National Blood Pressure Reference for Chinese Han Children and Adolescents Aged 7 to 17 Years

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Abstract—We sought to develop and validate a national blood pressure (BP) reference based on age, sex, and height for Chinese children. Data were obtained on 197 430 children aged 7 to 17 who participated in the Chinese National Survey on Students' Constitution and Health in 2010. BP percentiles were estimated and fitted using the lambda, mu, and sigma method and then compared with a US reference and China existing reference. In an external independent validation sample of 59 653 children aged 7 to 18 from 7 Chinese provinces in 2013, the prevalence of elevated BP was compared applying the 3 references. BP values were similar for boys and girls at the younger ages (7–13 years) and lower height percentiles, whereas higher at the older ages (14–17 years) for boys than girls. At medial height in boys and girls aged 7 to 13, the 50th, 90th, 95th, and 99th percentiles of BP for the new national reference were consistent with US reference and lower than current Chinese reference. In the independent sample, elevated BP prevalence, based on the new national reference, ranged from 7.8% to 18.5% among children aged 7 to 17, which was higher than the US reference values (4.3%–14.5%) and lower than the current Chinese reference (12.9%–25.5%) in each age group. The new national BP reference for Chinese children based on age, sex, and height from large-scale and nationally representative data seems to improve the ability for identifying Chinese hypertensive children and for stratifying them with regard to cardiovascular risk. **(*Hypertension*. 2017;70:897-906. DOI: 10.1161/HYPERTENSIONAHA.117.09983.)** ● **Online Data Supplement**

Key Words: blood pressure ■ China ■ hypertension ■ prevalence ■ students

Hypertension or elevated blood pressure (BP) is an important risk factor for cardiovascular disease, causing >7 million deaths worldwide each year.[1] In China, 2.043 million deaths, including 1.154 million men and 0.889 million women, were ascribed to hypertension in 2010, accounting for 24.6% of all deaths. In 2013, the total expenditure on health was 3186.9 billion RMB (Renminbi, Chinese legal tender) in China; the proportional cost for the direct economic burden of hypertension was 6.61%.[2] Elevated BP remains the most important individual risk factor related to cardiovascular disease burden in China.[2,3]

Hypertension, once considered a rare disease in children,[4] is now considered a major public health problem worldwide.[5,6] Hypertension can be progressive throughout childhood into adulthood, and elevated BP in childhood is the strongest predictor of hypertension in adulthood.[7–12] Therefore, it is important to recognize BP abnormalities in young people for improving and streamlining pediatric primary care.

There is no national BP reference for Chinese children that considers the influence of height. Height is relevant because of the additional pressure needed to overcome gravity to perfuse the brain.[13] The Chinese Capital Institute of Pediatrics (CIP) reference has been developed previously.[14] It used local data, which may lead to some bias because of regional disparities in China. On the basis of the locally informed Chinese CIP reference, the prevalence of elevated BP reported in 2010 national children's population was 16.1% and 12.9% for Chinese boys and girls, respectively.[14,15] On the basis of the same population above, using a United States–based BP reference[16] (which is from 2004 Fourth Report based on 1999–2000 National Health and Nutrition Examination Surveys data using 83 091 children and adolescents to establish BP criteria adjusting for age, sex, and height; and used among children and adolescents broadly not only in the United States but also worldwide), the prevalence of elevated BP for boys and girls was 6.8% and 5.8%, respectively.[16,17] With >2-fold differences in the estimates, further examination of the Chinese youth BP standards is needed.

The US reference has been widely applied to screening elevated BP in Chinese children, despite large national differences in height and weight for youth, especially for older adolescents. A national BP reference for Chinese children based on age, gender, and height is urgently needed, which should be developed using large-scale representative data and validated with an independent dataset. In addition to being clinically useful, a national BP standard may help researchers and health policymakers develop targeted intervention strategies.

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The objectives of the present study were to (1) develop a national BP reference based on age, sex, and height for Chinese children, (2) compare BP percentiles developed from the present study with values based on US and local Chinese references, and (3) validate the new national BP reference in an independent data set from China.

Methods

Study Samples

Data were drawn from 2 projects with school-aged youth in China, both adhered to the principles of the Declaration of Helsinki and the Code of Federal Regulations. Both projects were approved by the Medical Research Ethics Committee of the Peking University Health Science Center (IRB00001052-13082, IRB00001052-13034). Informed consent was obtained from both children and their parents. The procedures of 2 projects followed were in accordance with the guidelines, details of which have been published previously.[18,19] In brief, data were anonymized and deidentified before analysis to protect their privacy. For both projects, the students underwent a complete medical examination before data collection and were excluded if they had ≥1 of the following conditions: (1) serious organ disease (eg, heart, lung, liver, kidney); (2) abnormal physical development (eg, dwarfism, gigantism); (3) physical impairment or deformity (eg, severe scoliosis, pectus carinatum, limp, obvious O leg, X leg); or (4) acute disease symptoms (eg, diarrhea, high fever) during the past month and not yet recovered.

To develop the new national BP reference, we used data from the 2010 Chinese National Survey on Students' Constitution and Health (CNSSCH), which is the largest nationally representative survey of school-age children in China. The CNSSCH is a successive cross-sectional survey designed to investigate health status in Chinese school-aged children since 1985; the sampling procedures have been published previously.[18] Briefly, all participants were selected by stratified cluster sampling; that is, sampling took place in classes selected randomly from each grade in the selected schools. Sampling yielded equal numbers at 3 socioeconomic strata (ie, upper, moderate, low) at the regional level defined by regional gross domestic product, total yearly income per capita, average food consumption per capita, natural growth rate of population, and the regional social welfare index. The present study only included data from Han children aged 7 to 17 years. Data were from 26 mainland provincial capital cities and 4 municipalities, excluding Tibet (where the Han ethnicity is in the minority). All eligible participants had lived in the same area for at least 1 year. A total of 197 669 participants had complete records on age, sex, urban/rural area, systolic BP (SBP), and diastolic BP (DBP). In each sex/age subgroup, there were nearly 9000 participants and the ratio of urban/rural approximated 1:1.

To validate the new national reference, we analyzed data from an independent cross-sectional study conducted in 7 provinces of China: Liaoning, Tianjin, Ningxia, Shanghai, Chongqing, Hunan, and Guangdong. The survey was conducted in September 2013 and adopted a standardized and uniform research protocol, described in detail previously.[19] In short, a multistage cluster random sampling was used to obtain a representative sample of children and adolescents aged 7 to 18 years. Several districts from each province were randomly selected in the first stage. In the second stage, ≈12 to 16 schools were chosen from each district with equal numbers by school level (primary/secondary) and urban/rural classification. Within the selected schools, 2 classrooms per grade were randomly selected by a staff member not involved in the survey; all students aged 6 to 18 years were considered eligible in the selected classrooms. A total of 59 653 participants aged 7 to 18 years had complete records on SBP and DBP.

Physical Examination

Participants in the 2010 CNSSCH underwent a complete anthropometric evaluation. Height (cm), weight (kg), and BP (mm Hg) were measured by a team of trained technicians following a standardized procedure. Height was measured to the nearest 0.1 cm with a portable stadiometer, and weight was measured to the nearest 0.1 kg with a standardized scale. Both the stadiometers and scales were calibrated before use. Body mass index (BMI) was calculated as body weight (kg) divided by height (m) squared (kg/m^2). Obesity was defined using the references developed by the WGOC (Working Group on Obesity in China).[20] Children and adolescents with BMI at or exceeding the 95th age- and sex-specific BMI percentile values were defined as obese. For both boys and girls aged 18 years, those with observed BMI ≥28 kg/m^2 were considered obese.

BP was measured according to the recommendation of the National High Blood Pressure Education Program Working Group in Children and Adolescents, using an auscultation mercury sphygmomanometer (model XJ1ID, China) with an appropriate cuff for children. We chose an appropriate cuff with an inflatable bladder width that is at least 40% of the arm circumference at a point midway. And the cuff bladder length covered 80% to 100% of the circumference of the arm. The cuff was placed ≈2 cm above the crease of the right arm elbow. The child was seated comfortably for at least 10 minutes before the first reading. The feet of children were placed on a platform during BP measurement. SBP was determined by onset of the first Korotkoff sound (K1), and DBP was determined by the fifth Korotkoff sound (K5). An average of 3 BP measurements at a single visit was calculated for each child. Measurements at the survey site were conducted by a team of field professionals who had passed a training course in anthropometric measurements.

Data Management

The data were checked for logicality and integrity and had to meet the condition that SBP was greater than DBP. In addition, extreme values of BP were excluded (ie, >5 SDs from the sex- and age-specific mean). On the basis of data cleaning of the 2010 CNSSCH, 239 observations (0.07%) were removed leaving a final sample of 197 430, evenly distributed by age and sex (Table S1 in the online-only Data Supplement). In the validation database, 102 observations (0.17%) were removed, leaving 59 653 observations for analysis.

Height Percentiles Reference

Height percentiles (5th, 10th, 25th, 50th, 75th, 90th, and 95th) were computed by age and sex (Table 1). The reference sample was divided into 176 groups: 8 height percentiles, with 11 age groups, for boys and girls. BP levels and classification were determined for the new Chinese national BP reference for each sex/age/height percentile subgroup.

Statistical Analyses

The new Chinese national reference curves for BP by age, sex, and height were estimated and fitted using the lambda, mu, and sigma method,[21] with the program Lambda, Mu, and Sigma Chart Maker Pro 2.3. The parameters in the lambda, mu, and sigma method are presented in Table S2. The SBP and DBP values were calculated for the percentiles of 50th, 90th, 95th, and 99th and height percentiles for 5th, 10th, 25th, 50th, 75th, 90th, and 95th for boys and girls.

The calculated Chinese national SBP and DBP percentile values (50th, 90th, 95th, and 99th) were compared with the percentile values of the US reference[16] and the Chinese CIP reference[14] at median height. We created smoothed age-, sex- and height-specific SBP and DBP percentile value curves and compared the values to those from the US reference based on the Center for Disease Control growth charts in 2000 (www.cdc.gov/growthcharts), as shown in Figure S1. We then conducted a validation study with an independent data set and compared the prevalence of elevated BP based on the present Chinese national reference and other 2 references (the US reference and the Chinese CIP reference). Hypertension was defined for adults aged 18 years in the validation data set as SBP/DBP ≥140/90 mm Hg. The proportions identified as hypertensive based on the new Chinese national reference and the US and Chinese CIP references were compared using χ^2 tests in the

Table 1. Height Percentiles for Chinese Children Aged 7 to 17 Years: Boys and Girls

	Boys' Height Percentiles, cm							Girls' Height Percentiles, cm						
Age, y	5th	10th	25th	50th	75th	90th	95th	5th	10th	25th	50th	75th	90th	95th
7	115.7	117.9	121.5	125.5	129.5	133.3	135.4	114.3	116.5	120.1	124.1	128.1	131.9	134.0
8	120.6	122.9	126.5	130.7	134.9	138.7	141.0	119.2	121.5	125.2	129.3	133.6	137.2	139.6
9	125.0	127.4	131.4	135.8	140.3	144.2	146.6	124.0	126.4	130.3	135.0	139.6	143.9	146.5
10	130.0	132.1	136.1	140.8	145.4	149.8	152.4	129.1	131.8	136.0	141.2	146.3	150.7	153.3
11	133.7	136.4	141.0	146.0	151.3	156.5	159.7	134.2	137.1	142.0	147.3	152.7	157.1	159.6
12	138.4	141.2	146.0	152.0	158.6	164.1	167.3	139.7	142.6	147.5	152.5	157.1	160.9	163.5
13	145.1	148.2	154.0	160.2	166.2	170.7	173.4	145.6	148.0	152.0	156.1	160.0	163.8	166.0
14	151.6	155.0	160.4	165.7	170.5	175.0	177.5	148.2	150.4	154.0	157.8	161.6	165.1	167.2
15	157.2	160.0	164.4	169.0	173.4	177.4	180.0	149.2	151.4	154.8	158.4	162.2	166.0	168.0
16	160.0	162.4	166.3	170.5	174.9	178.8	181.0	150.0	151.7	155.2	159.0	162.8	166.3	168.3
17	161.2	163.3	167.1	171.4	175.6	179.5	181.9	150.1	152.0	155.3	159.2	163.1	166.6	168.8

validation sample. All conventional descriptive analyses were performed using IBM SPSS Statistics version 17.0; P values <0.05 (2-sided) were considered statistically significant.

Results

Study Sample

The mean height, weight, BMI, SBP, and DBP increased with age in both sexes (Table 2). The prevalence of overweight and obesity in boys was 1.5- to 2.2-fold greater than that of girls in each age group.

Chinese Childhood BP Reference

Tables 3 and 4 show the 50th, 90th, 95th, and 99th percentiles for SBP and DBP by age (7–17) and height percentiles (5th, 10th, 25th, 50th, 75th, 90th, and 95th). For both sexes, the BP percentile values increased with age and height percentiles

Comparison to the US Reference

The height, weight, and BMI values in the 2010 CNSSCH were similar to that reported for the US population in younger children, whereas lower in older adolescents (Figure S1). Figure 1A and 1B shows the 50th, 90th, 95th, and 99th percentiles for SBP and DBP for Chinese boys and girls aged 7 to 17 years at median height with comparisons for the new Chinese Childhood BP (CCBP) reference and the US reference. For SBP, relative to the US reference values, the 95th and 99th percentiles for the CCBP reference were higher for boys aged 7 to 15 years and lower for boys aged 16 to 17 years, whereas the 50th and 90th percentiles were similar. For girls, relative to the US reference values, the 50th percentile of SBP of the CCBP reference was lower; the 90th and 95th percentiles of SBP were similar for ages 7 to 11 years and lower at ages 12 and older. For DBP, in both sexes, compared with the US reference, the CCBP reference had higher 50th percentiles and

Table 2. Baseline Characteristics of the Reference Study Population in Chinese National Survey on Students' Constitution and Health 2010, China (mean±SD)

	Height, cm		Weight, kg		BMI, kg/m^2		SBP, mm Hg		DBP, mm Hg		Overweight/ Obesity, %	
Age/y	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
7	125.5±6.0	124.1±5.9	25.5±5.4	23.8±4.5	16.1±2.4	15.4±2.0	95.6±11.1	94.2±11.0	59.2±10.1	58.6±9.8	21.0	14.8
8	130.7±6.2	129.4±6.2	28.5±6.2	26.5±5.4	16.5±2.6	15.7±2.3	97.8±11.0	96.4±10.9	61.0±9.7	60.2±9.6	20.9	13.3
9	135.8±6.6	135.0±6.8	31.8±7.5	29.7±6.3	17.1±3.0	16.2±2.4	99.2±11.3	98.0±10.9	62.0±10.0	61.7±9.7	22.3	12.3
10	140.9±6.9	141.3±7.4	35.5±8.8	33.8±7.5	17.7±3.2	16.8±2.6	101.5±11.1	100.0±11.0	63.5±9.7	63.1±9.4	23.6	11.6
11	146.2±7.9	147.2±7.7	39.6±10.1	38.2±8.6	18.3±3.4	17.4±2.8	103.2±11.2	102.6±11.0	64.4±9.5	64.7±9.4	24.0	10.8
12	152.4±8.9	152.2±7.2	44.0±11.5	42.3±8.9	18.7±3.5	18.2±2.9	104.8±11.4	103.1±10.7	64.5±9.5	64.6±9.1	21.0	10.1
13	159.9±8.7	156.0±6.2	49.4±11.6	46.2±8.6	19.1±3.4	18.9±2.9	107.5±11.7	103.9±10.6	65.5±9.8	65.2±8.9	17.9	10.1
14	165.3±7.8	157.8±5.8	53.8±11.7	48.6±8.1	19.6±3.3	19.5±2.8	109.9±11.5	105.0±10.7	67.2±9.6	66.1±8.8	15.6	10.1
15	168.8±7.0	158.5±5.7	57.2±11.4	50.1±7.8	20.0±3.3	19.9±2.7	111.5±11.4	105.2±10.3	68.2±9.3	66.2±8.8	15.4	9.5
16	170.5±6.4	159.0±5.7	59.2±10.6	51.1±7.3	20.3±3.1	20.2±2.5	112.9±11.3	105.3±10.6	69.1±9.3	66.6±8.5	13.1	8.5
17	171.4±6.3	159.3±5.7	61.0±10.6	51.7±7.3	20.7±3.1	20.4±2.5	114.4±11.3	106.0±10.7	70.1±9.2	66.7±8.7	14.0	8.8
Total	151.6±17.5	147.3±13.9	44.1±15.7	40.2±12.3	18.6±3.5	18.0±3.1	105.3±12.8	101.8±11.4	65.0±10.2	64.0±9.5	19.0	10.9

BMI indicates body mass index; DBP, diastolic blood pressure; and SBP, systolic blood pressure.

Table 3. Percentiles of Blood Pressure Levels for Boys by Age and Height

Age, y	Blood Pressure Percentiles	SBP, mm Hg								DBP, mm Hg							
		Height Percentiles								Height Percentiles							
		<5th	≥5th	≥10th	≥25th	≥50th	≥75th	≥90th	≥95th	<5th	≥5th	≥10th	≥25th	≥50th	≥75th	≥90th	≥95th
7	50th	91	92	93	94	96	97	99	100	57	57	58	59	60	61	63	64
	90th	104	106	108	109	110	112	113	116	69	70	71	71	72	73	75	75
	95th	108	110	112	113	115	117	118	121	72	74	74	74	75	77	78	79
	99th	116	119	121	123	124	127	127	131	79	80	80	81	81	83	85	85
8	50th	93	94	94	96	98	99	101	103	58	59	60	60	61	62	64	65
	90th	106	108	109	111	112	115	116	119	70	71	72	72	73	75	76	77
	95th	110	112	113	115	117	119	120	124	73	75	75	76	76	78	80	80
	99th	119	121	122	124	126	128	129	134	80	81	81	82	82	84	86	86
9	50th	94	95	96	98	99	102	103	105	59	60	61	62	63	64	65	66
	90th	108	109	110	112	114	117	118	121	71	72	72	74	74	76	77	78
	95th	112	114	114	117	119	121	122	126	74	76	76	77	77	79	81	81
	99th	120	122	123	126	128	130	131	136	81	82	82	83	83	85	87	87
10	50th	96	97	97	100	101	104	106	108	60	61	62	63	64	65	66	67
	90th	109	111	112	114	116	119	121	124	72	73	73	75	75	77	78	78
	95th	113	115	116	119	121	123	125	129	75	76	76	78	78	80	81	82
	99th	122	123	124	127	129	132	133	139	82	82	82	84	84	86	87	87
11	50th	97	98	99	101	104	106	108	110	61	62	63	64	65	66	67	68
	90th	110	112	113	116	118	121	123	126	73	73	74	75	76	78	78	79
	95th	115	116	117	120	123	126	128	131	76	77	77	79	79	81	81	82
	99th	123	124	126	129	131	134	136	141	82	82	83	84	85	87	87	88
12	50th	98	99	101	103	106	109	110	112	62	63	64	65	66	67	67	68
	90th	111	113	115	118	121	123	125	128	74	74	75	76	77	78	79	80
	95th	116	117	119	122	125	128	130	133	77	77	78	79	80	81	82	83
	99th	124	125	128	131	134	136	138	142	83	83	84	85	85	87	87	88
13	50th	99	101	104	106	108	111	112	114	63	64	65	66	67	68	68	69
	90th	113	115	118	121	123	125	127	130	75	75	76	77	78	79	79	80
	95th	117	119	122	125	127	130	132	134	78	78	79	80	81	82	82	83
	99th	126	127	130	133	136	138	140	144	84	84	85	86	86	87	87	89
14	50th	102	104	107	109	110	112	113	115	65	65	66	67	68	69	69	70
	90th	116	118	121	123	125	127	128	130	76	76	77	78	79	80	80	81
	95th	120	122	125	128	129	131	133	135	79	79	80	81	82	83	83	84
	99th	129	130	133	136	138	139	141	144	85	85	86	87	87	88	88	89
15	50th	105	107	109	111	112	113	114	115	66	67	68	68	69	69	70	70
	90th	119	122	123	125	127	128	129	131	77	77	79	79	80	80	81	81
	95th	123	126	128	130	131	132	133	136	80	80	82	82	83	83	83	84
	99th	132	134	136	138	139	140	141	145	86	86	87	87	88	88	88	90
16	50th	108	110	111	112	113	114	115	116	67	68	69	69	70	70	71	71
	90th	122	125	126	127	128	129	130	132	78	79	80	80	81	81	81	82
	95th	127	129	130	131	132	133	134	136	81	82	83	83	84	84	84	85
	99th	135	137	138	139	140	141	142	145	87	87	88	88	89	89	89	90

(*Continued*)

Table 3. Continued

Age, y	Blood Pressure Percentiles	SBP, mm Hg								DBP, mm Hg							
		Height Percentiles								Height Percentiles							
		<5th	≥5th	≥10th	≥25th	≥50th	≥75th	≥90th	≥95th	<5th	≥5th	≥10th	≥25th	≥50th	≥75th	≥90th	≥95th
17	50th	111	112	113	114	115	115	116	117	68	69	70	70	71	71	72	72
	90th	125	127	127	128	129	130	131	132	79	80	81	81	82	82	82	83
	95th	129	131	131	132	133	134	135	136	82	83	84	84	85	85	85	86
	99th	137	140	140	140	141	142	143	145	88	89	89	89	90	90	90	91

DBP indicates diastolic blood pressure; and SBP, systolic blood pressure.

lower 99th percentiles for ages 7 to 17 years. The 90th and 95th percentiles of DBP in both sexes were similar in both references, and the new national CCBP reference had slightly lower 90th and 95th percentiles of DBP in girls aged 13 to 17.

Comparison to the Chinese CIP Reference

Figure 1C and 1D shows the 50th, 90th, 95th, and 99th percentiles for SBP and DBP for Chinese boys and girls aged 7 to 17 years at median height with comparisons for the new national

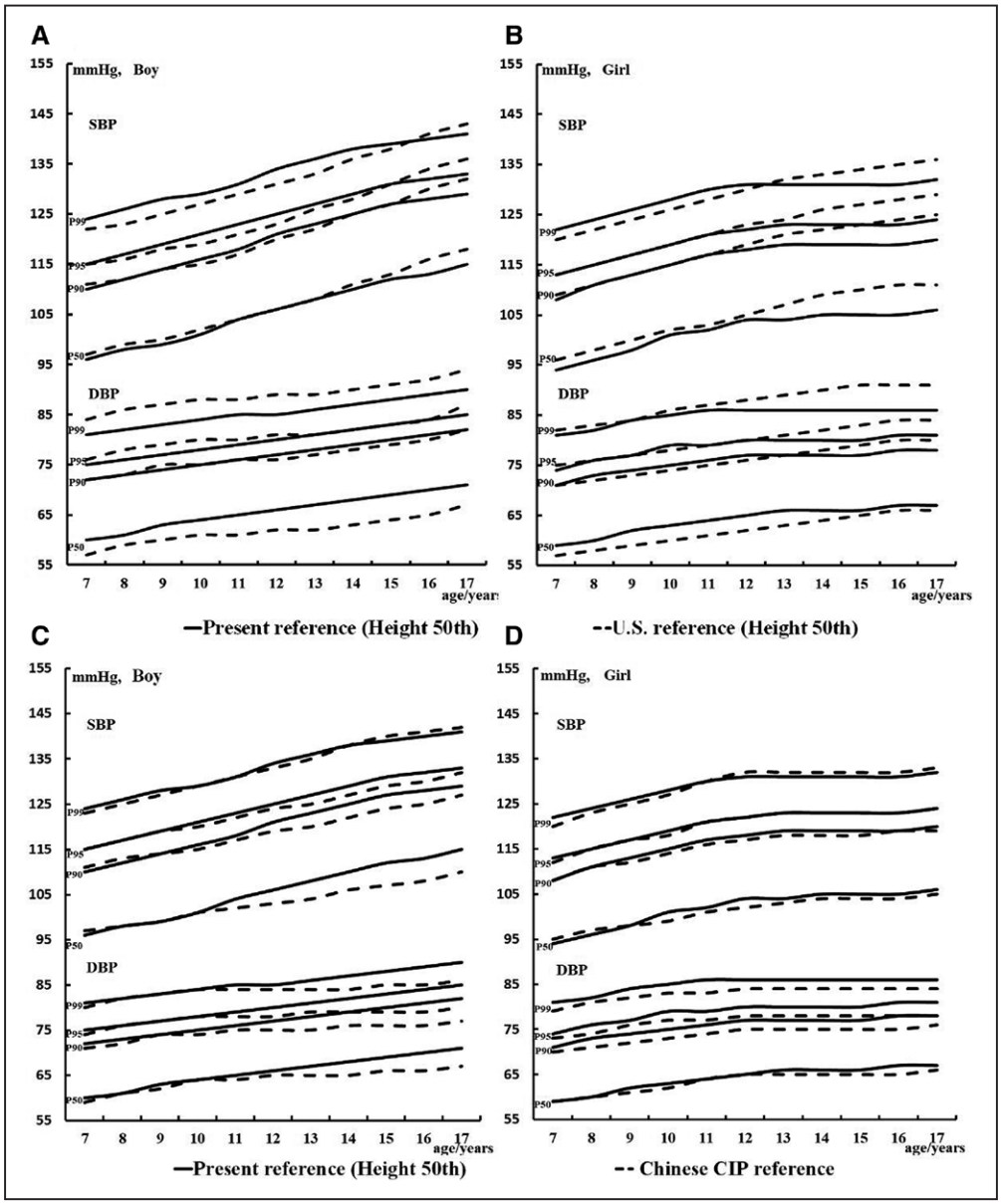

Figure 1. The 50th, 90th, 95th, and 99th percentiles for systolic blood pressure (SBP) and diastolic blood pressure (DBP) for Chinese boys and girls aged 7 to 17 y at median height. Pn indicates nth percentile. **A**, **B**, Comparison of the new Chinese national blood pressure (BP) reference to the US reference; and (**C** and **D**) show comparison of the new Chinese national BP reference to the Chinese Capital Institute of Pediatrics (CIP) reference.

CCBP reference to the existing Chinese CIP reference. The 50th, 90th, 95th, and 99th percentiles of SBP and DBP at median height (50th) in boys aged 7 to 11 years were similar for the CCBP reference and the existing Chinese CIP reference. The 50th percentiles of SBP were higher, and the 99th percentiles were lower than those in the CIP reference in boys, whereas the 90th and 95th percentiles were similar at the age of 12 to 17 years. The 50th, 90th, and 95th percentiles of SBP in boys at the 25th height group were lower at younger ages and were higher at older ages than those in the CIP reference. The 50th, 90th, 95th, and 99th percentiles of SBP in girls at the 25th and 50th height groups were similar in both references. The 90th, 95th, and 99th percentiles of DBP in girls aged 7 to 17 years were higher than those in the CIP reference, except for the 50th percentiles.

Validation Study

In the validation sample, applying the 3 reference standards, the total prevalence of hypertension varied appreciably (Figure 2). Overall and for boys and girls analyzed separately, χ^2 tests indicated statistically significant differences between the BP reference values at every age level from 7 to 17 years (P<0.001). For boys and girls, aged 7 to 17, the prevalence of hypertension ranged from 7.8% to 18.5% based on the CCBP reference, 4.3% to 14.5% based on the US reference, and 12.9% to 25.5% based on the Chinese CIP reference. The curve shape of the prevalence of hypertension from ages 7 to 18 with the CCBP reference was similar to that of the US reference. Both showed that the prevalence of hypertension increased from the ages of 7 to 10 and declined thereafter. In contrast, the prevalence of hypertension increased continually based on the Chinese CIP reference from the ages of 12 to 17. For adolescents aged 17, the prevalence of hypertension was 9.1% based on the CCBP reference and 5.0% based on the US reference, which was close to that for adults aged 18 (5.0%), and far from the result for adolescents aged 17 based on the Chinese CIP reference (25.5%), especially for boys (30.1%).

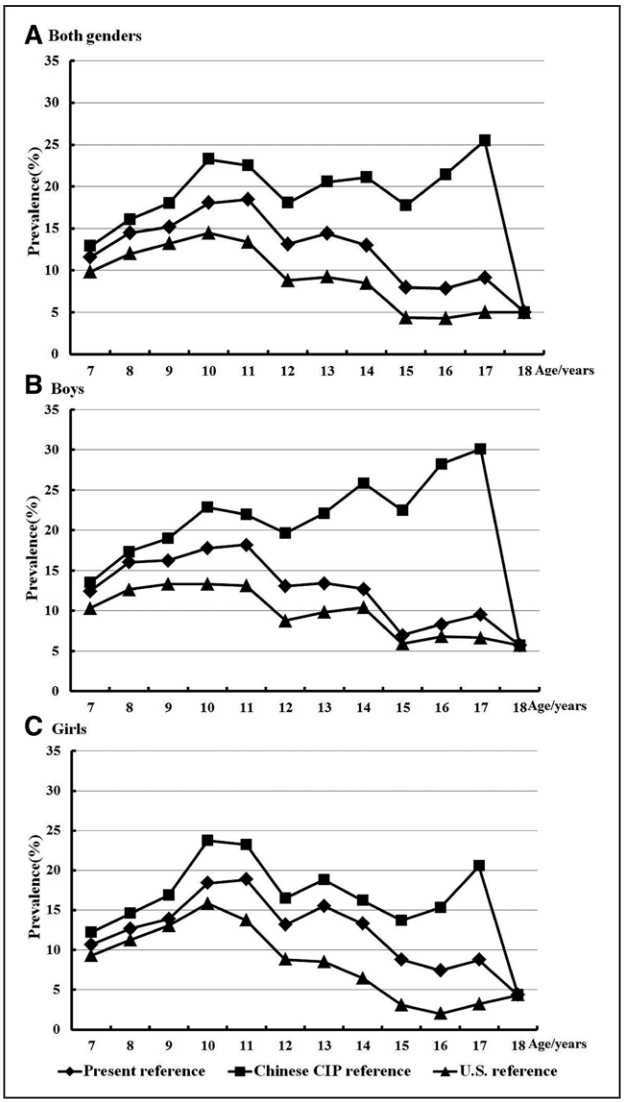

Figure 2. The total prevalence of hypertension (or elevated blood pressure [BP]) in (**A**) the full sample, (**B**) boys, and (**C**) girls aged 7 to 18 y of age applying 3 references: the new national Chinese reference, the US reference, and the Chinese Capital Institute of Pediatrics (CIP) reference. Hypertension (or elevated BP) was defined for adults aged 18 years as systolic BP/diastolic BP ≥140/90 mm Hg.

Discussion

This is the first study to provide national Chinese Childhood BP percentiles for boys and girls aged 7 to 17 years with 8 height percentile groups. The reference values were developed using data covering the whole country, consisting of nearly 200 000 children and adolescents in China. This reference is intended to screen for hypertension or elevated BP in Chinese children and guide pediatric healthcare providers, in concert with sound clinical judgment. The new reference, with population estimates, also can be applied to formulate relevant health policy by government and health policymakers.

The 90th and 95th percentiles of BP by sex, age, and height percentiles from the present study can be used as threshold values to detect pre-hypertension and hypertension among Chinese children and adolescents. We recommend that pre-hypertension or prehigh BP be defined as average SBP and DBP levels that are ≥90th percentiles but <95th percentile (shaded in Tables 3 and 4). In our study, we found those values to identify pre-hypertension, which approximates what has been recommended for adults. As with adults, pre-hypertension is also defined in children and adolescents with the average SBP/DBP of 120 to 139/80 to 89 mm Hg ranges,[6,22,23] whereas hypertension or high BP is defined as average SBP and DBP that is ≥95th percentiles for sex, age, and height. For clinical diagnoses, measurements should be taken on at least 3 separate occasions. Furthermore, BP should be staged if the BP (SBP and DBP) is ≥95th percentile. Stage 1 is defined by BP between the 95th and 99th percentiles plus 5 mm Hg. Stage 2 is defined by BP ≥99th percentile plus 5 mm Hg. If BP is stage 1 or stage 2 for a child, we suggest that further measurements should be repeated on 2 more occasions within the month. If hypertension is confirmed, the child should undergo further evaluation and be considered for appropriate intervention. The measurement of BP is recommended by using the auscultation with mercury, which has long been considered the gold standard and remains the main recommended method in several previous hypertension guidelines.[16,24,25] In addition,

Table 4. Percentiles of Blood Pressure Levels for Girls by Age and Height

Age, y	Blood Pressure Percentiles	SBP, mm Hg								DBP, mm Hg							
		Height Percentiles								Height Percentiles							
		<5th	≥5th	≥10th	≥25th	≥50th	≥75th	≥90th	≥95th	<5th	≥5th	≥10th	≥25th	≥50th	≥75th	≥90th	≥95th
7	50th	90	90	92	93	94	96	97	99	56	56	58	58	59	60	61	61
	90th	104	104	106	107	108	110	112	115	69	69	70	70	71	72	73	74
	95th	109	109	111	111	113	115	117	121	73	73	74	74	74	75	76	77
	99th	119	119	120	120	122	123	126	131	79	79	80	80	81	81	83	84
8	50th	91	92	93	95	96	98	100	101	57	58	59	60	60	62	63	63
	90th	106	106	108	109	111	113	114	117	70	70	71	72	73	73	75	75
	95th	110	110	113	113	115	117	119	123	74	74	75	75	76	77	78	78
	99th	120	120	122	122	124	126	128	133	81	81	82	82	82	82	85	85
9	50th	93	94	95	97	98	100	102	103	59	60	60	61	62	63	64	65
	90th	107	108	110	111	113	115	117	119	71	72	73	73	74	75	76	77
	95th	112	112	114	115	117	119	121	124	75	76	76	77	77	78	79	81
	99th	121	121	123	124	126	128	130	134	82	82	83	83	84	84	86	87
10	50th	94	96	97	99	101	102	104	105	60	61	62	63	63	65	65	67
	90th	109	110	111	113	115	117	118	121	73	74	74	75	75	76	77	78
	95th	113	114	116	117	119	121	123	125	77	77	78	78	79	79	80	81
	99th	122	123	125	126	128	130	132	135	84	84	84	84	85	85	87	87
11	50th	96	97	99	100	102	104	105	106	61	63	63	64	64	65	66	67
	90th	110	111	113	115	117	119	120	121	74	75	75	76	76	77	78	78
	95th	115	116	117	119	121	123	124	126	78	78	79	79	79	80	81	81
	99th	124	125	126	128	130	131	133	135	85	85	85	85	86	86	87	87
12	50th	98	99	101	102	104	105	106	107	62	64	64	65	65	66	66	67
	90th	112	113	115	116	118	119	121	122	75	75	76	76	77	77	78	78
	95th	116	117	119	121	122	124	125	126	79	79	79	80	80	80	81	81
	99th	125	126	128	129	131	132	133	135	85	85	86	86	86	86	87	87
13	50th	99	100	102	103	104	105	106	107	63	64	64	65	66	66	67	67
	90th	114	114	116	117	119	119	121	122	76	76	76	77	77	77	78	78
	95th	118	119	120	122	123	124	125	126	79	79	80	80	80	80	81	81
	99th	127	127	129	130	131	132	134	135	85	85	86	86	86	86	87	87
14	50th	101	102	103	104	105	105	106	107	64	65	65	66	66	67	67	68
	90th	116	116	117	118	119	120	121	122	76	76	77	77	77	78	78	78
	95th	120	120	121	122	123	124	125	126	80	80	80	80	80	80	81	81
	99th	129	129	130	131	131	132	134	135	86	86	86	86	86	86	88	88
15	50th	103	103	104	104	105	106	107	107	65	66	66	66	66	67	67	68
	90th	117	117	118	119	119	120	121	122	77	77	77	77	77	78	79	79
	95th	122	121	122	123	123	124	126	126	80	80	80	80	80	81	82	82
	99th	130	130	130	131	131	133	134	135	86	86	86	86	86	86	88	88
16	50th	104	104	104	105	105	106	107	107	65	66	66	66	67	67	68	68
	90th	118	118	118	119	119	120	121	122	77	77	77	77	78	78	79	79
	95th	122	122	122	123	123	125	126	126	80	80	80	80	81	81	82	82
	99th	130	130	131	132	131	133	134	135	86	86	86	86	86	86	88	88

(*Continued*)

Table 4. Continued

Age, y	Blood Pressure Percentiles	SBP, mm Hg								DBP, mm Hg							
		Height Percentiles								Height Percentiles							
		<5th	≥5th	≥10th	≥25th	≥50th	≥75th	≥90th	≥95th	<5th	≥5th	≥10th	≥25th	≥50th	≥75th	≥90th	≥95th
17	50th	104	104	105	105	106	106	107	108	66	66	66	67	67	68	68	68
	90th	118	118	118	120	120	121	122	122	77	77	77	78	78	79	79	79
	95th	122	122	123	124	124	125	126	126	80	80	81	81	81	81	82	82
	99th	131	131	131	132	132	134	135	135	86	86	86	86	86	87	88	88

DBP indicates diastolic blood pressure; and SBP, systolic blood pressure.

as the CCBP reference is used based on an average of 3 BP measurements taken by mercury sphygmomanometers, an average of 3 BP measurements would be more appropriate than 1 BP measure when this reference is used.

We found that the prevalence of hypertension with the CCBP reference was close to the results with the US reference in the independent validation study, and the distributions were similar. In addition, the prevalence of hypertension based on the BBCP reference can connect smoothly to that of adults. There were notable limitations found with the locally based Chinese CIP reference, which was not based on height,[26,27] especially among older adolescents. Height was not included in construction of the Chinese CIP reference because the sample size was not large enough to support stratification by height. The findings here indicate bias in BP values when height is not considered. Notably, the prevalence of pediatric hypertension based on the Chinese CIP reference is far higher than that reported for the same population in China.[15,28]

BP reference in children without consideration of height is inadequate and may result in inaccurate BP evaluation in pediatric medical examination especially among children who are very tall or short.[29–32] A previous study indicated that the influence of height on BP may even be greater than age.[33] Because of the important determination of body size to BP in children and adolescents, the new national Chinese guidelines were developed to provide specific percentiles of SBP and DBP by age, sex, and height percentiles,[6,16,29,34,35] similar to the US reference in 2004, Canada 2016 guidelines, and the European 2009/2016 guidelines. The US reference has been used by many Chinese researchers and widely internationally. However, its height percentiles were adopted from the American 2000 Center for Disease Control growth charts, which are not applicable to Chinese children. We found that there were great differences in height, weight, and BMI for both boys and girls in China and the United States (Figure S1); the gap increased in late puberty, which may underestimate the prevalence of hypertension and reduce the accuracy of BP evaluation in children.

The present study has several strengths. First, ≈0.2 million participants of Han nationality accounting for ≈92% of the total Chinese population were included in the 2010 CNSSCH data set used to develop the BBCP reference. Therefore, the CCBP reference is widely applicable to Chinese children and adolescents. Further, the sample size was large enough so that the BBCP reference had 8 height percentiles groups (<5th, 5th, 10th, 25th, 50th, 75th, 90th, and 95th); in previous studies, the group of <5th was not available. Overall, a consistent trend in the prevalence of hypertension was found in children and adolescents aged 7 to 17 and with close connection to adults aged 18 applying both the BBCP reference and the US reference, but not the Chinese CIP reference.

Limitations of the present study should be noted. First, it may be preferable to develop a BP reference based on health outcomes in childhood or later in adulthood associated with a certain level of BP, such as target organ damage, cardiovascular morbidity, or mortality.[36–38] However, long-term and large-scale cohort studies of the type needed for validation do not exist. The procedures we used here to develop the BBCP reference were consistent with the majority of BP references. Second, BP levels in our study were obtained at a single visit, which should be confirmed on repeated visits according to the guidelines. The US reference in 2004 recommended that hypertension should be defined by using the results of elevated BP on at least 3 occasions in children and adolescents. However, the diagnosis of hypertension for adults or children mainly depends on 1 to 3 readings by a single screening visit in most epidemiological studies.[39,40] Third, the study methods only chose Korotkoff phase 5 (K5; the disappearance of the sound) to assess DBP in children without using Korotkoff phase 4 (K4; the muffling of the sound). However, a large number of current pediatric BP references recommend the use of K5, such as the US reference,[16] the international BP reference,[34] the 2009 and 2016 guidelines the European Society of Hypertension,[6,25] and the 2014 recommendation of the American Heart Association[41] as well as the 2016 Canadian guidelines.[42] In addition, K5 has been recommended and universally used to measure DBP in adults.

Perspectives

In summary, this study proposes a BP reference by age, sex, and height for Chinese children and adolescents aged 7 to 17 years. These are the first BP percentiles based on a large national sample and 8 height percentile categories in China. The BBCP reference will be useful for individual BP evaluation and management and for elevated BP screening in epidemiological investigations.

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and reviewed and revised the article; J. Ma and Y. Song contributed to the conceptualization and design of the study, supervised the data collection, the statistical analyses, and initial drafting of the article, and reviewed and revised the article; B. Dong contributed to the conceptualization and design of the study and reviewed and revised the article; Z. Wang, Z. Yang, and X. Wang assisted with the statistical analyses and reviewed the article; and J.J. Prochaska assisted with the statistical analyses and critically reviewed and revised the article. All authors approved the final article as submitted and agree to be accountable for all aspects of the work.

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Disclosures

None.

Reference

1. World Health Organization. Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks. http://who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf. Accessed December 18, 2009.
2. National Center for Cardiovascular Disease of China. *Report on Cardiovascular Diseases in China*. Beijing, China: Encyclopedia of China Publishing House; 2015. http://www.nccd.org.cn/UploadFile/201607/20160718113619135135.pdf. Accessed May 10, 2016.
3. Li Y, Wang DD, Ley SH, Howard AG, He Y, Lu Y, Danaei G, Hu FB. Potential impact of time trend of life-style factors on cardiovascular disease burden in China. *J Am Coll Cardiol*. 2016;68:818–833. doi: 10.1016/j.jacc.2016.06.011.
4. Chiolero A, Bovet P, Paradis G. Screening for elevated blood pressure in children and adolescents: a critical appraisal. *JAMA Pediatr*. 2013;167:266–273. doi: 10.1001/jamapediatrics.2013.438.
5. Ingelfinger JR. The child or adolescent with elevated blood pressure. *N Engl J Med*. 2014;370:2316–2325.
6. Lurbe IFE. 2016 - European Society of Hypertension Guidelines for the management of high blood pressure in children and adolescents. *An Pediatr*. 2016;85:167–169.
7. Chen X, Wang Y. Tracking of blood pressure from childhood to adulthood: a systematic review and meta-regression analysis. *Circulation*. 2008;117:3171–3180. doi: 10.1161/CIRCULATIONAHA.107.730366.
8. Toschke AM, Kohl L, Mansmann U, von Kries R. Meta-analysis of blood pressure tracking from childhood to adulthood and implications for the design of intervention trials. *Acta Paediatr*. 2010;99:24–29. doi: 10.1111/j.1651-2227.2009.01544.x.
9. Vik KL, Romundstad P, Nilsen TI. Tracking of cardiovascular risk factors across generations: family linkage within the population-based HUNT study, Norway. *J Epidemiol Community Health*. 2013;67:564–570. doi: 10.1136/jech-2012-201634.
10. Tirosh A, Afek A, Rudich A, Percik R, Gordon B, Ayalon N, Derazne E, Tzur D, Gershnabel D, Grossman E, Karasik A, Shamiss A, Shai I. Progression of normotensive adolescents to hypertensive adults: a study of 26,980 teenagers. *Hypertension*. 2010;56:203–209. doi: 10.1161/HYPERTENSIONAHA.109.146415.
11. Mahoney LT, Burns TL, Stanford W, Thompson BH, Witt JD, Rost CA, Lauer RM. Coronary risk factors measured in childhood and young adult life are associated with coronary artery calcification in young adults: the Muscatine Study. *J Am Coll Cardiol*. 1996;27:277–284.
12. Erlingsdottir A, Indridason OS, Thorvaldsson O, Edvardsson VO. Blood pressure in children and target-organ damage later in life. *Pediatr Nephrol*. 2010;25:323–328. doi: 10.1007/s00467-009-1350-3.
13. Regnault N, Kleinman KP, Rifas-Shiman SL, Langenberg C, Lipshultz SE, Gillman MW. Components of height and blood pressure in childhood. *Int J Epidemiol*. 2014;43:149–159. doi: 10.1093/ije/dyt248.
14. Mi J, Wang TY, Meng LH, Zhu GJ, Han SM, Zhong Y, Liu GS, Wan YP, Xiong F, Shi JP, Yan WL, Zhou PM. Development of blood pressure reference standards for Chinese children and adolescents. *CJEBP*. 2010;5:4–14.
15. Dong B, Ma J, Wang HJ, Wang ZQ. The association of overweight and obesity with blood pressure among Chinese children and adolescents. *Biomed Environ Sci*. 2013;26:437–444. doi: 10.3967/0895-3988.2013.06.004.
16. 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;114:555–576.
17. Dong B, Wang Z, Wang HJ, Ma J. Population attributable risk of overweight and obesity for high blood pressure in Chinese children. *Blood Press*. 2015;24:230–236. doi: 10.3109/08037051.2015.1030904.
18. Ji CY, Chen TJ; Working Group on Obesity in China (WGOC). Empirical changes in the prevalence of overweight and obesity among Chinese students from 1985 to 2010 and corresponding preventive strategies. *Biomed Environ Sci*. 2013;26:1–12. doi: 10.3967/0895-3988.2013.01.001.
19. Chen Y, Ma L, Ma Y, et al. A national school-based health lifestyles interventions among Chinese children and adolescents against obesity: rationale, design and methodology of a randomized controlled trial in China. *BMC Public Health*. 2015;15:210. doi: 10.1186/s12889-015-1516-9.
20. Ji CY; Working Group on Obesity in China. Report on childhood obesity in China (1)–body mass index reference for screening overweight and obesity in Chinese school-age children. *Biomed Environ Sci*. 2005;18:390–400.
21. Cole TJ, Green PJ. Smoothing reference centile curves: the LMS method and penalized likelihood. *Stat Med*. 1992;11:1305–1319.
22. Lenfant C, Chobanian AV, Jones DW, Roccella EJ; Joint National Committee on the Prevention, Detection, Evaluation, and Treatment of High Blood Pressure. Seventh report of the Joint National Committee on the Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (JNC 7): resetting the hypertension sails. *Hypertension*. 2003;41:1178–1179. doi: 10.1161/01.HYP.0000075790.33892.AE.
23. Siu AL; U.S. Preventive Services Task Force. Screening for high blood pressure in adults: U.S. Preventive Services Task Force recommendation statement. *Ann Intern Med*. 2015;163:778–786. doi: 10.7326/M15-2223.
24. Kavey RE, Daniels SR, Lauer RM, Atkins DL, Hayman LL, Taubert K; American Heart Association. American Heart Association guidelines for primary prevention of atherosclerotic cardiovascular disease beginning in childhood. *Circulation*. 2003;107:1562–1566. doi: 10.1161/01.CIR.0000061521.15730.6E.
25. Lurbe E, Cifkova R, Cruickshank JK, et al; Sociedad Europea de Hipertensión. Management of high blood pressure in children and adolescents: recommendations of the European Society of Hypertension. *An Pediatr*. 2010;73:51.e1–51.e28. doi: 10.1016/j.anpedi.2010.04.001.
26. Blumenthal S, Epps RP, Heavenrich R, Lauer RM, Lieberman E, Mirkin B, Mitchell SC, Boyar Naito V, O'Hare D, McFate Smith W, Tarazi RC, Upson D. Report of the task force on blood pressure control in children. *Pediatrics*. 1977;59(2 suppl 5):I–II, 797.
27. Report of the Second Task Force on Blood Pressure Control in Children–1987. Task force on blood pressure control in children. National Heart, Lung, and Blood Institute, Bethesda, Maryland. *Pediatrics*. 1987;79:1–25.
28. Dong B, Wang Z, Song Y, Wang HJ, Ma J. Understanding trends in blood pressure and their associations with body mass index in Chinese children, from 1985 to 2010: a cross-sectional observational study. *BMJ Open*. 2015;5:e009050.
29. Rosner B, Cook N, Portman R, Daniels S, Falkner B. Determination of blood pressure percentiles in normal-weight children: some methodological issues. *Am J Epidemiol*. 2008;167:653–666. doi: 10.1093/aje/kwm348.
30. Rosner B, Cook N, Portman R, Daniels S, Falkner B. Blood pressure differences by ethnic group among United States children and adolescents. *Hypertension*. 2009;54:502–508. doi: 10.1161/HYPERTENSIONAHA.109.134049.
31. Gillum RF, Prineas RJ, Horibe H. Maturation vs age: assessing blood pressure by height. *J Natl Med Assoc*. 1982;74:43–46.
32. Rosner B, Prineas RJ, Loggie JM, Daniels SR. Blood pressure nomograms for children and adolescents, by height, sex, and age, in the United States. *J Pediatr*. 1993;123:871–886.
33. Wang Z, Ma J, Dong B, Song Y, Hu PJ, Zhang B. Comparison of blood pressure levels among four age groups of Chinese children matched by height. *J Hum Hypertens*. 2012;26:437–442. doi: 10.1038/jhh.2011.45.
34. Xi B, Zong X, Kelishadi R, et al; International Child Blood Pressure References Establishment Consortium. Establishing international blood pressure references among nonoverweight children and adolescents aged 6 to 17 years. *Circulation*. 2016;133:398–408. doi: 10.1161/CIRCULATIONAHA.115.017936.

35. Yan W, Liu F, Li X, Wu L, Zhang Y, Cheng Y, Zhou W, Huang G. Blood pressure percentiles by age and height for non-overweight Chinese children and adolescents: analysis of the China Health and Nutrition Surveys 1991-2009. *BMC Pediatr*. 2013;13:195. doi: 10.1186/1471-2431-13-195.
36. Franks PW, Hanson RL, Knowler WC, Sievers ML, Bennett PH, Looker HC. Childhood obesity, other cardiovascular risk factors, and premature death. *N Engl J Med*. 2010;362:485–493. doi: 10.1056/NEJMoa0904130.
37. 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.
38. Gray L, Lee IM, Sesso HD, Batty GD. Blood pressure in early adulthood, hypertension in middle age, and future cardiovascular disease mortality: HAHS (Harvard Alumni Health Study). *J Am Coll Cardiol*. 2011;58:2396–2403. doi: 10.1016/j.jacc.2011.07.045.
39. Ibrahim MM, Damasceno A. Hypertension in developing countries. *Lancet*. 2012;380:611–619. doi: 10.1016/S0140-6736(12)60861-7.
40. de Moraes AC, Lacerda MB, Moreno LA, Horta BL, Carvalho HB. Prevalence of high blood pressure in 122,053 adolescents: a systematic review and meta-regression. *Medicine*. 2014;93:e232. doi: 10.1097/MD.0000000000000232.
41. Flynn JT, Daniels SR, Hayman LL, Maahs DM, McCrindle BW, Mitsnefes M, Zachariah JP, Urbina EM; American Heart Association Atherosclerosis, Hypertension and Obesity in Youth Committee of the Council on Cardiovascular Disease in the Young. Update: ambulatory blood pressure monitoring in children and adolescents: a scientific statement from the American Heart Association. *Hypertension*. 2014;63:1116–1135. doi: 10.1161/HYP.0000000000000007.
42. Harris KC, Benoit G, Dionne J, Feber J, Cloutier L, Zarnke KB, Padwal RS, Rabi DM, Fournier A; CHEP Guidelines Task Force. Hypertension Canada's 2016 Canadian Hypertension Education Program guidelines for blood pressure measurement, diagnosis, and assessment of risk of pediatric hypertension. *Can J Cardiol*. 2016;32:589–597. doi: 10.1016/j.cjca.2016.02.075.

Novelty and Significance

What Is New?

- Present new national blood pressure (BP) reference will be helpful clinically for working with Asian patients and useful at a population level for formulating relevant health policies by government and health policymakers in China and other Asian countries.

What Is Relevant?

- It is important to recognize BP abnormalities in children and adolescents by using an appropriate BP standard.
- Needed is a national BP reference for Chinese children based on age, sex, and height using the largest nationally representative sample of school-age children in China, which should be also validated with an independent large-scale database.

Summary

We established and validated a new national BP reference for Chinese children based on age, sex, and height by using large-scale and nationally representative data. It also has significant implications for the prevention and control of chronic diseases in children and adolescents to reduce cardiovascular disease burden.