Trends in Elevated Blood Pressure Among US Children and Adolescents: 1999–2012

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BACKGROUND
The prevalence of elevated blood pressure (BP) has been reported to increase significantly among the US children and adolescents from 1988–1994 to 1999–2008. We aimed to examine the recent trends in BP levels and prevalence of elevated BP, as well as related influencing factors among US children and adolescents.

METHODS
Data of National Health and Nutrition Examination Survey (NHANES) 1999–2012 were combined into 3 time periods (1999–2002, 2003–2008, and 2009–2012) for the analysis. A total of 14,270 US children and adolescents aged 8–17 years were included in the current analysis. The sex-, age-, and height-BP standards recommended by the US Fourth Report were used to define high BP and elevated BP (including pre-HBP and HBP).

RESULTS
Mean systolic BP (SBP) and diastolic BP (DBP) decreased by 0.7 and 4.2 mm Hg from 1999–2002 to 2009–2012, respectively. In 2009–2012, the prevalence of elevated BP and HBP in children and adolescents were 9.6% and 1.6%, with the absolute reduction of 2.8% and 1.3% from 1999–2002 to 2009–2012, respectively. In addition, daily intakes of total energy, carbohydrate, total saturated fatty acids, and caffeine decreased during the period between 1999–2002 and 2009–2012 (all $P < 0.05$), whereas daily intake of total polyunsaturated fatty acids and dietary fiber increased ($P < 0.05$).

CONCLUSIONS
Mean BP levels as well as the prevalence of elevated BP and HBP among US children and adolescents have declined during the past decade. In addition, there might be an associated change in dietary factors.

Keywords: blood pressure; children; elevated blood pressure; hypertension; trends.

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Childhood high blood pressure (HBP) is a serious public health challenge worldwide due to associated increases in risks of end organ damages, such as ventricular hypertrophy and carotid intima-media thickness.[1] HBP in childhood is modestly correlated with that in adulthood.[2] Thus, identification and early intervention or treatment on children with HBP is very important for prevention or controlling of hypertension as well as BP-related cardiovascular diseases in adulthood.[3]

To date, 4 studies have examined the trends in BP and HBP in US children and adolescents using the National Health and Nutrition Examination Survey (NHANES).[4–7] Compared to NHANES III (1988–1994), mean BP levels and prevalence of elevated BP have greatly increased during 1999–2008, even after adjustment for body mass index (BMI). However, these studies did not identify factors other than obesity contributed to the increased trends. The most recent publication pooled data of NHANES 1999–2008 to examine the related risk factors for elevated BP in children,[7] but it did not address whether trends in these determinants were in parallel with the changes in prevalence of elevated BP during 1999–2008.[7]

The current study aimed to examine secular trends in BP levels as well as prevalence of elevated BP and HBP in US children and adolescents, using NHANES data collected during 1999–2012. We also examined the trends in potential contributors including nutritional factors.

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METHODS

Study design and subjects

The NHANES uses a complex, multistage probability sampling design to select a representative of the US civilian, noninstitutionalized population. The detailed information of this survey has been described elsewhere.[4–7] Briefly, NHANES program began in 1960s and became a continuous program from 1999 by the National Center for Health Statistics of the Centers for Disease Control and Prevention (CDC). A standard questionnaire was used to collect the personal information by trained interviewers at home. Physical examination, such as measurement on body weight, height, waist circumference (WC), systolic BP (SBP), and diastolic BP (DBP), was conducted in a mobile examination center. Written informed consent was obtained from children and adolescents and/or their parents. NHANES was approved by the National Center for Health Statistics Ethics Review Board.

In the current analysis, we used the continuous NHANES data (NHANES 1999–2000, 2001–2002, 2003–2004, 2005–2006, 2007–2008, 2009–2010, and 2011–2012) for data analyses. BP values were only available in children older than 8 years. We combined the adjacent survey cycles into 3 time periods, i.e., 1999–2002, 2003–2008, and 2009–2012 because of the following 2 reasons. First, the prevalence of HBP in all children defined by the US Fourth Report[3] across 7 survey periods was 3.0%, 2.8%, 3.0%, 2.9%, 2.7%, 1.7%, and 1.6%, respectively. The figures were similar in the first 2 survey periods (1999–2000 and 2001–2002), as well as in the following 3 survey periods of 2003–2004, 2005–2006, and 2007–2008, and in the last 2 periods (2009–2010 and 2011–2012). Second, we would like to increase the statistical power for the analyzed groups, just similar to previous studies on examination of trends in elevated BP in US children using NHANES data.[4–7] Finally, a total of 14,270 US children and adolescents aged 8–17 years with complete data on sex, age, race/ethnicity, SBP, DBP, height, and body weight were included in the current study.

Measurements

SBP, DBP, height, body weight, and WC were measured using calibrated equipment according to the standardized protocols.[4–9] All BP measurements were obtained using a sphygmomanometer by certified examiners after children and adolescents' 5 minutes sitting. Appropriate BP cuff sizes were selected based on each participant's arm circumference. SBP was defined using the first Korotkoff phase and DBP was measured as the 5th Korotkoff phase. Up to 3 BP readings were obtained and the last 2 readings were averaged as BP levels. To be consistent with previous studies and to make full use of the data,[4–7] the second reading was used when only 2 readings were available; the 1 reading was used if only 1 reading was available. About 84.6% subjects had 3 BP measurements in the all NHANES between 1999 and 2012.

Body weight was measured on a Toledo self-zeroing weight scale, and height was measured with a stadiometer to the nearest millimeter.[8] WC was measured using a steel measuring tape to the nearest 0.1 cm at the high point of the iliac crest at minimal respiration when the participant was in a standing position.[9] A 24-hour dietary recall questionnaire was used to collect information on dietary intakes of all participants during two continuous days at the mobile examination center. Nutrient intake from foods was estimated using the US Department of Agriculture Food and Nutrient Databases for Dietary Studies for each 2-year NHANES cycle.[10]

Definitions

According to the Fourth Report of National High Blood Pressure Education Program Working Group on HBP in Children and Adolescents, HBP is defined as average SBP and/or DBP that is ≥95th percentile for gender, age, and height reference, while pre-HBP is defined as average SBP or DBP levels that are ≥90th percentile but <95th percentile or SBP/DBP ≥120/80 mm Hg.[3] In the current analysis, elevated BP included HBP and pre-HBP.

BMI was calculated as kilograms per square meter (kg/m^2). Obesity and overweight were defined as BMI ≥ age- and sex-specific 95th percentile and 85th–95th percentile in the US CDC 2000 Growth Charts, respectively.[8] Central obesity was defined as WC ≥ age- and sex-specific 90th percentile generated from NHANES III.[11]

Statistical analysis

Children with SBP or DBP values less than or more than mean ± 4 SD were excluded from all data analyses, as well

Table 1. Characteristics of US children and adolescents aged 8–17 years, NHANES 1999–2012

	1999–2002	2003–2008	2009–2012	*P* value
n	4,864	6,096	3,311	
Boys, % (SE)	51.2(0.8)	50.6(0.9)	49.2(1.4)	0.199
Age group, % (SE)				
8–12 years	49.2(1.1)	47.4(1)	47.3(1.2)	0.278
13–17 years	50.8(1.1)	52.6(1)	52.7(1.2)	
Race/ethnicity, % (SE)				
Non-Hispanic White	59.9(2.1)	60.9(2.3)	56.7(3.0)	
Non-Hispanic Black	15.1(1.8)	14.9(1.3)	14.0(1.6)	0.243
Hispanic	18.9(2.3)	17.7(1.5)	21.2(2.5)	
Other races	6.2(0.7)	6.5(0.8)	8.1(0.8)	

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as subjects with DBP value equal to zero and those who had alcohol, cigarettes, and coffee in the past 30 minutes before the measurements. All data analyses were performed using SAS 9.2 (SAS Institute, Cary, NC), with adjustment for weights and complex survey design of the NHANES. In accordance with previous publications using the NHANES data,[4–7] all the subjects were divided into 2 age subgroups: 8–12 years subgroup and 13–17 years subgroup. The differences in distributions of sex, age group, and race/ethnicity across 3 time periods (1999–2002, 2003–2008, and 2009–2012) were examined using the SAS SURVEYLOGISTIC procedure. Trends in mean SBP and DBP levels and nutritional factors (e.g., sodium, potassium, etc) from 1999–2002 to 2009–2012 were examined with SAS SURVEYREG, and trends in prevalence of elevated BP and HBP during the same period were tested using SAS SURVEYLOGISTIC procedure. Sex, age, race/ethnicity, and BMI-Z score were adjusted when applicable. To investigate the association of sodium intake with BP and elevated BP, sodium intake was adjusted for total energy intake = (sodium intake) × 2,000/total energy intake and expressed in quintiles.[7] A 2-sided value of $P < 0.05$ was considered to be statistically significant.

RESULTS

Characteristics of the study population

The distributions of sex, age, and racial/ethnic groups were not significantly different across 3 periods (1999–2002, 2003–2008, and 2009–2012) (all $P > 0.05$, Table 1).

Trends in mean BP values from 1999–2002 to 2009–2012

Mean DBP levels significantly decreased from 1999–2002 to 2009–2012 in total population and in all subgroups by sex, age, and race/ethnicity, while SBP values significantly decreased in total population, 8–12 years subgroup, girls, and Non-Hispanic Whites (all $P < 0.05$, Table 1). The average differences of mean SBP and DBP in total subjects between 1999–2002 and 2009–2012 were 0.7 and 4.2 mm Hg,

Table 2. Trends in mean blood pressure levels (mm Hg) among US children and adolescents aged 8–17 years, NHANES 1999–2012

	1999–2002	2003–2008	2009–2012	Absolute change[a]	*P* value for trend[b]	*P* value for trend[c]
SBP						
Total	105.6(0.3)	106(0.3)	104.9(0.3)	−0.7	0.019	0.005
Age group						
8–12 years	102.2(0.4)	102.9(0.4)	101.5(0.3)	−0.7	0.034	0.029
13–17 years	109(0.3)	109.2(0.3)	108.1(0.4)	−0.9	0.060	0.011
Sex						
Boys	107.3(0.3)	107.7(0.4)	106.6(0.4)	−0.7	0.067	0.026
Girls	103.8(0.4)	104.4(0.4)	103.1(0.3)	−0.7	0.026	0.012
Race/ethnicity						
Non-Hispanic White	104.9(0.3)	106(0.4)	104.6(0.3)	−0.3	0.017	0.017
Non-Hispanic Black	107.2(0.4)	107(0.4)	106.6(0.4)	−0.6	0.584	0.267
Hispanic	105.8(0.4)	105.7(0.4)	104.3(0.5)	−1.5	0.054	0.019
Other races	106.6(0.9)	103.3(0.8)	103.9(0.7)	−2.7	0.014	0.135
DBP						
Total	60.3(0.4)	57.3(0.4)	56.1(0.8)	−4.2	<0.001	<0.001
Age group						
8–12 years	57.7(0.4)	54.6(0.5)	52.7(0.9)	−5.0	<0.001	<0.001
13–17 years	62.8(0.5)	60.0(0.4)	59.5(0.8)	−3.3	<0.001	<0.001
Sex						
Boys	59.4(0.5)	56.3(0.4)	55.0(0.9)	−4.4	<0.001	<0.001
Girls	61.1(0.4)	58.3(0.4)	57.3(0.8)	−3.8	<0.001	<0.001
Race/ethnicity						
Non-Hispanic White	60.3(0.4)	57.5(0.5)	56.8(1.1)	−3.5	<0.001	<0.001
Non-Hispanic Black	59.6(0.6)	57.4(0.4)	56.5(1.0)	−3.1	0.003	0.003
Hispanic	60.5(0.4)	56.6(0.4)	54.4(1.0)	−6.1	<0.001	<0.001
Other races	62.2(1.7)	57.4(0.8)	55.9(1.1)	−6.3	0.007	0.009

Abbreviations: DBP, diastolic blood pressure; SBP, systolic blood pressure.
[a]BP levels in 2009–2012 minus that in 1999–2002. [b]Adjusted for sex, age, race/ethnicity. [c]Adjusted for sex, age, race/ethnicity and BMI-Z value.

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respectively (Table 2, Figure 1A,B). The trends kept similarly whether or not adjustment for BMI-Z scores.

Trends in prevalence of elevated BP and HBP from 1999–2002 to 2009–2012

In 2009–2012, the prevalence of elevated BP and HBP were 9.6% and 1.6%, respectively. Compared to those in 1999–2002, the prevalence of elevated BP in 2009–2012 decreased in total population, 13–17 years subgroup, boys subgroup, and Non-Hispanic Whites (all $P < 0.05$). The prevalence of HBP significantly decreased in total population, 8–12 years subgroup, each sex subgroup, and Hispanic population (Table 3, Figure 1C,D). The trends kept similarly whether or not adjustment for BMI-Z scores.

As is shown in Table 4, compared to those in 1999–2002, subjects surveyed in 2003–2008 and 2009–2012 were more unlikely to have elevated BP with odds ratio (OR) [95% confidence intervals (CIs)] of 0.97 (0.78, 1.22) in 2003–2008 survey years and 0.74 (0.59, 0.94) in 2009–2012 survey years, with adjustment for sex, age, and race/ethnicity. Similar trends were observed for HBP (Table 4). The results did not substantially change with further adjustment for BMI-Z value or nutritional factors listed in Table 5 (sodium and potassium, etc.) (data not shown).

Influencing factors for elevated BP and HBP

Compared to children and non-Hispanic Whites, adolescents and non-Hispanic Blacks were more likely to have elevated BP with ORs (95% CIs) of 2.62 (2.19–3.14) and 1.39 (1.18, 1.63), respectively. However, girls were less likely to have elevated BP than boys [OR (95% CI) is 0.50 (0.42, 0.59)] (Table 4). Similar trends were found for influencing factors of HBP (Table 4).

Trends in anthropometric and dietary factors from 1999–2002 to 2009–2012

Table 5 presents trends in potential BP influencing factors, including anthropometric and dietary variables. No significant secular changes in proportion of overweight and central obesity were observed from 1999–2002 to 2009–2012 (all $P > 0.05$), while a slight increase was observed in general obesity from 1999–2002 to 2009–2012 ($P = 0.015$). For dietary intakes, daily intakes of energy, carbohydrate, total fat, and total saturated fatty acids decreased, while daily intake of total polyunsaturated fatty acids and dietary fiber increased significantly (all $P < 0.05$). However, daily intakes of sodium, potassium, protein, cholesterol, and caffeine did not change significantly from 1999–2002 to 2009–2012 (all $P > 0.05$). The trends kept similarly whether or not adjustment for BMI-Z scores. In addition, we investigated the association of sodium intake with BP and elevated BP in US children and adolescents (Supplementary Table S1). The above results suggested that compared with recommended level of sodium intake (≤2,300 mg/d), higher sodium intake was associated with higher SBP (P for trend = 0.052) and prevalence of elevated BP (P for trend = 0.022, OR (95% CI) = 1.30(1.04–1.62) for sodium >3,450 mg/d vs. ≤2,300 mg/d). The strength of association seemed stronger with survey periods.

DISCUSSION

In the current study, we observed secular decreases in BP levels, and prevalence of elevated BP and HBP in US

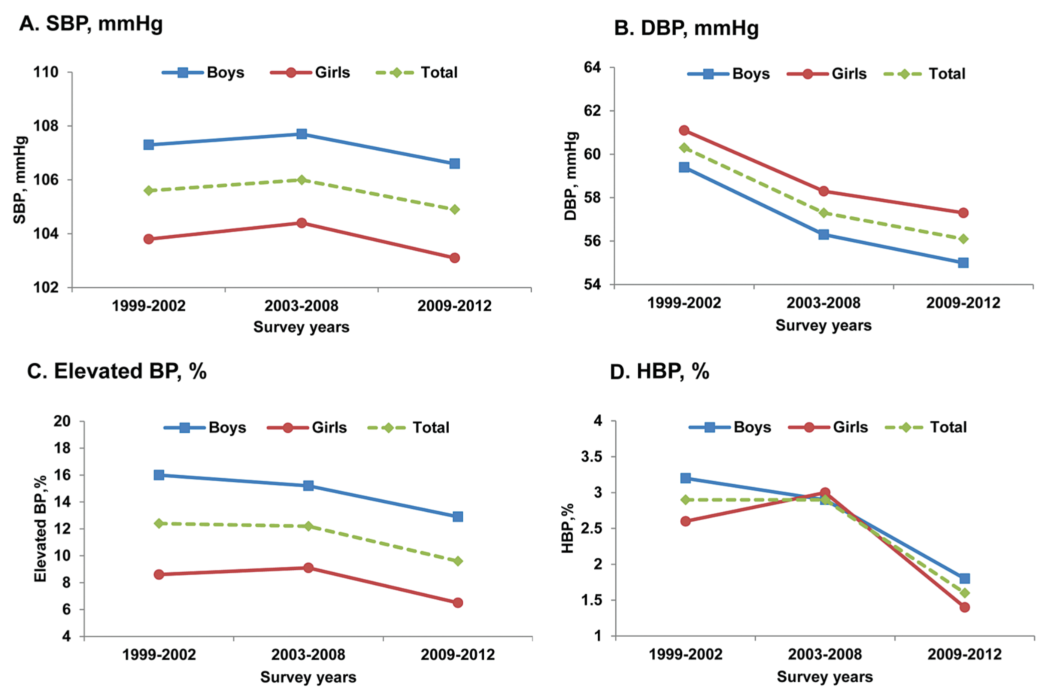

Figure 1. Secular trends in (A) SBP, (B) DBP, (C) elevated BP, and (D) HBP by sex.

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Table 3. Trends in prevalence (%) of elevated blood pressure and high blood pressure among US children and adolescents aged 8–17 years, NHANES 1999–2012

	1999–2002	2003–2008	2009–2012	Absolute change[b]	*P* value for trend[c]	*P* value for trend[d]
Elevated BP[a]						
Total	12.4(0.8)	12.2(0.9)	9.6(0.8)	−2.8	0.011	0.002
Age group						
8–12 years	6.9(1.0)	8.1(1.1)	5.3(0.7)	−1.6	0.162	0.106
13–17 years	17.7(1.0)	15.9(1.1)	13.6(1.3)	−4.1	0.017	0.003
Sex						
Boys	16.0(1.1)	15.2(1.2)	12.9(1.3)	−3.1	0.020	0.006
Girls	8.6(1.1)	9.1(0.9)	6.5(0.9)	−2.1	0.139	0.076
Race/ethnicity						
Non-Hispanic White	11.6(1.1)	12.5(1.2)	8.4(1.1)	−3.2	0.042	0.011
Non-Hispanic Black	14.5(1.2)	14.3(0.9)	13.8(1.1)	−0.7	0.344	0.144
Hispanic	12.5(1.4)	10.9(1.0)	10.4(1.5)	−2.1	0.260	0.190
Other races	14.6(3.1)	8.0(1.9)	8.8(2.1)	−5.8	0.128	0.180
HBP						
Total	2.9(0.3)	2.9(0.4)	1.6(0.3)	−1.3	0.003	0.001
Age group						
8–12 years	2.8(0.5)	3.6(0.6)	1.2(0.4)	−1.6	0.018	0.012
13–17 years	3.0(0.4)	2.4(0.4)	1.9(0.5)	−1.1	0.099	0.065
Sex						
Boys	3.2(0.4)	2.9(0.5)	1.8(0.5)	−1.4	0.045	0.028
Girls	2.6(0.5)	3.0(0.6)	1.4(0.2)	−1.2	0.028	0.019
Race/ethnicity						
Non-Hispanic White	2.4(0.4)	3.3(0.6)	1.3(0.4)	−1.1	0.116	0.085
Non-Hispanic Black	2.5(0.5)	3.0(0.4)	2.9(0.5)	0.4	0.589	0.851
Hispanic	4.4(0.8)	2.3(0.5)	1.7(0.5)	−2.7	0.006	0.005
Other races	4.7(2.4)	1.0(0.7)	0.9(0.4)	−3.8	0.024	0.039

Abbreviations: BP, blood pressure; HBP, high blood pressure.
[a]Including pre-HBP and HBP. [b]Prevalence in 2009–2012 minus that in 1999–2002. [c]Adjusted for sex, age and race/ethnicity. [d]Adjusted for sex, age, race/ethnicity, and BMI-Z value.

children and adolescents aged 8–17 years from 1999–2002 to 2009–2012, which might be associated with decrease in some nutritional factors (e.g., daily intakes of energy, carbohydrate, total fat, and total saturated fatty acids), and increase in daily intake of total polyunsaturated fatty acids and dietary fiber.

Comparison with other studies

Inconsistent country-specific secular trends in BP levels and prevalence of HBP in children have been reported since 2000.[12–18] The downward trends were found in Seychelles,[12] South Korea,[13] Japan,[14] and Iran,[15] whereas the upward trends were reported in China[16,17] and the United Kingdom.[18] For example, data from 4 waves of the Korean National Health and Nutrition Examination Survey, including a total of 5,909 adolescents aged 10–19 years, suggested that SBP decreased by 8.7 mm Hg in boys and 10 mm Hg in girls from 1998 to 2008; prevalence of HBP and elevated BP decreased relatively by 52% and 86%, respectively.[13] In contrast, mean BP levels and HBP prevalence in China were on the rise during recent years. The 2005 and 2010 Chinese National Surveys on Students' Constitution and Health revealed that mean SBP increased by 1.5 mm Hg in boys and 1.2 mm Hg in girls, whereas mean DBP increased by 1.1 mm Hg in boys and 1.0 mm Hg in girls, respectively.[16]

Previous studies using NHANES data examined the trends in BP values and HBP prevalence with NHANES III (1988–1994) as reference 4–7. All these studies indicated upward trends in BP levels from 1988–1994 to 1999–2008. The current study, using NHANES data of 1999–2012 with 1999–2002 survey years as reference, observed downward trends in BP levels and elevated BP prevalence. Inconsistent with previous 4 studies,[4–7] results of current study may indicate promising effects of public health improvement on

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Table 4. Influencing factors for elevated blood pressure and high blood pressure among US children and adolescents aged 8–17 years, NHANES 1999–2012

	OR[a]	95% CI[a]	*P* value[a]	*P* value[b]
Elevated BP (vs. normal BP)				
Survey period				
1999–2002	1			
2003–2008	0.97	0.78–1.22	0.805	0.619
2009–2012	0.74	0.59–0.94	0.012	0.002
Age group				
8–12 years	1			
13–17 years	2.62	2.19–3.14	<0.001	<0.001
Sex				
Boys	1			
Girls	0.50	0.42–0.59	<0.001	<0.001
Race/ethnicity				
Non-Hispanic White	1			
Non-Hispanic Black	1.39	1.18–1.63	<0.001	0.025
Hispanic	1.08	0.89–1.33	0.428	0.561
Other races	0.96	0.71–1.30	0.800	0.845
HBP (vs. normal BP)				
Survey period				
1999–2002	1			
2003–2008	1.01	0.69–1.47	0.973	0.868
2009–2012	0.52	0.34–0.80	0.003	<0.001
Age group				
8–12 years	1			
13–17 years	1.08	0.79–1.47	0.645	0.499
Sex				
Boys	1			
Girls	0.83	0.62–1.12	0.227	0.221
Race/ethnicity				
Non-Hispanic White	1			
Non-Hispanic Black	1.26	0.90–1.77	0.185	0.774
Hispanic	1.23	0.83–1.82	0.310	0.784
Other races	0.90	0.39–2.08	0.798	0.759

Abbreviations: BP, blood pressure; HBP, high blood pressure.
[a]Adjusted for sex, age, and race/ethnicity. [b]Adjusted for sex, age, race/ethnicity, and BMI-Z value.

healthy lifestyles and dietary behaviors on BP control in children and adolescents.

Influencing factors for childhood HBP

Obesity is a well established determinant of childhood HBP. Previous studies observed BP values and elevated BP increased in parallel with increase in BMI/WC and obesity.[16–18] Our recent meta-analysis additionally showed that childhood obesity prevention programs could help reduce BP, and such effect was observed even in studies that did not show significant improvement in obesity outcomes.[19] However, secular decrease in BP and elevated BP cannot be attributed to obesity status in the current analysis because general obesity has slightly increased, and prevalence of both overweight (defined by BMI) and central obesity (defined by WC) seemed stable during 2003–2012.

Salt intake is another important contributor to childhood BP change. It has been demonstrated that sodium intake was positively associated with SBP, but not with DBP after controlling for sex, age, and height, while potassium intake was

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Table 5. Trends in anthropometric and dietary factors among US children and adolescents aged 8–17 years, NHANES 1999–2012

	1999–2002	2003–2008	2009–2012	Absolute increase[a]	*P* value for trend[b]	*P* value for trend[c]
Anthropometric variables						
BMI category, % (SE)						
Overweight, ≥85th – <95th	15.4(0.7)	17.0(0.8)	16.7(0.8)	1.3	0.241	
Obese, ≥95th	17.1(1.0)	19.6(1.0)	20.3(0.7)	3.2	0.015	
WC ≥ 90th, % (SE)	17.9(1.0)	20.6(0.9)	19.9(0.9)	2.0	0.149	
Dietary intakes, mean (SE)						
Sodium (mg)	3,297.4(52.4)	3,371.2(33.6)	3,353.6(54.7)	56.2	0.419	0.384
Potassium (mg)	2,280(42.1)	2,198.8(26.1)	2,247.8(26.2)	−32.2	0.195	0.199
Energy (kcal)	2,136.9(26.8)	2,131.7(16.9)	2,052.9(22.7)	−84.0	0.021	0.028
Protein (g)	72.4(0.9)	74.7(0.8)	73(1.0)	0.6	0.115	0.109
Carbohydrate (g)	291.1(4.4)	282.6(2.5)	273.6(2.9)	−17.5	0.004	0.007
Total fat (g)	78(1.0)	80.3(0.8)	76.3(1.2)	−1.7	0.017	0.018
Total saturated fatty acids (g)	27.3(0.4)	27.8(0.3)	25.9(0.4)	−1.4	<0.001	0.001
Total monounsaturated fatty acids (g)	29.9(0.4)	29.8(0.3)	26.9(0.4)	−3.0	<0.001	<0.001
Total polyunsaturated fatty acids (g)	14.8(0.3)	16.0(0.2)	17.0(0.3)	2.2	<0.001	<0.001
Cholesterol (g)	243.1(4)	248(3.7)	234.7(4.9)	−8.4	0.092	0.104
Dietary fiber (g)	12.9(0.2)	13.4(0.2)	14.5(0.2)	1.6	<0.001	<0.001
Caffeine (g)	42.2(3)	37.5(1.9)	33.5(3.2)	−8.7	0.119	0.111

Abbreviations: BMI, body mass index; WC, waist circumference.
[a]Data in 2009–2012 minus those in 1999–2002. [b]Adjusted for sex, age, and race/ethnicity. [c]Adjusted for sex, age, race/ethnicity, and BMI-Z value.

reported to be inversely associated with BP levels.[7,20] Thus, the stably high dietary intake of sodium and low intake of potassium from 1999–2002 to 2009–2012 did not support the decrease in BP levels and elevated BP prevalence in this population.

However, reduction of daily intakes of energy, carbohydrate, total fat, and total saturated fatty acids among US children and adolescents may help explain the decrease in mean BP levels and prevalence of elevated BP. Higher intake of total saturated fatty acids was associated with higher SBP, DBP, and aortic pulse wave velocity (an index of arterial stiffness) after a 17.8-year follow-up in the Caerphilly Prospective Study including a total of 2,398 men aged 45–59 years.[21]

Total polyunsaturated fatty acids have been reported to be significantly associated with reduced arterial stiffness.[22] The increase in total polyunsaturated fatty acids intake supports the decrease in BP levels and elevated BP. Dietary fiber is a protective nutrient for BP.[23] Daily intake of dietary fiber, indicating consumption of vegetable, fruit, or coarse food grain, increased during the past decade in this population. Besides, increased frequencies of vegetable, fruit, and breakfast intakes and decreased frequencies of sweets and sweetened soft drinks intakes from 2001–2002 to 2009–2010 in US adolescents aged 11–16 years have also been reported by other study.[24] In addition, childhood BP decrease is unlikely to be affected by the use of antihypertensive medicines, which is rare in use in young population.

Strengths and limitations

Our study has several important strengths. On one hand, the large sample size of US children and adolescents from NHANES data make our results more powerful. On the other hand, the standardized protocol for BP measurement in the continuous surveys and rigorous quality controls guaranteed creditability of our findings. However, several limitations should be noted. First, the proportion of 3 BP measurements was 84.6% in the all NHANES between 1999 and 2012. In other words, 15.4% of all participants had only 1 or 2 BP measurements. To make full use of the data and be consistent with the previous studies using NHANES data,[4–7] we did not exclude subjects with less than 3 BP measurements. Nevertheless, sensitivity analysis after exclusion of these participants revealed that secular trends in BP values and prevalence of elevated BP did not change vitally. Second, in clinic practice, 1 child with elevated BP should be confirmed by at least 3 repeated visits of different times.[3] In this study, we used average BP levels in a single visit to represent BP values of the subjects; thus the prevalence of elevated BP would have been overestimated. However, this was unlikely to affect our trend findings. Third, 24-hour recall questionnaire was used to collect dietary information in NHANES which cannot fully capture the diet patterns in long term or introduce recall bias. Fourth, we assumed that the improvements in healthcare, parents' education, and overall children nutrition may also influence decreased trends in BP levels and prevalence of elevated BP in US children and adolescents. However, we are not accessible to related data

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currently to support our hypothesis. Fifth, there were concomitant decreases in both BP and risk dietary intake, but we do not know if there was a true association between these 2 factors in our study. Thus, causal relationships between influencing factors and BP decrease should be interpreted with caution. Sixth, the data on amount of physical activity and sedentary behaviors, as well as intake of diet foods, are not available currently, and further studies are required to examine their trends.

In conclusion, our findings suggested that both BP levels and prevalence of elevated BP have declined during the past decade. In addition, there might be an associated change in dietary factors. Whether interventions regarding obesity and dietary intake could further improve children BP need further investigation.

WHAT IS KNOWN ON THIS SUBJECT

The prevalence of elevated BP has been reported to increase significantly among the US children and adolescents from 1988–1994 to 1999–2008. However, little is known about recent trends in BP values and elevated BP.

WHAT THIS STUDY ADDS

Mean BP levels and prevalence of elevated BP among US children and adolescents have declined during the past decade (1999–2012).

SUPPLEMENTARY MATERIAL

Supplementary materials are available at *American Journal of Hypertension* (http://ajh.oxfordjournals.org).

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AUTHOR CONTRIBUTIONS

B.X. and Y.W. conceptualized and designed the study, and drafted the initial manuscript. T.Z. and B.X. carried out the initial analyses and reviewed and revised the manuscript. B.X., Y.W., and M.Z., F.L., X.Z., M.Z. critically revised the manuscript for important intellectual content.

All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

DISCLOSURE

The authors declared no conflict of interest.

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