 (5.8)	17.8 (2.8)	14.4 (1.8)	44.7 (4.8)	103.3 (10.0)	67.3 (9.7)
6	302	113.5 (6.4)	19.1 (3.6)	14.7 (1.9)	46.0 (5.8)	102.8 (10.4)	67.7 (9.3)
7	377	118.1 (6.4)	20.7 (3.7)	14.7 (1.8)	46.7 (5.9)	104.6 (10.0)	67.8 (9.7)
8	431	124.0 (7.4)	23.7 (5.8)	15.2 (2.4)	48.5 (7.3)	105.2 (10.5)	68.7 (9.4)
9	419	128.6 (7.6)	25.8 (6.0)	15.5 (2.4)	49.9 (6.9)	106.8 (10.3)	70.0 (9.4)
10	563	133.1 (8.0)	28.0 (6.9)	15.7 (2.6)	50.8 (7.7)	107.0 (10.6)	69.9 (9.6)
11	463	138.1 (8.2)	31.0 (7.9)	16.1 (2.7)	53.0 (8.2)	107.7 (10.4)	70.1 (0.7)
12	565	143.4 (8.9)	34.8 (8.6)	16.8 (3.1)	55.2 (8.8)	109.2 (10.9)	69.9 (10.0)
13	465	150.7 (9.8)	39.5 (9.7)	17.2 (3.1)	57.9 (9.3)	111.4 (11.5)	71.0 (9.8)
14	412	158.1 (9.2)	45.0 (11.1)	17.8 (3.3)	60.9 (10.3)	113.8 (12.4)	71.5 (10.3)
15	429	162.9 (8.7)	47.9 (10.0)	18.0 (3.3)	61.1 (9.3)	114.2 (11.8)	71.0 (9.8)

Values in mean (SD). BMI: body mass index; SBP: systolic blood pressure; DBP: diastolic blood pressure.

Hg, while that between 95th and 99th percentile was 8(1) mm Hg. Corresponding values for DBP were 4(0) and 7(0), respectively. Threshold for prehypertension was 4 mm Hg below hypertension thresholds for both SBP and DBP. Threshold for stage 2 hypertension was 13 and 12 mm Hg above hypertension thresholds for SBP and DBP, respectively.

DISCUSSION

This study shows that blood pressure increases with age, though the rise varied at different ages and differed in boys *versus* girls, especially with onset of adolescence. Univariate and multivariate analysis showed that, though height is significantly correlated with both systolic and diastolic blood pressures, its contribution is small. Hence, simplified blood pressure tables and charts based on age and gender only are presented here.

There are several limitations of our study. Ideally, blood pressure should be recorded on serial follow-up of a cohort of children. However, this design will require much longer period of study and more resources. Almost all similar studies have compared one-time blood pressure in children of different ages. Variability or concordance values during the training period were not recorded. Cuff-sizes were not strictly as per Task Force recommendations, though our method of using only two cuffs was practical and may make the process of BP recording simpler. Although oscillometric instruments were regularly checked against mercury sphygmomanometer, a rigorous standardization protocol was not used. We also could not explain the lack of smooth progression of blood pressure with age, though onset of puberty may contribute to an altered pattern. There is a possibility of regression dilution due to measurement error as the cause of deviant univariate analysis of height *versus* blood pressure. The probability of measurement error is also there due to lack of strict internal validity.

TABLE II PERCENTILES OF SYSTOLIC AND DIASTOLIC BLOOD PRESSURE BY AGE AND GENDER

	Systolic blood pressure									*Diastolic blood pressure*								
	Girls									*Girls*								
Age	p1	p5	p10	p25	p50	p75	p90	p95	p99	p1	p5	p10	p25	p50	p75	p90	p95	p99
5	76	83	87	93	100	108	114	118	125	45	51	55	60	67	73	79	82	89
6	77	84	88	95	102	109	116	120	127	46	52	55	61	67	74	80	83	90
7	79	86	90	96	103	111	117	121	129	46	53	56	62	68	75	80	84	91
8	80	87	91	98	105	112	119	123	130	47	53	57	63	69	75	81	85	91
9	82	89	93	99	107	114	120	124	132	48	54	57	63	70	76	82	86	92
10	83	90	94	101	108	115	122	126	133	48	55	58	64	70	77	83	86	93
11	85	92	96	103	110	117	124	128	136	49	55	59	65	71	78	83	87	94
12	86	94	98	104	112	119	126	130	138	50	56	59	65	72	78	84	88	95
13	87	95	99	106	113	121	128	132	140	50	57	60	66	73	79	85	89	96
14	89	96	100	107	114	122	129	133	141	52	58	61	67	74	80	86	90	97
15	89	97	101	108	115	123	129	133	141	53	59	63	68	75	81	87	97	
	Boys									*Boys*								
5	79	86	90	96	103	109	116	119	126	46	52	55	61	67	74	79	83	89
6	80	87	90	97	103	110	116	120	127	46	52	56	61	68	74	80	83	90
7	81	88	91	97	104	111	117	121	128	46	53	56	62	68	75	80	84	90
8	81	88	92	98	105	112	119	122	129	47	53	57	62	69	75	81	85	91
9	82	89	93	99	106	113	120	123	131	47	54	57	63	69	76	82	85	92
10	83	90	94	100	107	114	121	124	132	48	54	58	63	70	78	82	86	93
11	83	90	94	101	108	115	122	126	133	48	54	58	63	70	77	83	86	93
12	84	91	95	102	109	117	124	128	135	48	54	58	64	70	77	83	87	93
13	85	93	97	104	111	119	126	130	138	48	55	58	64	71	77	84	87	94
14	86	94	98	105	113	121	128	132	141	46	55	58	64	71	78	84	88	95
15	87	95	99	106	115	123	130	135	143	48	55	59	64	71	78	84	88	95

p1 to p99 indicate 1st to 99th percentile.

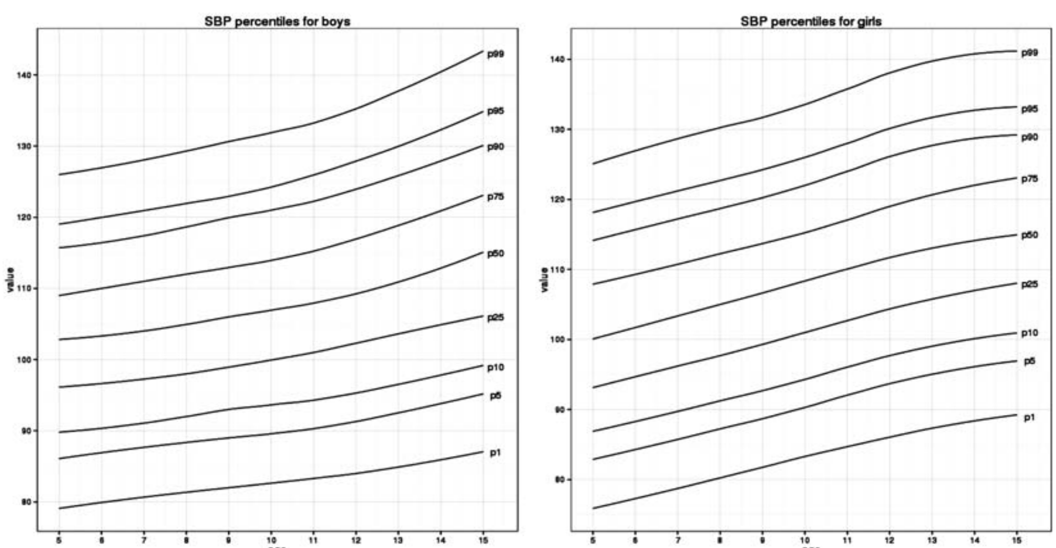

FIG. 1 *Systolic blood pressure (SBP) percentiles for boys and girls.*

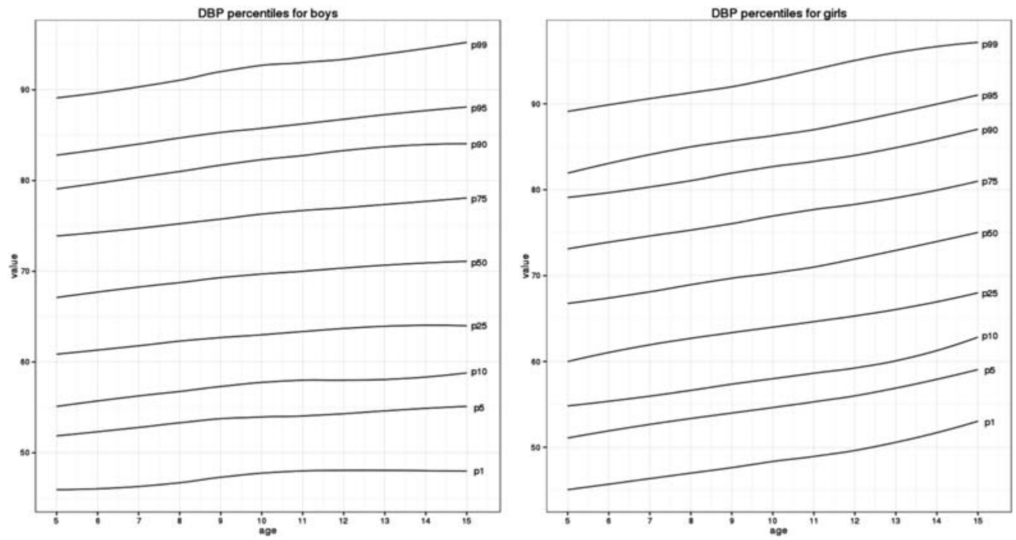

FIG. 2 *Diastolic blood pressure (DBP) percentiles for boys and girls.*

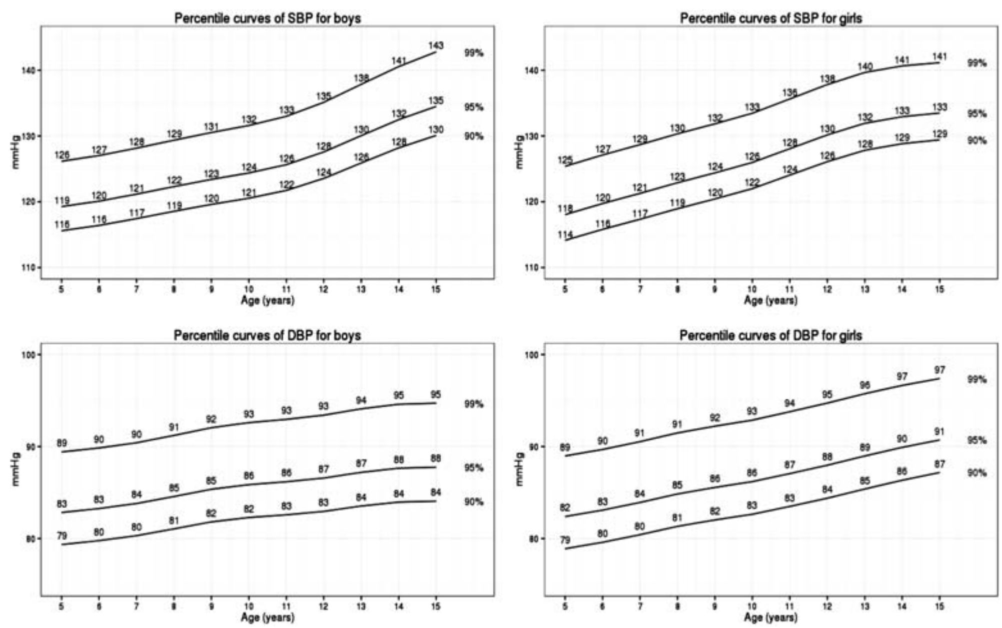

FIG. 3 *Annotated 90th, 95th and 99th percentile curves for systolic (SBP) and diatolic (DBP) for boys and girls. Normal blood pressure is below 90th percentile, prehypertension is from 90th to below 95th percentile, stage 1 hypertension is from 95th to below 99th percentile plus 5 mm Hg, while stage 2 hypertension starts from 99th percentile plus 5 mm Hg.*

Our findings are similar to those of Jackson, *et al*. [13] who reported blood pressure centiles from UK and presented charts based on age and gender only. They found weight to have a large and positive effect on blood pressure while height had a small negative effect. They also found that height and weight explained only 8% variance of systolic and even lower (0.5%) variance of diastolic blood pressure. Others have also attempted to develop simple blood pressure values for easy application. Kaelber and Pickett developed a simple BP table from the standard tables of the Fourth report [7]. Their simple blood pressure table had single blood pressure threshold values for each age and gender, thereby reducing the number of values from 476 to 64. Zuijdwijk, *et al*. [14] studied the sensitivity and specificity of these tables. They categorized patients as normotensive and hypertensive based on standard and simple tables in a retrospective cohort study. The

WHAT IS ALREADY KNOWN?

- Normal blood pressure standard in children is difficult to apply in busy clinics.

WHAT THIS STUDY ADDS?

- Normal blood pressure as measured by oscillometric method in Indian children is presented as simplified tables, charts, formulae and convenient thresholds.

sensitivities were 100% and 100% and specificities were 61% and 81% for identification of hypertension and abnormal blood pressure values, respectively. They concluded that this simple table is an effective screening tool. This is the first study from South Asian region to attempt simplification of hypertension threshold values.

Detection and control of hypertension in children has implications in terms of long-term cardiovascular morbidity and mortality [15]. Tracking of blood pressure from childhood to adulthood has been documented [11,16]. Elevated BP in children has also been linked to atherosclerotic plaques in adults [17,18]. Blood pressure screening and treatment in adolescents have been found to be cost-effective [19]. In adults, cut-off values were given for different stages of blood pressure by Sixth Joint National Committee (JNC-6) guidelines [20]. JNC-7 simplified these and recommended 120/80, 140/90 and 160/100 as thresholds for prehypertension, stage 1 hypertension and stage 2 hypertension, respectively [21]. All these are simple, round values which are easy to remember and hence easy to apply, aiding in widespread screening and treatment of hypertension in adults. These are used despite the fact that the blood pressure in adults also depends on age, gender, height, weight and waist circumference, and percentile curves for adults do not give only round values [22-25]. Similar simple, convenient values need to be developed for children so that screening of hypertension becomes easier and more practical.

Our study provides current distribution of systolic and diastolic blood pressure in Indian children as recorded using oscillometric method, which is fast becoming the universal mode of recording of these hemodynamic parameters. Simplified percentile tables and charts are developed using age and gender only. These methods are easier to apply than standard tables and may be used as screening tools to improve early detection and categorization of hypertension in children, after validation in clinical settings.

Acknowledgements: Gourav Kanogiya and Ravindra Singh Mehta, Research Staff, for helping with the study.

Contributors: RN: contributed to analysis, interpretation and manuscript preparation; AS: concept and design, data acquisition, interpretation, final approval; SR: supervision and intellectual content; SND: statistical analysis; AB: editing manuscript for important intellectual content.

Funding: Restricted funding from Indian Council of Medical Research. *Competing interest*: None stated.

REFERENCES

1. Bassareo PP, Mercuro G. Pediatric hypertension: An update on a burning problem. World J Cardiol. 2014;6:253-9.
2. Chiolero A. The quest for blood pressure reference values in children. J Hypertens. 2014;32:477-9.
3. Hansen ML, Gunn PW, Kaelber DC. Underdiagnosis of hypertension in children and adolescents. JAMA. 2007;298:874-9.
4. National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents. The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. Pediatrics. 2004;114:555-76.
5. Barba G, Buck C, Bammann K, Hadjigeorgiou C, Hebestreit A, Mårild S, *et al*. Blood pressure reference values for European non-overweight school children: the IDEFICS study. Int J Obes. 2005. 2014;38:S48-56.
6. Raj M, Sundaram R, Paul M, Kumar K. Blood pressure distribution in Indian children. Indian Pediatr. 2010;47:477-85.
7. Kaelber DC, Pickett F. Simple table to identify children and adolescents needing further evaluation of blood pressure. Pediatrics. 2009;123:e972-4.
8. Ostchega Y, Zhang G, Sorlie P, Hughes JP, Reed-Gillette DS, Nwankwo T, *et al*. Blood pressure randomized methodology study comparing automatic oscillometric and mercury sphygmomanometer devices: National Health and Nutrition Examination Survey, 2009-2010. Natl Health Stat Rep. 2012;59:1-15.
9. Chiolero A, Paradis G, Lambert M. Accuracy of oscillometric devices in children and adults. Blood Press. 2010;19:254-9.
10. Gillman MW, Cook NR. Blood pressure measurement in childhood epidemiological studies. Circulation. 1995;92:1049-57.
11. Chen X, Wang Y, Appel LJ, Mi J. Impacts of measurement protocols on blood pressure tracking from childhood into adulthood: a metaregression analysis. Hypertension. 2008;51:642-9.
12. Saxena A, Ramakrishnan S, Roy A, Seth S, Krishnan A, Misra P, *et al*. Prevalence and outcome of subclinical rheumatic heart disease in India: the RHEUMATIC

(Rheumatic Heart Echo Utilisation and Monitoring Actuarial Trends in Indian Children) study. Heart Br Card Soc. 2011;97:2018-22.
13. Jackson LV, Thalange NKS, Cole TJ. Blood pressure centiles for Great Britain. Arch Dis Child. 2007;92:298-303.
14. Zuijdwijk C, Feber J, Murnaghan O, Nakhla M. Detection of hypertension and prehypertension in paediatric patients with type 1 diabetes using a simple blood pressure table. Paediatr Child Health. 2013;18:461-4.
15. Sundström J, Neovius M, Tynelius P, Rasmussen F. Association of blood pressure in late adolescence with subsequent mortality: cohort study of Swedish male conscripts. BMJ. 2011;342:d643.
16. Chen X, Wang Y. Tracking of blood pressure from childhood to adulthood: a systematic review and meta-regression analysis. Circulation. 2008;117:3171-80.
17. Raitakari OT, Juonala M, Kähönen M, Taittonen L, Laitinen T, Mäki-Torkko N, *et al*. Cardiovascular risk factors in childhood and carotid artery intima-media thickness in adulthood: the Cardiovascular Risk in Young Finns Study. JAMA. 2003;290:2277-83.
18. Berenson GS, Srinivasan SR, Bao W, Newman WP, Tracy RE, Wattigney WA. Association between multiple cardiovascular risk factors and atherosclerosis in children and young adults. The Bogalusa Heart Study. N Engl J Med. 1998;338:1650-6.
19. Wang YC, Cheung AM, Bibbins-Domingo K, Prosser LA, Cook NR, Goldman L, *et al*. Effectiveness and cost-effectiveness of blood pressure screening in adolescents in the United States. J Pediatr. 2011;158:257-64.e1–7.
20. The sixth report of the Joint National Committee on prevention, detection, evaluation, and treatment of high blood pressure. Arch Intern Med. 1997;157:2413-46.
21. Chobanian AV, Bakris GL, Black HR, Cushman WC, Green LA, Izzo JL, *et al*. Seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure. Hypertension. 2003;42:1206-52.
22. Sive PH, Medalie JH, Kahn HA, Neufeld HN, Riss E. Correlation of weight-height index with diastolic and with systolic blood pressure. Br J Prev Soc Med. 1970;24:201-4.
23. Levine DA, Calhoun DA, Prineas RJ, Cushman M, Howard VJ, Howard G. Moderate waist circumference and hypertension prevalence: the REGARDS Study. Am J Hypertens. 2011;24:482-8.
24. Reckelhoff JF. Gender differences in the regulation of blood pressure. Hypertension. 2001;37:1199-208.
25. Balijepalli C, Lösch C, Bramlage P, Erbel R, Humphries KH, Jöckel K-H, *et al*. Percentile distribution of blood pressure readings in 35683 men and women aged 18 to 99 years. J Hum Hypertens. 2014;28:193-200.