



Comparison of Trends in Blood Pressure and the Prevalence of Obesity Among Korean and American Adolescents: A 12-Years Cross-sectional Study

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Objectives: This study was conducted to explore recent trends in the prevalence of pediatric elevated blood pressure and hypertension (HTN) in Korea and the United States, applying the new HTN reference values for adolescents.

Methods: This study analyzed 17 339 (8755 Korean and 8584 American) adolescents aged 10 to 17 who participated in the Korea National Health and Nutrition Examination Survey and the National Health and Nutrition Examination Survey, respectively, between 2005 and 2016. HTN was defined using percentile-based reference values for non-overweight adolescents from 7 nations, and obesity was defined by body mass index (BMI) based on country-specific growth charts. All analyses were stratified by sex and year-over-year changes were evaluated by calculating the *p* for trend.

Results: Systolic blood pressure showed a statistically meaningful upward trend in Korean boys and girls, while diastolic blood pressure did not show any significant changes. Both systolic and diastolic blood pressure levels declined among United States boys and girls. The prevalence of elevated blood pressure and HTN remained similar in Korean adolescents, but declined in both sexes among United States adolescents. BMI increased in both sexes among Korean adolescents, although the overweight and obesity rates stayed the same. No significant trends were found in any obesity indices among United States adolescents. The prevalence of elevated blood pressure and HTN by obesity level was higher among Korean adolescents than among their United States peers in both sexes, and the gap became higher at more severe levels of obesity.

Conclusions: Despite the strong correlation between obesity and HTN, recent trends in the prevalence of HTN and obesity among Korean and United States adolescents were strikingly different. Follow-up studies are necessary to determine why the prevalence of HTN was more than twice as high among Korean adolescents than among their United States counterparts.

Key words: Adolescents, Hypertension, Obesity, Republic of Korea, United States

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INTRODUCTION

Cardiovascular disease is a major cause of death in many countries around the world [1], and hypertension (HTN) is a well-known risk factor for cardiovascular disease [2]. HTN is a chronic condition that is more commonly found in adults, but in recent years has been increasingly reported in children and adolescents [3,4]. Those who develop HTN during child-

hood or adolescence are likely to continue to have the same condition in adulthood [5,6], underscoring the importance of the early diagnosis and management of HTN during childhood.

The risk factors known to be associated with pediatric HTN include sex, race, family history, low birth weight, obesity, dietary habits, and physical activity [7]. Of these risk factors, obesity has been suggested to be the largest contributor to pediatric HTN, as obese children are at a two-fold higher risk of developing HTN compared to normal-weight children [8].

While adolescent obesity has consistently increased in most countries over the past couple of decades [9], blood pressure (BP) trends have been distinct in each country. In some countries, the prevalence of HTN has declined even while obesity became more common [10,11], a trend that was also reported in a Korean pediatric study. According to a study conducted by Xi et al. [12], HTN cases among Korean adolescents significantly decreased between 1997 and 2012, even though the obesity rate increased over the same period, which is surprising considering the strong correlation between obesity and HTN in pediatric patients.

The diagnostic reference values for pediatric HTN have traditionally been based on BP percentiles of children and adolescents in certain age groups, regardless of their obesity level. These reference values therefore include both overweight/obese and normal-weight individuals. As a result, the threshold for HTN tends to increase when overweight/obesity rates go up, which disguises the true prevalence of HTN and makes it seem lower than it is. Considering this issue, the new pediatric HTN guidelines in 2017 [13] suggested new normative pediatric BP tables based on normal-weight children without including overweight and obese children. Percentile-based references for normal-weight children and adolescents in 7 countries, including Korea, have also been suggested to facilitate comparisons among nations [14].

This study was conducted to explore trends in the prevalence in pediatric elevated blood pressure (EBP) and HTN in Korea and the United States by analyzing Korean National Health and Nutrition Examination Survey (KNHANES) and National Health and Nutrition Examination Survey (NHANES) data using percentile-based reference values for normal-weight children and adolescents from 7 countries [14].

METHODS

Subjects

This study was conducted using data from adolescents aged 10 to 17 who participated in the KNHANES and NHANES between 2005 and 2016. A total of 8755 Korean subjects, including 4637 males and 4118 females, were selected out of the 12 508 KNHANES participants in the relevant age range, after the exclusion of 3753 individuals with missing BP, height, or weight data. For the United States subjects, a total of 8584 adolescents, including 4355 males and 4229 females, were selected from the 8988 NHANES participants in the relevant age range, after the exclusion of 404 individuals. Participants in the 2006 KNHANES were excluded due to missing survey data (Figure 1).

Anthropometric Measurements and Definition of Obesity

Anthropometric measurements were carried out by skilled researchers. For the height measurements, participants stepped on a stadiometer, stood straight, and looked forward. Weight was measured by having participants step onto a scale and stand still, after calibration. Height and weight were each measured once, and body mass index (BMI) was calculated using the measured values dividing weight (kg) by height squared (m^2). Obesity was defined by a BMI in the 95th percentile or higher based on the sex- and age-specific growth charts of each country (2007 Korean National Growth Charts for Korea [15], Centers for Disease Control and Prevention growth charts; United States, 2000 [16]), overweight was defined as a BMI between the 85th percentile and 95th percentile, and normal weight as a BMI below the 85th percentile.

Blood Pressure Measurements and Definition of Hypertension

Skilled measurers measured BP using a standard mercury sphygmomanometer following standardized guidelines [17]. An appropriate cuff size was selected based on the circumference of the upper arm of the subjects. BP was measured with participants seated, after 5 minutes of rest. Systolic blood pressure (SBP) was defined as Korotkoff phase 1, and diastolic blood pressure (DBP) was defined as Korotkoff phase 5. BP was measured 3 times in total, and the average of the second and third measurements was used as the final value.

Prior to 2005, KNHANES determined the final BP values by

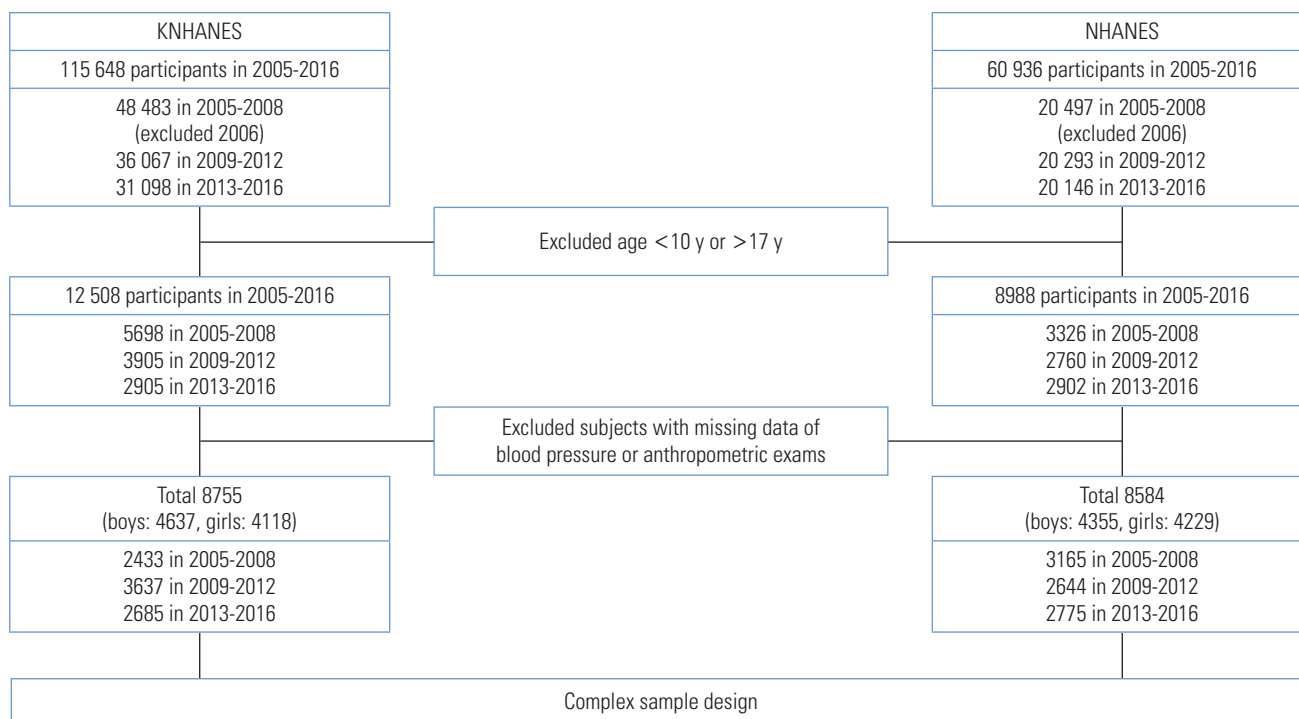


Figure 1. Flowchart of the study design. KNHANES, Korean National Health and Nutrition Examination Survey; NHANES, National Health and Nutrition Examination Survey.

averaging 2 BP measurements, and then switched to averaging the second and third of 3 measurements until 2016, when this study ended. The measurement environment has changed since 2007 depending on the year, equipment, and height of the measuring stand, but adjusted standards were subsequently presented considering potential errors due to such differences. The adjusted values were used in this study to minimize the potential of serious errors occurring due to variations in the measurement environment.

HTN was defined in accordance to the percentile reference for non-overweight adolescents from 7 nations, including Korea [14]. The term “preHTN” was replaced with the term “EBP” pursuant to the 2017 American Academy of Pediatrics (AAP) guidelines [13]. Normal BP, EBP, and HTN were defined based on percentiles by sex, age, and BP by height.

- (1) Normal BP: Both SBP and DBP less than the 90th percentile
- (2) EBP: SBP or DBP between the 90th and 95th percentiles
- (3) HTN: SBP or DBP in the 95th percentile or higher

Statistical Analysis

For the analysis, the 12-year (2005-2016) data from both Korea and the United States were grouped into 3 sets of 4-year

data (2005-2008, 2009-2012, and 2013-2016). For the Korean data, the 2005, 2007, and 2008 data were combined into a single set due to the absence of the 2006 data. A multistage analysis was carried out for sex utilizing a complex sample design reflecting multistage, stratified, and weighted values. Weighted values for each merged dataset were calculated when merging the yearly data. The prevalence of obesity and HTN was presented as percentages, while arithmetic averages were calculated for other variables. When comparing general characteristics between Korean and United States adolescents, the independent *t*-test was used for continuous variables and the chi-square test was used for categorical variables. Year-over-year trends for the 3 sets of 4-year data were analyzed using the *p* for trend. Statistical significance was defined as *p*-value < 0.05, and SAS version 9.4 (SAS Institute Inc., Cary, NC, USA) was used for the analysis.

Ethics Statement

This study is not subject to ethical review as it is conducted using public data of KNHANES in Korea and NHANES data in the United States.

RESULTS

General Characteristics of the Subjects

The general characteristics of all Korean and United States subjects of this study are presented in Table 1 by sex. Height was similar among boys in both countries, while United States girls were taller than their Korean counterparts. The 12-year average values for weight, BMI, and rates of overweight and obesity were all meaningfully higher among United States adolescents than among their Korean counterparts. The obesity rates for United States adolescents were 20.6% for boys and 18.7% for girls, 2.5 times to 3.0 times higher than the Korean obesity rates of 7.1% and 7.5%. BP-related indices showed that DBP and the prevalence of EBP and HTN were higher among Korean adolescents, while only SBP was higher among United States male and female adolescents (Table 1).

Table 1. Characteristics of adolescents aged 10-17 years in Korea and the United States from 2005-2008 to 2013-2016

Variables	Korea	United States	p-value
Boys Total (n)	4637	4355	-
Age (y)	13.3 (0.0)	13.5 (0.0)	<0.001
Height (cm)	163.0 (0.2)	163.1 (0.3)	0.868
Weight (kg)	56.2 (0.3)	60.7 (0.5)	<0.001
BMI (kg/m ²)	20.8 (0.1)	22.3 (0.1)	<0.001
Obesity level (%)			<0.001
Overweight	12.7 (0.5)	16.8 (0.6)	
Obese	7.1 (0.4)	20.6 (0.9)	
SBP (mmHg)	108.0 (0.2)	108.7 (0.2)	0.035
DBP (mmHg)	65.8 (0.2)	56.3 (0.4)	<0.001
EBP (%)	7.3 (0.5)	6.2 (0.5)	0.010
HTN (%)	6.4 (0.4)	4.0 (0.4)	<0.001
Girls Total (n)	4118	4229	-
Age (y)	13.4 (0.0)	13.6 (0.0)	<0.001
Height (cm)	156.4 (0.1)	157.4 (0.2)	<0.001
Weight (kg)	49.7 (0.2)	56.8 (0.4)	<0.001
BMI (kg/m ²)	20.2 (0.1)	22.7 (0.1)	<0.001
Obesity level (%)			<0.001
Overweight	10.8 (0.6)	17.0 (0.7)	
Obese	7.5 (0.5)	18.7 (0.8)	
SBP (mmHg)	103.9 (0.2)	105.3 (0.2)	<0.001
DBP (mmHg)	65.1 (0.2)	58.7 (0.4)	<0.001
EBP (%)	6.0 (0.4)	4.8 (0.5)	0.002
HTN (%)	4.7 (0.4)	3.9 (0.4)	0.045

Continuous variables are expressed as mean (SE); categorical variables are expressed as percentage (SE).

SE, standard error; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; EBP, elevated blood pressure; HTN, hypertension.

Trends in the Prevalence of Blood Pressure and Hypertension

Figure 2 illustrates the 12-year trends of SBP, DBP, and the prevalence of EBP and HTN. SBP showed statistically meaningful upward trends in Korean boys and girls (p for trend <0.001 for both males and females), while United States female adolescents showed a significantly declining trend (p for trend=0.002) and a slight decrease was observed among United States male adolescents, but was not statistically meaningful (Figure 2A). The only statistically meaningful change in DBP was a decrease among United States female adolescents (p trend=0.032) (Figure 2B).

The prevalence of EBP did not demonstrate significant changes in either male or female Korean subjects, although it meaningfully decreased among United States subjects of both sexes (p for trend=0.025, p for trend=0.011 in males and females, respectively). The prevalence of EBP among Korean adolescents between 2013-2016 was 8.3% among boys and 5.8% among girls, 1.4 times to 1.8 times higher than the rates of 4.7% and 4.1% among United States adolescents (Figure 2C). The prevalence of HTN showed similar trends as that of EBP, with no significant change in Korean subjects of both sexes, whereas HTN decreased with statistical significance in both United States male and female subjects (p for trend=0.017, p for trend=0.015 in males and females, respectively). The prevalence of HTN was consistently higher among Korean subjects over the entire study period, except for the 2005-2008 Korean female data. The prevalence of HTN among Korean adolescents was 7.5% for boys and 6.1% for girls between 2013 and 2016, 2 times to 2.5 times higher than that of United States adolescents (2.9% and 2.9% for each sex) (Figure 2D).

Trends in Body Mass Index and Overweight/Obesity Rates

Figure 3 illustrates the 12-year trends in BMI and overweight/obesity rates among Korean and United States adolescents. BMI values showed statistically significant upward trends in Korean male and female subjects (p for trend=0.038, p for trend=0.019 in males and females), while United States male and female subjects did not show clear trends (Figure 3A). The absolute magnitude of the increase in BMI values was higher among United States subjects in both sexes, but the changes were not found to be statistically significant because the standard error was higher in the United States subjects. Although this information is not included in Figure 3A, the standard er-

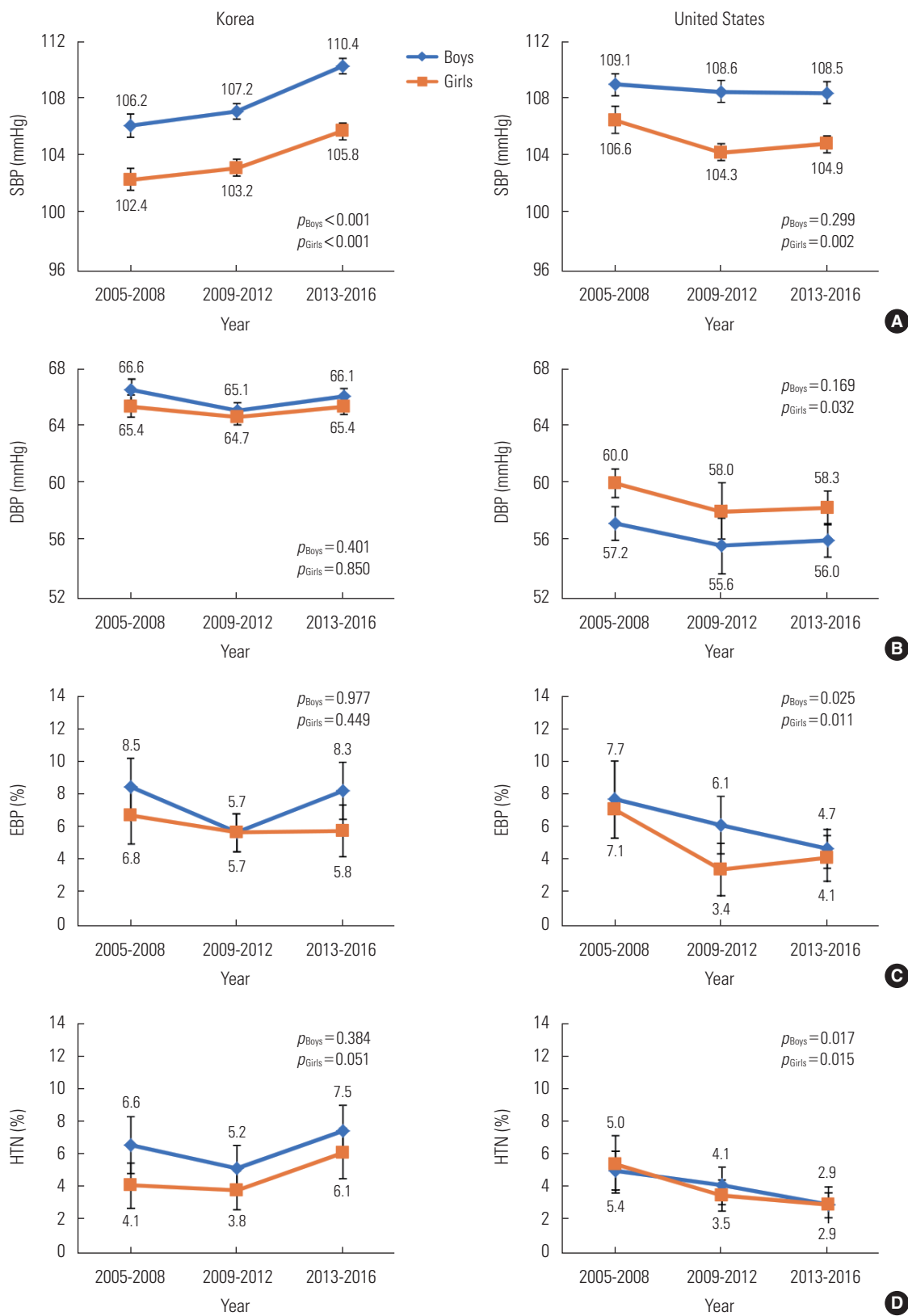


Figure 2. Trends in (A) systolic blood pressure (SBP), (B) diastolic blood pressure (DBP), and the prevalence of (C) elevated blood pressure (EBP), and (D) hypertension (HTN) among adolescents aged 10-17 years in Korea and the United States from 2005-2008 to 2013-2016.

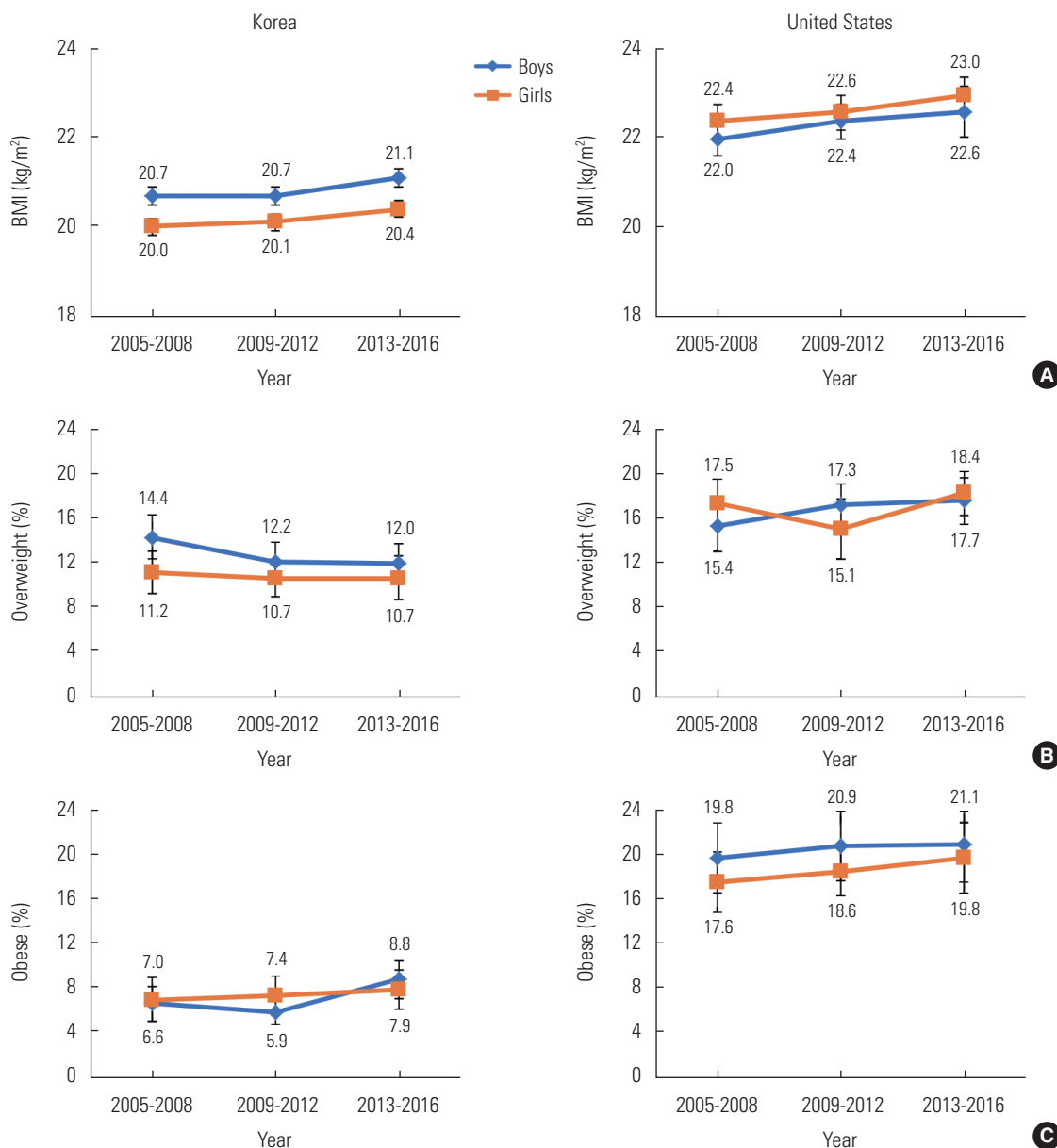


Figure 3. Trends in (A) body mass index (BMI) and the prevalence of (B) overweight, and (C) obesity among adolescents aged 10-17 years in Korea and the United States from 2005-2008 to 2013-2016.

ror of BMI for Korean adolescents was approximately 0.1 for both sexes for all 3 periods of data, versus 0.2 and 0.3 in the United States subjects. Meanwhile, the prevalence of overweight and obesity did not change significantly in either country (Figure 3B and 3C).

Prevalence of Elevated Blood Pressure and Hypertension by Obesity Level

Figure 4 demonstrates the prevalence of EBP and HTN among all subjects divided into normal-weight, overweight, and obese

groups. The prevalence of EBP and HTN increased as obesity became more severe, from the normal-weight group to the overweight group and the obese group. EBP and HTN were more common in Korea in all 3 groups. However, the discrepancy became larger as the level of obesity became more severe. For instance, in the normal-weight subjects, HTN was found in 4.7% and 2.6% of the male Korean and United States subjects, respectively, and in 3.2% and 2.7% of the female Korean and United States subjects, respectively, while the corresponding figures were 9.6% and 4.2% for males and 7.4% and 4.6% for

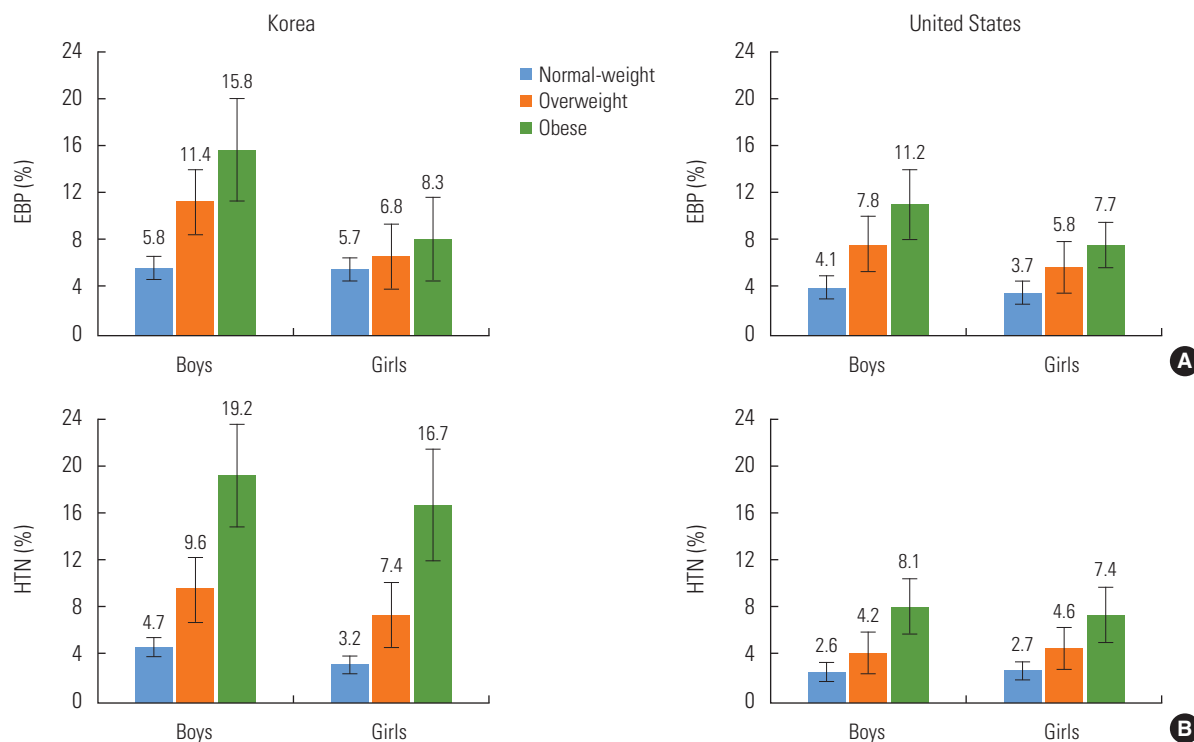


Figure 4. Prevalence of (A) elevated blood pressure (EBP) and (B) hypertension (HTN) by obesity level among adolescents aged 10-17 years in Korea and the United States from 2005-2008 to 2013-2016.

females in the overweight group and 19.2% and 8.1% for males and 16.7% and 7.4% for females in the obese group, respectively.

DISCUSSION

This study compared trends in BP and obesity rates between 2005 and 2016 among Korean and United States adolescents based on large-scale representative data from each country. SBP levels were similar in both countries, unlike DBP, which was strikingly distinct. For instance, the DBP of Korean adolescents was 8-10 mmHg higher than that of their United States peers. Similarly high DBP values among Korean adolescents have been reported in previous studies [14,18], and analogous results have been reported for other East Asian countries, particularly China [12]. The present study found that EBP and HTN were more commonly found among Korean adolescents, although their SBP tended to be lower, which was likely caused by the higher DBP among Korean adolescents. Studies on adult subjects have also shown higher DBP values among Koreans than among Americans, and only slightly lower SBP values among Koreans [19, 20].

SBP showed a significant increase over the period analyzed in the study among Korean adolescents of both sexes, while DBP remained steady over the same period. In contrast, both SBP and DBP decreased in United States adolescents, especially among girls. This trend is somewhat different from the results of previous studies, including that of Xi et al. [12], who suggested a downward trend in both SBP and DBP in both Korean boys and girls between 1997 and 2012 [12]. This inconsistency may result from the mismatch in the periods when the studies were conducted. In the study of Xi et al. [12], SBP was highest among Korean adolescents between 1997 and 2000, the earliest period analyzed in their study, and then continued to decrease from 1997 to 2008, before starting to increase again in 2008. Meanwhile, in other East Asian countries, especially China, SBP and DBP in boys increased between 1997 and 2012, while girls did not experience any significant changes [12]. Over the same period, Japanese boys and girls exhibited declining SBP and DBP [10,21], reflecting inconsistent BP trends among East Asian nations.

When EBP and HTN were calculated among the Korean and United States subjects using the international references based on 7 nations [14], both conditions were more prevalent

in Korean adolescents of both sexes. However, these results cannot be directly compared with those of previous studies due to changes in the definition of HTN. For example, many of the previously conducted studies on the prevalence of pediatric HTN [4,22] were based on the 2004 Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents [23], which suggested BP percentile charts based on the physical development of United States children and adolescents, which may be inappropriate to apply directly to their peers in other countries. Given such limitations, several countries, including Korea, developed their own percentile-based reference values for BP [24,25] based on the physical development of children and adolescents in each nation [26].

In the updated 2017 AAP guidelines [13], a new percentile chart for BP was suggested that took into account the correlation between obesity and HTN by only including normal-weight United States children and adolescents, and not overweight and obese children and adolescents. The new guideline helped resolve the issue of instability in the definition of HTN depending on the obesity rate, but was still inappropriate to apply to children and adolescents outside of the United States. Subsequently, in 2018, international BP references based on non-overweight children and adolescents from 7 select nations, including Korea and the United States, were released [14]; these values were utilized in this study to evaluate the prevalence of EBP and HTN.

The inconsistent percentile-based reference values for HTN led to varying results in comparisons of the prevalence of HTN among Korean and United States children over the same period. This study used reference values based on only non-overweight children and adolescents, leading to the expectation that the results would show a higher prevalence than reported previously. The study of Xi et al. [12] based on the 2004 Fourth Report [23] concluded that HTN was present in 3.1% of boys and 2.1% of girls between 2009 and 2010 and 4.2% and 3.1% of boys and girls, respectively, between 2011 and 2012, while the figures were higher in this study, at 5.2% and 3.8%, respectively. United States children and adolescents showed similar trends, with figures of 1.7% and 1.5% for boys and girls, respectively, between 2009 and 2010, and 2.2% and 1.3%, respectively, between 2011 and 2012 when the 2004 Fourth Report criteria were applied [23], while higher values (4.1% and 3.5% for boys and girls, respectively) were found between 2009 and 2012 in this study.

During the period of this study, the prevalence of EBP and HTN among Korean subjects did not show meaningful upward or downward trends. The stagnant prevalence of HTN despite the meaningful increase in SBP over the same period is probably because the magnitude of the increase was not high enough to affect the overall prevalence of HTN. If the upward trend of SBP continues, more cases of EBP or HTN will likely occur. Recent studies of Korean children and adolescents have reported fewer cases of HTN in Korea [12,27], which can be interpreted as a result of using BP reference values that included those obtained from overweight and obese children and adolescents. In China, the prevalence of HTN did not show significant changes between 1997 and 2012 when the United States 2004 Fourth Report criteria [23] were applied by Xi et al. [12], but meaningfully increased when a different set of reference values was applied [24]. In contrast, the United States subjects showed meaningful decreases in EBP and HTN in both sexes. This result is consistent with the observed downward trend in SBP and DBP, as well as the results of previous studies reporting a decreasing trend in the prevalence of HTN [22,28] and the results of this study.

Meanwhile, a factor that might explain the upward trend in SBP among Korean children and adolescents is the age distribution of subjects, which has changed over time. During the entire period of the study, the proportion of the 13-17 age group increased from 54.7% (male) and 55.1% (female) of the population to 59.7% (male) and 63.0% (female) in Korea, whereas in the United States, the proportion of that age group decreased from 63.6% (male) and 64.5% (female) to 59.3% (male) and 58.6% (female) (Supplemental Material 1). This difference in the age distribution may have contributed to the conflicting trends in SBP between Korean and United States subjects.

Unlike BP, obesity-related indices including BMI, the overweight rate, and the obesity rate were all higher among United States subjects than among their Korean counterparts. In particular, the obesity rates of the United States subjects were 2.5 times to 3.0 times higher than those of the Korean subjects. Interestingly, HTN was more common among Korean adolescents in the normal-weight, overweight, and obese groups, and the Korean overweight and obese groups were twice or more likely to have developed HTN. This result implies that obesity potentially plays a more significant role in adolescent obesity in Korea than in the United States, although this possibility remains to be proven in follow-up studies.

Korean adolescents showed a slight increase in their BMI, while maintaining stable overweight and obesity rates. When comparing these results with the trends in BP indices, BMI and SBP moved hand-in-hand, showing similar patterns in Korean adolescents. In contrast, obesity and BP showed distinct patterns in United States adolescents, as obesity levels remained stable while BP indices decreased. Previous studies have suggested similar patterns, as the obesity rate increased between 2001 and 2012 [29], while HTN became less common [28] over the same period in United States adolescents. The root causes of such results have yet to be determined, but a potential factor could be changes in diet. A study on the dietary habits of American adolescents between 1999 and 2012 suggested a lower intake of calories and a higher proportion of unsaturated fatty acid intake to saturated fatty acid intake [30]. Saturated and unsaturated fatty acids are known to have opposite effects on BP and arteriosclerosis [31], so a relatively higher intake of unsaturated fatty acids could have contributed to the lower rate of HTN by improving arteriosclerosis and preventing increases in BP levels. Another study conducted from 2001 to 2009 found that United States adolescents were drinking less soda [32], which potentially contributed to a lower prevalence of HTN based on studies demonstrating a correlation between sugar intake and higher BP, regardless of obesity. Future studies will be necessary, as many other factors are known to affect the risk of pediatric HTN [7].

The limitations of this study are as follows. First, this study focused on trends in overweight and obesity rates and BP over 12 years, but it would have been preferable to include even longer-term data. This study focused on the most recent 12 years because it was difficult to directly compare data before 2005, because the NHANES was carried out as an annual survey starting in 1999, whereas the KNHANES became an annual survey in 2005. Second, there is a possibility that the measurements of BP were incorrect, although measurements were carried out in accordance to standard guidelines. For instance, environmental differences in physical measurements between the 2 nations may have caused errors in physical measurements, including those of BP. The KNHANES also suggested the possibility of measurement errors between July 2008 and December 2010 and presented revised values in the recommendations for determining BP in humans using sphygmomanometers from the American Heart Association [33]. Third, restricted access to information on risk factors and the cross-sectional study design limit the ability to infer conclusions re-

garding the direct association between obesity and HTN. Despite such limitations, this study is meaningful in that it compared Korean and United States adolescents using reference values based on non-overweight children and adolescents from 7 countries.

In conclusion, the trends in the prevalence of HTN and obesity showed largely different trajectories in Korean and United States adolescents despite the strong correlation between obesity and HTN. Follow-up studies are needed to explain the causes of these discrepancies. Above all, since HTN is much more common in obese children and adolescents, weight control is necessary to manage HTN.

SUPPLEMENTAL MATERIALS

Supplemental material is available at <https://doi.org/10.3961/jpmph.19.198>.

CONFLICT OF INTEREST

The authors have no conflicts of interest associated with the material presented in this paper.

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AUTHOR CONTRIBUTIONS

Conceptualization: SH, DHL. Data curation: SH, SK. Formal analysis: SH, SK. Methodology: DHL, YML, JYS. Visualization: SH, SK. Writing - original draft: SH. Writing - review & editing: DHL, YML, JYS, SK.

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