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
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. The prevalence of hypertension has been increasing among obese children and adolescents in particular. Control of pediatric hypertension is very important since it is related to cardiovascular morbidity and mortality in adulthood.

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. Diagnosis is complicated because the reference values are sex-, age- and height-specific. In addition, the classification of BP in adolescents varies between guidelines.

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”, which has been adopted by other guidelines’ standard BP tables. These tables contained data from children and adolescents, including overweight and obese individuals. Overweightness and obesity are known to have an effect on BP, therefore, the NHBPEP’s 2017 Clinical Practice Guideline contains new tables based on the same population data while excluding overweight and obese participants.

Other groups have also established country-specific BP tables for limited age groups. The Identification and prevention of Dietary- and lifestyle-induced health EFrfects 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.

Previous Korean studies on normative BP tables have been performed. In 2008, Lee et al. 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. Kim et al. also established...
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/). 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. The KCDC reference data were used to determine sex- and age-specific percentile cutoffs for height.
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/m²) |
|-----|-------------|------------------------|-------------|-------------|
| 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.
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 NHANES Working Group on High Blood Pressure in Children and Adolescents reports, the 2017 Clinical Practice guidelines, and the European guidelines. 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, 3.18–3.53; DBP for girls, r=4.73, p<0.001, 95% CI, 4.45–4.94). 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.
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 girls.

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. (continued to the next page)
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. In the European and Canadian guidelines for diagnosis of hypertension, the normative BP tables of ‘The Fourth Report’ are used. However, BP levels in adolescence differ between different ethnic populations. 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.

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.
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. 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. 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. 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 4. BP percentiles for boys by height**

| Height (cm) | 50th SBP percentile (mmHg) | 90th SBP percentile (mmHg) | 95th SBP percentile (mmHg) | 99th SBP percentile (mmHg) | 50th DBP percentile (mmHg) | 90th DBP percentile (mmHg) | 95th DBP percentile (mmHg) | 99th DBP percentile (mmHg) |
|-------------|-----------------------------|------------------------------|----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| 124         | 95                          | 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                          | 83                          |
| 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.
adolescents. 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. 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. The Chinese study also used data from the China Health and Nutritional Survey conducted from 1991 to 2009.

In 2008, Lee et al. 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. 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.

### Table 5. BP percentiles for girls by height

| Height (cm) | 50th SBP percentile (mmHg) | 90th SBP percentile (mmHg) | 95th SBP percentile (mmHg) | 99th SBP percentile (mmHg) | 50th DBP percentile (mmHg) | 90th DBP percentile (mmHg) | 95th DBP percentile (mmHg) | 99th DBP percentile (mmHg) |
|-------------|-----------------------------|----------------------------|-----------------------------|-----------------------------|-----------------------------|----------------------------|-----------------------------|-----------------------------|
| 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                        | 132                        | 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.
### 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                  |
|             |             |                   |                       |                       |                       |                       |
| **10**      | 131.9       | 5th               | 98                    | 111                   | 115                   | 123                   |
|             | 134.0       | 10th              | 99                    | 112                   | 116                   | 124                   |
|             | 137.5       | 25th              | 100                   | 113                   | 117                   | 126                   |
|             | 141.5       | 50th              | 102                   | 115                   | 119                   | 127                   |
|             | 145.6       | 75th              | 103                   | 116                   | 120                   | 129                   |
|             | 149.4       | 90th              | 104                   | 117                   | 121                   | 130                   |
|             | 151.7       | 95th              | 104                   | 118                   | 122                   | 131                   |
| **11**      | 137.0       | 5th               | 101                   | 114                   | 118                   | 127                   |
|             | 139.3       | 10th              | 102                   | 115                   | 119                   | 127                   |
|             | 143.2       | 25th              | 103                   | 116                   | 120                   | 129                   |
|             | 147.7       | 50th              | 104                   | 117                   | 121                   | 130                   |
|             | 152.2       | 75th              | 105                   | 119                   | 123                   | 132                   |
|             | 156.4       | 90th              | 106                   | 120                   | 124                   | 133                   |
|             | 158.9       | 95th              | 107                   | 121                   | 125                   | 134                   |
| **12**      | 142.6       | 5th               | 103                   | 116                   | 120                   | 129                   |
|             | 145.5       | 10th              | 104                   | 117                   | 121                   | 130                   |
|             | 149.8       | 25th              | 105                   | 118                   | 123                   | 131                   |
|             | 154.7       | 50th              | 106                   | 120                   | 124                   | 133                   |
|             | 159.6       | 75th              | 108                   | 122                   | 126                   | 135                   |
|             | 164.0       | 90th              | 109                   | 123                   | 127                   | 136                   |
|             | 166.5       | 95th              | 109                   | 123                   | 128                   | 137                   |
| **13**      | 149.1       | 5th               | 105                   | 118                   | 123                   | 132                   |
|             | 152.0       | 10th              | 106                   | 120                   | 124                   | 133                   |
|             | 156.8       | 25th              | 107                   | 121                   | 126                   | 135                   |
|             | 161.8       | 50th              | 109                   | 123                   | 127                   | 136                   |
|             | 166.5       | 75th              | 110                   | 124                   | 128                   | 138                   |
|             | 170.6       | 90th              | 111                   | 125                   | 130                   | 139                   |
|             | 173.0       | 95th              | 111                   | 125                   | 130                   | 139                   |
| **14**      | 155.4       | 5th               | 108                   | 121                   | 126                   | 135                   |
|             | 158.2       | 10th              | 108                   | 122                   | 127                   | 136                   |
|             | 162.7       | 25th              | 109                   | 124                   | 128                   | 137                   |
|             | 167.2       | 50th              | 110                   | 125                   | 129                   | 139                   |
|             | 171.5       | 75th              | 111                   | 126                   | 130                   | 140                   |
|             | 175.1       | 90th              | 112                   | 126                   | 131                   | 141                   |
|             | 177.2       | 95th              | 112                   | 127                   | 132                   | 141                   |
| **15**      | 160.1       | 5th               | 109                   | 124                   | 128                   | 137                   |
|             | 162.5       | 10th              | 110                   | 124                   | 129                   | 138                   |
|             | 166.3       | 25th              | 111                   | 125                   | 130                   | 139                   |
|             | 170.4       | 50th              | 112                   | 126                   | 131                   | 140                   |
|             | 174.3       | 75th              | 113                   | 127                   | 132                   | 141                   |
|             | 177.7       | 90th              | 113                   | 128                   | 133                   | 142                   |
|             | 179.6       | 95th              | 114                   | 128                   | 133                   | 143                   |
| **16**      | 162.8       | 5th               | 111                   | 125                   | 129                   | 139                   |
|             | 164.9       | 10th              | 111                   | 125                   | 130                   | 139                   |
|             | 168.3       | 25th              | 112                   | 126                   | 131                   | 140                   |
|             | 172.1       | 50th              | 112                   | 127                   | 132                   | 141                   |
|             | 175.8       | 75th              | 113                   | 128                   | 133                   | 142                   |
|             | 179.2       | 90th              | 114                   | 129                   | 134                   | 143                   |
|             | 181.1       | 95th              | 115                   | 129                   | 134                   | 144                   |
| **17**      | 164.1       | 5th               | 111                   | 125                   | 130                   | 139                   |
|             | 166.1       | 10th              | 112                   | 126                   | 131                   | 140                   |
|             | 169.4       | 25th              | 112                   | 127                   | 131                   | 141                   |
|             | 173.1       | 50th              | 113                   | 128                   | 133                   | 142                   |
|             | 176.9       | 75th              | 114                   | 129                   | 134                   | 143                   |
|             | 180.3       | 90th              | 115                   | 130                   | 134                   | 144                   |
|             | 182.3       | 95th              | 115                   | 130                   | 135                   | 145                   |

(continued to the next page)
Blood Pressure Tables for Korean Children

| 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                    |
|             | 170.5       | 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.

| Age (years) | Height (cm) | Height Percentile | SBP Percentile (mmHg) | DBP Percentile (mmHg) |
|-------------|-------------|-------------------|------------------------|------------------------|
|             |             | 50th              | 90th                  | 95th                  | 99th                  | 50th              | 90th                  | 95th                  | 99th                  |
| 11          | 138.0       | 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                    | 60                    | 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                    |
| 12          | 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                    |
| 13          | 140.0       | 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                    | 81                    | 87                    |
| 14          | 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                    |
|             | 166.6       | 95th              | 108                    | 121                    | 126                    | 134                    | 66                    | 77                    | 81                    | 87                    |
| 15          | 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                    |

(continued to the next page)
addition, DBP assessed using the Dinamap Procare 200 monitor, which was used in the study by Lee et al., 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.

Unlike previous Korean studies, 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. 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. 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. 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

| 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 |
| 17 | 168.7 | 95th | 109 | 123 | 127 | 136 | 68 | 79 | 82 | 89 |

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