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Blood Pressure Reference Values for Normal Weight Korean Children and Adolescents: Data from The Korea National Health and Nutrition Examination Survey 1998–2016: The Korean Working Group of Pediatric Hypertension

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ABSTRACT

Background and Objectives: Hypertension is becoming one of the most common health conditions in children and adolescents due to increasing childhood obesity. We aimed to provide the auscultatory blood pressure (BP) normative reference values for Korean non-overweight children and adolescents.
Methods: BP measurements in children and adolescents aged 10 to 18 years were performed in the Korean National Health and Nutrition Examination Survey (KNHANES) from 1998 to 2016. BP was measured using a mercury sphygmomanometer. Sex-, age- and height-specific

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The authors have no financial conflicts of interest.

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systolic BP (SBP) and diastolic BP (DBP) percentiles were calculated in the non-overweight children (n=10,442). We used the General Additive Model for Location Scale and Shape method to calculate BP percentiles.
Results: The 50th, 90th, 95th, and 99th percentiles of SBP and DBP tables and graphs of non-overweight children and adolescents aged 10 to 18 years were presented by age and height percentiles. We found that the SBP and DBP at the 95th percentile were well correlated with height. The BP tables presented by height contained BP values from 124 cm to 190 cm for boys and from 120 cm to 178 cm for girls. Boys had higher SBP and DBP.
Conclusions: We provided the sex-, age- and height-specific auscultatory BP values using the KNHANES big data. These may be useful in diagnosis and treatment of hypertension in Korean children and adolescents.

Keywords: Blood pressure; Hypertension; Adolescent; Auscultation

INTRODUCTION

Elevated blood pressure (BP) in children and adolescents is becoming one of the most common health conditions worldwide due to the increased prevalence of overweightness and obesity in this age group.[1)2)] The prevalence of hypertension has been increasing among obese children and adolescents in particular.[3)] Control of pediatric hypertension is very important since it is related to cardiovascular morbidity and mortality in adulthood.[4)]

The definition of pediatric hypertension is based on the normative distribution of BP in the population and defined as systolic BP (SBP) and/or diastolic BP (DBP) ≥95th percentile.[5)] Diagnosis is complicated because the reference values are sex-, age- and height-specific.[5)] In addition, the classification of BP in adolescents varies between guidelines.[5-7)]

The National High Blood Pressure Education Program (NHBPEP) Working Group on High Blood Pressure in Children and Adolescents suggested a definition of hypertension and provided normative BP reference values arranged by age, sex, height, and height percentile in "The Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents",[5)] which has been adopted by other guidelines' standard BP tables.[6)8)] These tables contained data from children and adolescents, including overweight and obese individuals. Overweightness and obesity are known to have an effect on BP;[9)] therefore, the NHBPEP's 2017 Clinical Practice Guideline contains new tables based on the same population data while excluding overweight and obese participants.[7)]

Other groups have also established country-specific BP tables for limited age groups.[10-12)] The Identification and prevention of Dietary- and lifestyle-induced health EFfects In Children and infantS (IDEFICS) consortium provide oscillometric BP reference values in European non-overweight schoolchildren aged 2 to 11 years for monitoring and planning population strategies for disease prevention.[10)]

Previous Korean studies on normative BP tables have been performed. In 2008, Lee et al.[13)] provided normative age-, sex-, and height-specific BP references using data from Korean children and adolescents aged 7 to 20 years. However, BP measurements were performed using oscillometric devices, which makes their clinical application difficult since hypertension is diagnosed using the auscultatory method.[5-7)] Kim et al.[14)] also established

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BP tables using data from the Korean National Health and Nutrition Examination Survey (KNHANES) in which auscultatory BP measurements were performed. These BP tables include the data of overweight and obese individuals; therefore, they cannot represent normative BP values for normal-weight youth.

In this study, we aimed to develop normative age-, sex-, and height-specific BP tables using BP data of non-overweight children and adolescents aged 10 to 18 years from the KNHANES between 1998 and 2016.

METHODS

Study population

This study was based on data acquired from the KNHANES. The KNHANES is a nationally representative cross-sectional survey that collects health- and nutrition-related data annually from stratified, multistage probability samples of Korean households representing the civilian, noninstitutionalized population. The KNHANES consists of health interview, health behavior, health examination, and nutritional surveys. A detailed description of the plan and operation of the survey is available on the KNHANES website (http://knhanes.cdc.go.kr/).[15)16)]

After exclusion of overweight and obese participants (body mass index [BMI] >85th percentile), we analyzed 10,442 participants (5,489 boys and 4,953 girls) aged 10–18 years from KNHANES conducted from 1998 to 2016. Informed consent was obtained from all participants in the KNHANES. The protocol of the KNHANES was approved by the Institutional Review Board of the Korea Centers for Disease Control and Prevention (KCDC) (X-1604-344-901).

Anthropometric measurements

Anthropometric measurements of all participants were performed by trained personnel. Height was determined to the nearest 0.1 cm using a stadiometer (Seca 225; Seca, Hamburg, Germany). Weight was measured to the nearest 0.1 kg using an electronic balance (GL-6000-20; G-tech, Seoul, Korea). BP was measured with a mercury sphygmomanometer with a cuff of appropriate size after the participant had been seated quietly for 5 minutes with the right arm supported at the level of the heart. The same instruments (Baumanometer sphygmomanometer; W.A. Baum Co Inc., Copiague, NY, USA and Littmann Stethoscopes; 3M, Maplewood, MN, USA) were used across the surveys. The appropriate cuff size was defined as an inflatable bladder width that is at least 40% of the arm's circumference at a point midway between the olecranon and the acromion. For such a cuff to be considered optimal, its bladder length must cover 80% to 100% of the arm's circumference. Quality control of BP measurement methods was conducted during each survey. Healthcare professionals (nurses and technicians) were trained before each KNHANES according to a standardized protocol. The first (K1; the first appearance of sound) and fifth (K5; the disappearance of sound) Korotkoff sounds represented the SBP and DBP, respectively. BP was measured 3 times in each participant, and the mean SBP and DBP was calculated as the average of the second and third readings.

Overweightness was defined as 85th percentile ≤ BMI <95th percentile, and obesity as BMI ≥95th percentile according to the age- and sex-specific reference standards for Korean children and adolescents.[17)] The KCDC reference data were used to determine sex- and age-specific percentile cutoffs for height.[17)]

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Statistical method

We estimated percentiles of SBP and DBP as a function of age and height as covariates, stratified by sex using the General Additive Models for Location Scale and Shape method.

The functions were derived by considering all possible linear and additive effects of age and height on SBP and DBP. Among the many functional combinations considered, the model that minimized the Akaike information criterion was adopted as the most optimal model to estimate the percentiles of BP. Finally, using the most optimal model, the reference values of 50th, 90th, and 95th percentiles of SBP and DBP were computed by each age and height for non-overweight boys and girls.

In addition, comparisons of SBP and DBP according to sex and height and BP were conducted using Stata/SE 15 (StataCorp, College Station, TX, USA). A p value <0.05 was considered statistically significant.

RESULTS

From 1998 to 2016, BP measurements were performed in 12,416 children and adolescents aged 10 to 18 years. Among them, 10,442 non-overweight participants were included in the final analysis (**Table 1**). The sample was composed equally of boys and girls (boys to girls=5,489 [52.6%] to 4,953 [47.4%)]). The mean values of height and BMI according to age are presented in **Table 1**.

Tables 2 and **3** present the normative auscultatory SBP and DBP percentiles (50th, 90th, 95th, and 99th) for non-overweight children and adolescents by age. Overall, boys had a significantly higher SBP at the 95th percentile compared to girls (p=0.044); however, there was no significant difference in DBP at the 95th percentile (p=0.356). The SBP at the 95th percentile of boys was higher than that of girls for all ages, and the DBP at the 95th percentile

Table 1. Characteristics of normal* weight participants

Sex	Age (years)	Number of participants	Height (cm)	BMI (kg/m^2)
Boys	10	659	142.8 (6.4)	19.1 (3.2)
	11	686	149.4 (7.1)	19.7 (3.5)
	12	691	156.7 (7.9)	20.0 (3.7)
	13	670	163.8 (7.5)	20.5 (3.6)
	14	648	168.8 (6.4)	21.2 (4.0)
	15	609	171.9 (5.7)	21.5 (3.8)
	16	554	173.1 (5.9)	21.8 (3.8)
	17	516	174.0 (6.1)	22.1 (3.7)
	18	456	174.2 (5.9)	22.4 (3.9)
Girls	10	644	143.4 (7.0)	17.9 (2.7)
	11	589	150.2 (7.0)	18.6 (3.1)
	12	609	155.5 (6.2)	19.3 (3.1)
	13	619	158.2 (5.4)	20.2 (3.0)
	14	570	159.8 (5.1)	20.5 (3.1)
	15	505	160.0 (5.1)	20.6 (3.1)
	16	515	160.8 (5.2)	21.1 (3.5)
	17	495	161.2 (5.6)	21.4 (3.3)
	18	407	161.3 (5.8)	21.4 (3.2)

Data are shown as mean (standard deviation).
BMI = body mass index.
*Normal weight is defined as a BMI <85th percentile.

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Table 2. BP percentiles for boys by age

Age (years)	SBP percentile (mmHg)				DBP percentile (mmHg)			
	50th	90th	95th	99th	50th	90th	95th	99th
10	102	115	120	128	60	71	74	81
11	104	118	122	131	62	73	76	83
12	106	120	124	133	64	75	78	85
13	108	122	126	136	65	77	80	86
14	110	124	128	138	67	78	81	88
15	111	125	130	140	68	80	83	89
16	112	127	132	141	70	81	84	90
17	114	129	133	143	71	82	85	91
18	115	130	135	145	72	83	86	92

BP = blood pressure; SBP = systolic blood pressure; DBP = diastolic blood pressure.

Table 3. BP percentiles for girls by age

Age (years)	SBP percentile (mmHg)				DBP percentile (mmHg)			
	50th	90th	95th	99th	50th	90th	95th	99th
10	102	115	119	128	62	73	76	83
11	103	117	121	129	63	74	77	84
12	105	118	122	131	64	75	78	85
13	106	119	123	132	65	76	79	85
14	106	120	124	133	66	77	80	86
15	107	121	125	133	67	77	80	87
16	108	121	125	134	68	78	81	87
17	108	122	126	135	68	79	82	88
18	109	122	127	135	69	79	82	88

BP = blood pressure; SBP = systolic blood pressure; DBP = diastolic blood pressure.

of boys was higher after the age of 13 years. **Figure 1** shows BP curves of SBP and DBP at the 50th, 90th, 95th, and 99th percentiles for boys and girls by age.

Tables 4 and **5** show normative auscultatory SBP and DBP percentiles (50th, 90th, 95th, and 99th) for non-overweight children and adolescents by height. These tables contain SBP and DBP percentiles from 124 cm to 190 cm for boys and from 120 cm to 178 cm for girls.

Overall, boys had higher SBP (p=0.001) and DBP (p=0.002) at the 95th percentile compared to girls by age. Boys taller than 146 cm had higher SBP at the 95th percentile compared to girls of the same height; however, the DBP at the 95th percentile of boys was higher than that of girls at all heights. **Figure 1** shows the SBP and DBP 50th, 90th, 95th, 99th percentile curves for boys and girls by height.

Hypertension was defined as SBP and/or DBP ≥95th percentile in accordance with the Fourth NHBPEP Working Group on High Blood Pressure in Children and Adolescents reports, the 2017 Clinical Practice guidelines, and the European guidelines.[5-7] In the present study, the SBP and DBP values at the 95th percentile were strongly correlated with height (SBP for boys, r=2.55, p<0.001, 95% confidence interval [CI], 2.52–2.58; DBP for boys, r=4.01, p<0.001, 95% CI, 3.88–4.14; SBP for girls, r=3.21, p<0.001, 95% CI, 3.18–3.5; DBP for girls, r=4.73, p<0.001, 95% CI, 4.51–4.94). The SBP and DBP values at the 50th, 90th, 99th percentile also showed a strong correlation with height.

Tables 6 and **7** show the age- and height-stratified SBP and DBP distributions (50th, 90th, 95th, and 99th BP percentiles according to the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles of height at the same ages) in non-overweight children participating in the KNHANES.

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DISCUSSION

Our study provided normative BP tables and graphs of non-overweight children and adolescents aged 10 to 18 years by age and height. Boys had higher SBP and DBP at the 95th percentile. We found that the SBP and DBP at the 95th percentile were well correlated with height. The BP tables presented by height contain BP values from 124 cm to 190 cm for boys and from 120 cm to 178 cm for girls.

In our study, boys had higher SBP at the 95th percentile and higher SBP and DBP at the 95th percentile compared to girls by height; however, there was no significant difference in the DBP at the 95th percentile compared to girls by age. The new BP tables of the 2017 Clinical Practice Guidelines also showed higher SBP and DBP at the 95th percentile in boys than in

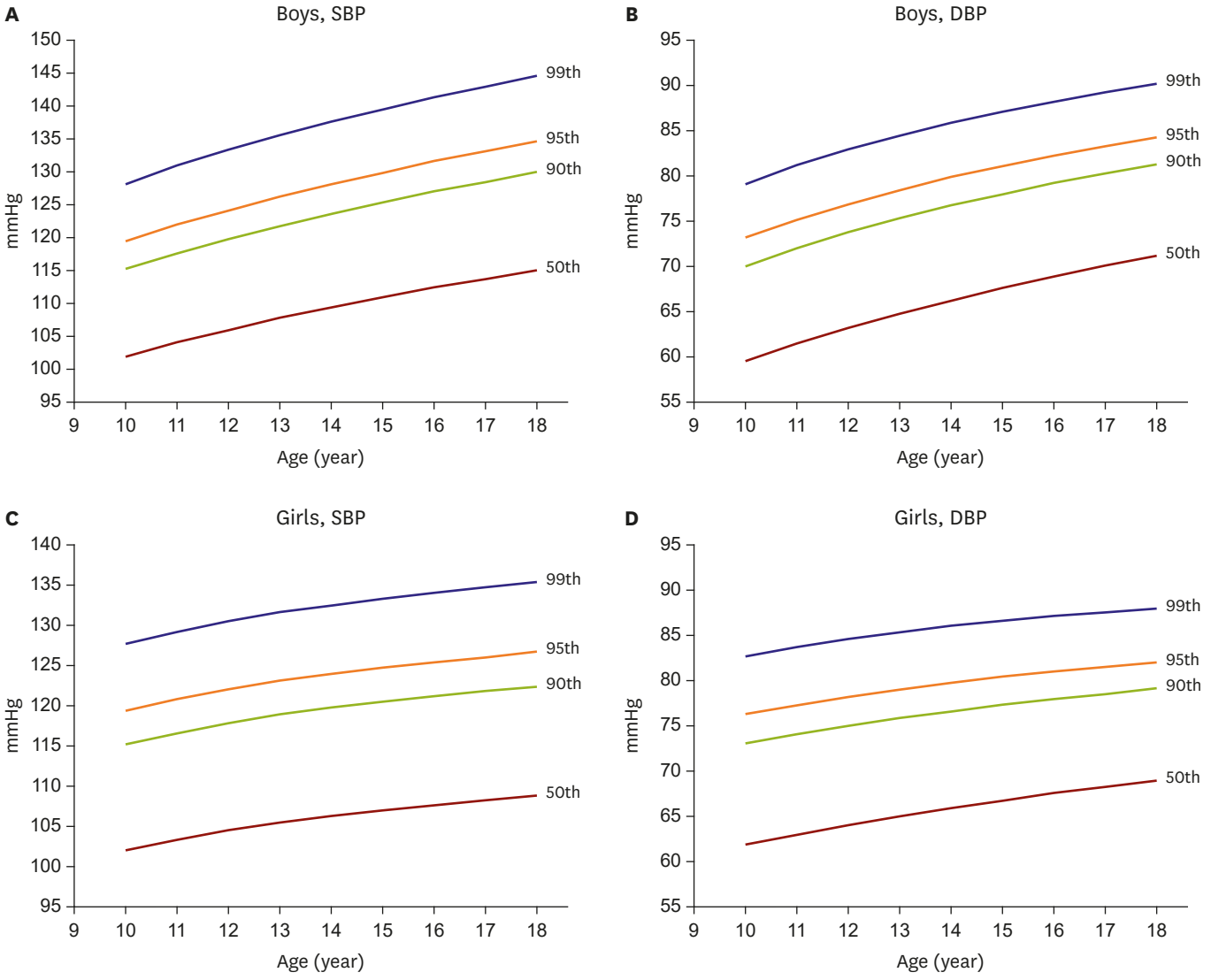

Figure 1. BP percentiles by (A-D) age and by (E-H) height. (A) SBP for boys by age. (B) DBP for boys by age. (C) SBP for girls by age. (D) DBP for girls by age. (E) SBP for boys by height. (F) DBP for boys by height. (G) SBP for girls by height. (H) DBP for girls by height.
BP = blood pressure; DBP = diastolic blood pressure; SBP = systolic blood pressure.

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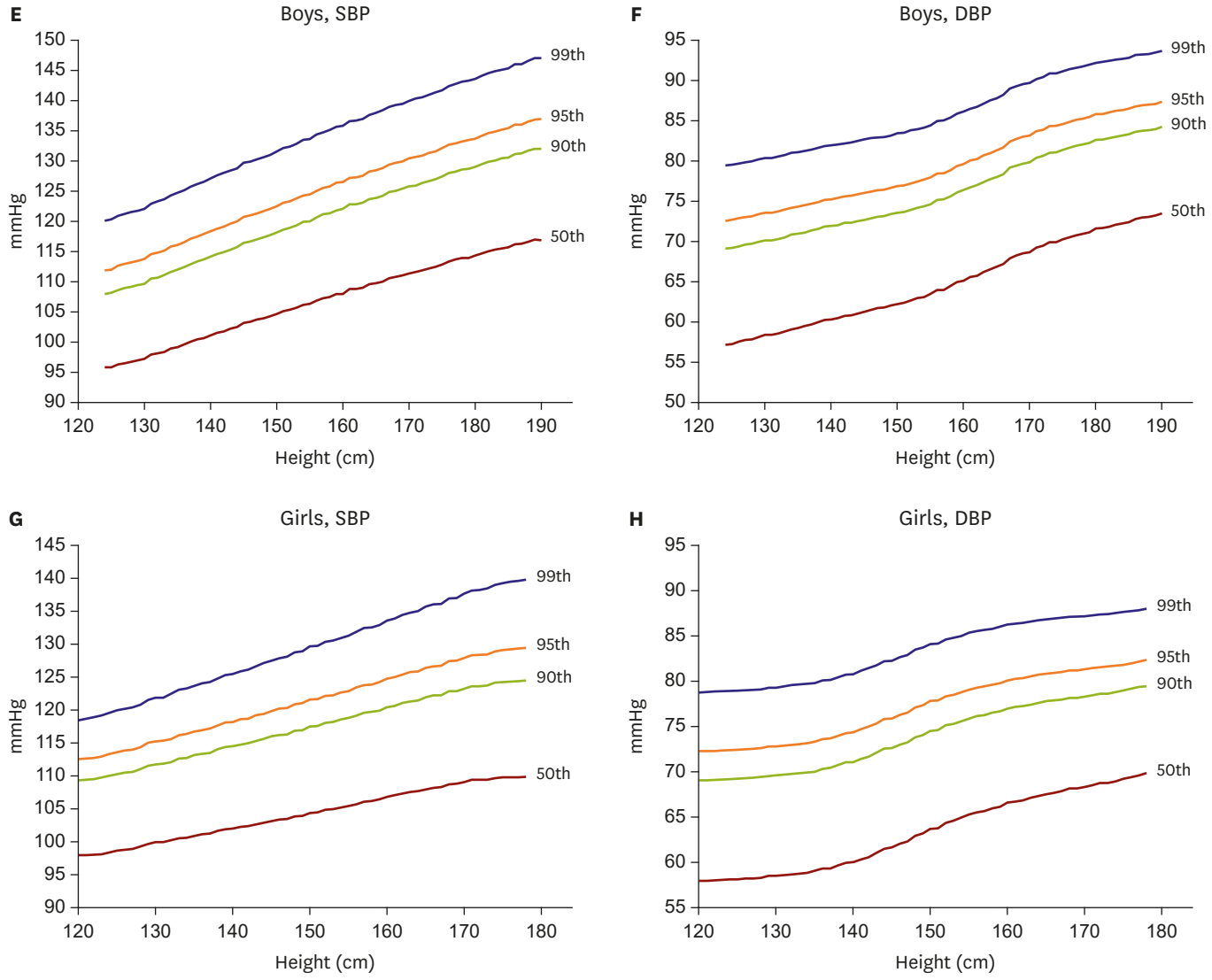

Figure 1. (Continued) BP percentiles by (A-D) age and by (E-H) height. (A) SBP for boys by age. (B) DBP for boys by age. (C) SBP for girls by age. (D) DBP for girls by age. (E) SBP for boys by height. (F) DBP for boys by height. (G) SBP for girls by height. (H) DBP for girls by height.
BP = blood pressure; DBP = diastolic blood pressure; SBP = systolic blood pressure.

girls of the same age.[7] This phenomenon might be explained by genetic differences between the sexes.

The definition of pediatric hypertension varies, and should ideally refer to normative BP values.[2][6][7] In the European and Canadian guidelines for diagnosis of hypertension, the normative BP tables of 'The Fourth Report' are used.[6][8] The 2017 Clinical Practice Guideline presents new BP tables of non-overweight children and adolescents updated from The Fourth Report.[7] However, BP levels in adolescence differ between different ethnic populations.[18] In our study, the values of SBP at the 95th percentile for 10-year-old boys were 1–4 mmHg higher and the values of DBP at the 95th percentile were 2–3 mmHg lower than the new BP tables in the 2017 Clinical Practice Guidelines. On the other hand, the values of SBP at the 95th percentile for boys of the same age were 7–8 mmHg higher and the values of DBP at the 95th percentile were 5–10 mmHg higher than the Chinese BP tables.[12] In the Chinese study,

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Table 4. BP percentiles for boys by height

Height (cm)	SBP percentile (mmHg)				DBP percentile (mmHg)			
	50th	90th	95th	99th	50th	90th	95th	99th
124	96	108	112	120	57	69	73	79
126	96	109	113	121	57	69	73	80
128	97	109	113	122	58	70	73	80
130	97	110	114	122	58	70	74	80
132	98	111	115	123	59	70	74	81
134	99	112	116	124	59	71	74	81
136	100	113	117	125	59	71	75	81
138	101	113	118	126	60	71	75	82
140	101	114	118	127	60	72	75	82
142	102	115	119	128	61	72	76	82
144	103	116	120	129	61	73	76	82
146	103	117	121	130	61	73	76	83
148	104	117	122	131	62	73	76	83
150	105	118	123	132	62	74	77	83
152	105	119	123	132	63	74	77	84
154	106	120	124	134	63	74	78	84
156	107	121	125	134	64	75	78	85
158	108	121	126	135	64	76	79	85
160	108	122	127	136	65	76	80	86
162	109	123	127	137	66	77	80	87
164	110	124	128	138	67	78	81	87
166	110	124	129	138	67	78	82	88
168	111	125	130	139	68	79	83	89
170	112	126	130	140	69	80	83	90
172	112	126	131	141	69	81	84	90
174	113	127	132	141	70	81	84	91
176	113	128	133	142	70	82	85	91
178	114	129	133	143	71	82	85	92
180	114	129	134	144	72	83	86	92
182	115	130	135	145	72	83	86	92
184	116	130	135	145	72	83	86	93
186	116	131	136	146	73	84	87	93
188	117	132	137	147	73	84	87	93
190	117	132	137	147	73	84	87	94

BP = blood pressure; SBP = systolic blood pressure; DBP = diastolic blood pressure.

the 10-year-old boys were 4–8 cm shorter than Korean boys of the same age. This difference emphasizes the need for data for specific ethnicities. We will analyze these differences in our next study.

The normative BP tables from other study groups are based on sex, age, and height.[2)7)10-12)] It is reasonable to develop normative BP tables not only by age but also by height because the height differed by 17 to 25 cm in the same age group in our study, and SBP and DBP at the 95th percentile were better correlated with height than age. Additionally, since height distribution varies according to the ethnic population, the BP cutoffs for exact height values are helpful for more practical and accurate diagnosis of individual BP assessment.

In The Fourth Report, the normative BP reference values contained the data from children and adolescents, including overweight and obese individuals. Overweightness and obesity are known to have an effect on BP.[9)] Since they are strongly correlated with elevated BP, BP data that includes measurements obtained from overweight and obese individuals may bias the diagnosis of hypertension.[7)] For this reason, recent BP references exclude overweight and obese individuals to represent normative BP values for normal-weight children and

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Table 5. BP percentiles for girls by height

Height (cm)	SBP percentile (mmHg)				DBP percentile (mmHg)			
	50th	90th	95th	99th	50th	90th	95th	99th
120	98	109	113	119	58	69	72	79
122	98	110	113	119	58	69	72	79
124	98	110	113	120	58	69	72	79
126	99	111	114	120	58	69	73	79
128	99	111	114	121	58	69	73	79
130	100	112	115	122	58	70	73	79
132	100	112	116	122	59	70	73	80
134	101	113	116	123	59	70	73	80
136	101	113	117	124	59	70	74	80
138	102	114	118	125	60	71	74	80
140	102	115	118	126	60	71	74	81
142	102	115	119	126	61	72	75	81
144	103	116	120	127	62	73	76	82
146	103	116	120	128	62	73	76	83
148	104	117	121	129	63	74	77	83
150	104	117	122	130	64	75	78	84
152	105	118	122	130	64	75	78	85
154	105	119	123	131	65	76	79	85
156	106	119	123	132	66	76	79	86
158	106	120	124	133	66	77	80	86
160	107	120	125	134	67	77	80	86
162	107	121	125	134	67	77	80	86
164	108	121	126	135	67	78	81	87
166	108	122	127	136	68	78	81	87
168	109	123	127	137	68	78	81	87
170	109	123	128	138	68	78	81	87
172	109	124	128	138	69	79	82	87
174	110	124	129	139	69	79	82	88
176	110	124	129	139	69	79	82	88
178	110	125	129	140	70	79	82	88

BP = blood pressure; SBP = systolic blood pressure; DBP = diastolic blood pressure.

adolescents.[7)10)12)] In our study, the normative BP values also excluded overweight and obese children and adolescents.

We presented the normative BP values using data from KNHANES, which has been conducted to evaluate the health and nutritional status of the Korean population since 1998.[15)] The well-designed and controlled surveys performed by the Korean Centers for Disease Control and Prevention and the statistics and data collected by KNHANES have been used for assessing the health indicators requested by international organizations and the development of growth charts for Korean children and adolescents. Other study groups have also used their national data for normative BP tables. The NHBPEP Working Group on High Blood Pressure in Children and Adolescents included data from the US National Health and Nutritional Examination Survey in the BP tables presented in The Fourth Report.[5)] The Chinese study also used data from the China Health and Nutritional Survey conducted from 1991 to 2009.[12)]

In 2008, Lee et al.[13)] provided normative age-, sex-, and height-specific oscillometric BP references using data from 57,433 Korean children and adolescents aged 7 to 20 years. However, the oscillometric measurement approach makes it difficult to apply the results to the clinical setting since diagnosis of hypertension is performed by the auscultatory method.[5-7)] In a previous other study, the Dinamap systolic pressure data were found to be 10 mmHg higher than the auscultatory data, while diastolic pressures were 5 mmHg higher.[19)] In

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Table 6. BP percentiles for boys by age and height percentile

Age (years)	Height (cm)	Height Percentile	SBP percentile (mmHg)				DBP percentile (mmHg)			
			50th	90th	95th	99th	50th	90th	95th	99th
10	131.9	5th	98	111	115	123	58	70	74	80
	134.0	10th	99	112	116	124	59	70	74	80
	137.5	25th	100	113	117	126	59	71	74	81
	141.5	50th	102	115	119	127	60	71	74	81
	145.6	75th	103	116	120	129	60	72	75	81
	149.4	90th	104	117	121	130	61	72	75	81
	151.7	95th	104	118	122	131	61	72	75	81
11	137.0	5th	101	114	118	127	60	72	75	82
	139.3	10th	102	115	119	127	60	72	76	82
	143.2	25th	103	116	120	129	61	72	76	82
	147.7	50th	104	117	121	130	62	73	76	82
	152.2	75th	105	119	123	132	62	73	77	83
	156.4	90th	106	120	124	133	63	74	77	83
	158.9	95th	107	121	125	134	63	74	77	83
12	142.6	5th	103	116	120	129	62	74	77	83
	145.3	10th	104	117	121	130	62	74	77	84
	149.8	25th	105	118	123	131	63	74	78	84
	154.7	50th	106	120	124	133	64	75	78	84
	159.6	75th	108	122	126	135	64	75	78	85
	164.0	90th	109	123	127	136	65	76	79	85
	166.5	95th	109	123	128	137	65	76	79	85
13	149.1	5th	105	118	123	132	64	75	79	85
	152.0	10th	106	120	124	133	64	76	79	85
	156.8	25th	107	121	126	135	65	76	79	86
	161.8	50th	109	123	127	136	66	77	80	86
	166.5	75th	110	124	128	138	66	77	80	86
	170.6	90th	111	125	130	139	67	77	81	86
	173.0	95th	111	125	130	139	67	78	81	87
14	155.4	5th	108	121	126	135	66	77	80	87
	158.2	10th	108	122	127	136	66	77	81	87
	162.7	25th	109	124	128	137	67	78	81	87
	167.2	50th	110	125	129	139	67	78	81	87
	171.5	75th	111	126	130	140	68	79	82	88
	175.1	90th	112	126	131	141	68	79	82	88
	177.2	95th	112	127	132	141	69	79	82	88
15	160.1	5th	109	124	128	137	67	79	82	88
	162.5	10th	110	124	129	138	68	79	82	88
	166.3	25th	111	125	130	139	68	79	83	89
	170.4	50th	112	126	131	140	69	80	83	89
	174.3	75th	113	127	132	141	69	80	83	89
	177.7	90th	113	128	133	142	70	80	83	89
	179.6	95th	114	128	133	143	70	81	84	89
16	162.8	5th	111	125	129	139	69	80	83	90
	164.9	10th	111	125	130	139	69	80	84	90
	168.3	25th	112	126	131	140	69	81	84	90
	172.1	50th	112	127	132	141	70	81	84	90
	175.8	75th	113	128	133	142	70	81	84	90
	179.2	90th	114	129	134	143	71	82	85	91
	181.1	95th	115	129	134	144	71	82	85	91
17	164.1	5th	111	125	130	139	70	81	85	91
	166.1	10th	112	126	131	140	70	81	85	91
	169.4	25th	112	127	131	141	70	82	85	91
	173.1	50th	113	128	133	142	71	82	85	92
	176.9	75th	114	129	134	143	72	82	86	92
	180.3	90th	115	130	134	144	72	83	86	92
	182.3	95th	115	130	135	145	72	83	86	92

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Table 6. (Continued) BP percentiles for boys by age and height percentile

Age (years)	Height (cm)	Height Percentile	SBP percentile (mmHg)				DBP percentile (mmHg)			
			50th	90th	95th	99th	50th	90th	95th	99th
18	165.1	5th	112	126	131	140	71	82	86	92
	167.1	10th	112	127	131	141	71	83	86	92
	170.4	25th	113	128	132	142	71	83	86	93
	174.1	50th	114	128	133	143	72	83	87	93
	177.9	75th	115	130	134	144	72	84	87	93
	181.3	90th	116	131	135	145	73	84	87	93
	183.5	95th	116	131	136	146	73	84	87	93

BP = blood pressure; SBP = systolic blood pressure; DBP = diastolic blood pressure.

Table 7. BP percentiles for girls by age and height percentile

Age (years)	Height (cm)	Height percentile	SBP percentile (mmHg)				DBP percentile (mmHg)			
			50th	90th	95th	99th	50th	90th	95th	99th
10	132.1	5th	99	112	115	123	59	69	72	78
	134.3	10th	99	112	116	124	59	70	73	78
	138.0	25th	100	113	117	125	60	71	73	79
	142.2	50th	101	114	118	126	61	71	74	80
	146.5	75th	103	116	120	128	62	72	75	81
	150.4	90th	104	117	121	129	62	73	76	82
	152.8	95th	104	118	122	130	63	74	77	83
11	138.0	5th	101	114	118	125	61	71	74	80
	140.4	10th	101	114	118	126	61	72	75	80
	144.4	25th	102	115	119	127	62	72	75	81
	148.7	50th	103	117	121	129	63	73	76	82
	152.9	75th	105	118	122	130	63	74	77	83
	156.5	90th	105	119	123	131	64	75	78	84
	158.7	95th	106	119	124	132	64	75	79	85
12	143.6	5th	102	115	119	127	62	73	76	81
	146.0	10th	103	116	120	128	63	73	76	82
	149.8	25th	104	117	121	129	63	74	77	83
	153.9	50th	105	118	122	131	64	75	78	84
	157.8	75th	106	119	123	131	65	76	79	85
	161.2	90th	106	120	124	132	65	76	79	85
	163.1	95th	107	120	125	133	66	77	80	86
13	147.9	5th	104	117	121	129	63	74	77	83
	150.0	10th	104	118	122	130	64	75	78	83
	153.5	25th	105	118	123	131	64	75	78	84
	157.3	50th	106	119	124	132	65	76	79	85
	160.9	75th	107	120	124	133	66	77	80	86
	164.1	90th	107	121	125	133	66	77	80	86
	166.0	95th	108	121	126	134	66	77	81	87
14	150.0	5th	105	118	122	130	64	75	78	84
	152.1	10th	105	119	123	131	65	75	78	84
	155.4	25th	106	119	123	131	65	76	79	85
	159.0	50th	107	120	124	132	66	77	80	86
	162.6	75th	107	121	125	133	66	77	80	86
	165.7	90th	108	122	126	134	67	78	81	87
	167.5	95th	108	122	126	135	67	78	81	87
15	151.1	5th	106	119	123	131	65	76	79	85
	153.1	10th	106	119	123	131	65	76	79	85
	156.3	25th	107	120	124	132	66	77	80	86
	159.8	50th	107	121	125	133	67	77	80	86
	163.3	75th	108	122	126	134	67	78	81	87
	166.5	90th	109	122	126	135	68	78	82	88
	168.3	95th	109	123	127	135	68	79	82	88

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Table 7. (Continued) BP percentiles for girls by age and height percentile

Age (years)	Height (cm)	Height percentile	SBP percentile (mmHg)				DBP percentile (mmHg)			
			50th	90th	95th	99th	50th	90th	95th	99th
16	151.8	5th	106	119	123	131	65	76	79	85
	153.7	10th	106	120	124	132	66	76	79	85
	156.7	25th	107	120	124	133	66	77	80	86
	160.1	50th	108	121	125	133	67	78	81	87
	163.6	75th	108	122	126	134	67	78	81	87
	166.8	90th	109	123	127	135	68	79	82	88
	168.7	95th	109	123	127	136	68	79	82	89
17	152.5	5th	106	119	124	132	66	76	79	85
	154.2	10th	107	120	124	132	66	77	80	86
	157.1	25th	107	121	125	133	67	77	80	86
	160.5	50th	108	122	126	134	67	78	81	87
	163.9	75th	109	122	127	135	68	79	82	88
	167.1	90th	109	123	127	136	69	79	82	89
	169.0	95th	110	124	128	136	69	80	83	89
18	153.0	5th	107	120	124	132	66	77	80	86
	154.7	10th	107	120	124	132	67	77	80	86
	157.6	25th	108	121	125	133	67	78	81	87
	160.9	50th	109	122	126	134	68	78	82	88
	164.3	75th	109	123	127	135	68	79	82	88
	167.4	90th	110	124	128	136	69	80	83	89
	169.3	95th	110	124	128	136	69	80	83	89

BP = blood pressure; SBP = systolic blood pressure; DBP = diastolic blood pressure.

addition, DBP assessed using the Dinamap Procare 200 monitor, which was used in the study by Lee et al.[20], failed the 2010 International Protocol of European Society of Hypertension. These findings preclude the interchange of the auscultatory and oscillometric methods. In our study, the values of SBP and DBP at the 95th percentile of 10-year-old boys were 4–6 mmHg lower and 1–3 mmHg higher, respectively, than references provided by Lee et al.[20]

Unlike previous Korean studies,[13][14] the normative BP tables in this study present the patients' height according to the sex-, age-, and height percentiles (**Tables 6** and **7**). Physicians can use these height data to determine a patient's height percentile and diagnose hypertension if SBP and/or DBP are ≥95th percentile.

Applying normative BP references in real practice faces another challenge since the definition of hypertension in adolescents differs between guidelines. For example, pediatric hypertension in The Fourth Report is defined as SBP and/or DBP ≥95th percentile for sex, age and height on repetitive measurement.[5] The 2016 European Society for Hypertension guidelines use a definition for individuals 16 years or older that is based on the absolute cutoff used for adults, ≥140/90 mmHg.[6] In contrast, the Clinical Practice Guideline, which was revised from The Fourth Report, defined hypertension in patients 13 years or older as ≥130/80 mmHg, which corresponds to the American Heart Association guidelines' definition.[7] Since there are no Korean guidelines for pediatric hypertension, the decision to use a particular definition for diagnosis is arbitrary. The definition of hypertension for Korean children and adolescents will be discussed in the next Korean Pediatric Hypertension Guideline developed by the Korean Working Group of Pediatric Hypertension.

Our study has some limitations. First, regarding the age range of the reference values, we could not provide normative data for participants younger than 10 years. This resulted from the fact that we used the data from KNHANES. In these surveys, the items differ according

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to the participants' age and the year in which the survey was conducted. Throughout the surveys, BP measurements have been performed for participants older than 10 years, which resulted in a lack of data from children who are younger than 10 years. Second, BP measurements had been performed by well-trained nurses at public health centers between 1998 and 2005, and at the KCDC from 2007 onwards. In spite of quality control during BP measurements and training of healthcare professionals, intra- and interobserver variability is inevitable. Statistical correction for this variability was not performed, which is another limitation of the present study.

In conclusion, we developed normative reference values of sex-, age- and height-specific auscultatory BP using the KNHANES big data. These may be useful in early diagnosis and treatment of hypertension in Korean children and adolescents, thus minimizing the long-term consequences of hypertension.

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