Trends in Blood Pressure Among Children and Adolescents

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Context The prevalence of overweight among children and adolescents increased between 1988 and 2000. The change in blood pressure among children and adolescents over that time and the role of overweight is unknown.

Objective To examine trends in systolic and diastolic blood pressure among children and adolescents between 1988 and 2000.

Design, Setting, and Population Two serially conducted cross-sectional studies using nationally representative samples of children and adolescents, aged 8 to 17 years, from the third National Health and Nutrition Examination Survey (NHANES III) conducted in 1988-1994 (n=3496) and NHANES 1999-2000 (n=2086).

Main Outcome Measures Systolic and diastolic blood pressure levels.

Results In 1999-2000, the mean (SE) systolic blood pressure was 106.0 (0.3) mm Hg and diastolic blood pressure was 61.7 (0.5) mm Hg. After adjustment for age, mean systolic blood pressure was 1.6 mm Hg higher among non-Hispanic black girls ($P=.11$) and 2.9 mm Hg higher among non-Hispanic black boys ($P<.001$) compared with non-Hispanic whites. Among Mexican Americans, girls' systolic blood pressure was 1.0 mm Hg higher ($P=.21$) and boys' was 2.7 mm Hg higher ($P<.001$) compared with non-Hispanic whites ($P<.001$). With further adjustment for body mass index, these differences were attenuated. After age, race/ethnicity, and sex standardization, systolic blood pressure was 1.4 (95% confidence interval [CI], 0.6-2.2) mm Hg higher ($P<.001$) and diastolic blood pressure was 3.3 (95% CI, 2.1-4.5) mm Hg higher in 1999-2000 ($P<.001$) compared with 1988-1994. With further adjustment for differences in the body mass index distribution in 1988-1994 and 1999-2000, the increase in systolic blood pressure was reduced by 29% and diastolic blood pressure was reduced by 12%.

Conclusions Blood pressure has increased over the past decade among children and adolescents. This increase is partially attributable to an increased prevalence of overweight.

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High blood pressure is an established risk factor for cardiovascular disease.[1-3] Furthermore, high blood pressure contributes substantially to cardiovascular disease incidence and premature mortality.[2,4] Cardiovascular disease events occur most frequently during or after the fifth decade of life but pathophysiological and epidemiological evidence suggests that essential hypertension and the precursors of cardiovascular disease originate in childhood.[5] Of particular note, some studies show that increased blood pressure levels during childhood strongly predict hypertension in young adulthood.[6-8]

Hajjar and Kotchen[9] reported an apparent increase in the prevalence of hypertension among US adults. Among those 18 years or older, the age-standardized prevalence of hypertension increased from 25.0% in 1988 to 28.7% in 2000.[10] This analysis also indicated that a concurrent increase in body mass index (BMI) was responsible for most but not all of the increase in prevalence of hypertension.

Using serial National Health and Nutrition Examination Surveys (NHANES), Ogden et al[11] reported a substantial increase in the prevalence of overweight among children and adolescents in the United States between 1988 and 2000. Given the relationship between BMI and blood pressure, we hypothesized that blood pressure levels might have increased during the same period.

We characterized blood pressure levels among participants aged 8 through 17 years in the NHANES 1999-2000. Additionally, we compared systolic and diastolic blood pressure levels in 1999-2000 with corresponding values in 1988-1994, using experience from the third NHANES (NHANES III), and evaluated the relationship between BMI trends and blood pressure levels.

METHODS

NHANES III and NHANES 1999-2000 are nationally representative cross-sectional surveys of the civilian noninstitutionalized population in the United States.[12,13] Details of the procedures involved in these studies have been published in detail. In brief, the design for each of these studies included a stratified multistage probability sample based on selection of counties, blocks, households, and persons within households. NHANES III and NHANES 1999-2000

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were designed to oversample Mexican Americans, non-Hispanic blacks, and children and adolescents to improve estimates for these groups. Response rates were 86% for the interview portion and 78% for the examination portion of NHANES III; and 82% for the interview portion and 76% for the examination portion of NHANES 1999-2000.[13]

Each NHANES consisted of an in-home interview followed by an examination at a mobile examination center. Of relevance to the current analysis, variables collected in the home interview were age, race, and sex. Overall, 3 hours were allocated for NHANES examinations. Study participants 8 years or older underwent a standardized physical examination that included height, weight, and blood pressure measurements. Height was measured with participants standing on the floor using a fixed stadiometer with a vertical backboard and movable headboard. Weight was taken by asking each participant to stand on the center of the platform of a digital scale (Mettler-Toledo Int Inc, Columbus, Ohio) while wearing underwear, a disposable gown, and foam slippers. Body mass index was calculated as weight in kilograms divided by height in meters squared.

Blood Pressure Measurement

For children and adolescents between the ages of 8 and 17 years in NHANES III and NHANES 1999-2000, up to 3 blood pressure measurements were taken by a physician using the standard protocol of the American Heart Association during a single visit to a mobile examination center.[14,15] Blood pressure measurements were not taken for children younger than 8 years in NHANES 1999-2000. Three blood pressure measurements were available for 85% of children and adolescents aged 8 to 17 years who participated in the examination portion of NHANES III and 88% of children and adolescents who participated in the examination portion of NHANES 1999-2000. Blood pressure was measured with the participant in a seated position following 5 minutes of quiet rest. Quality control for the blood pressure measurements included quarterly recertification with retraining if necessary, annual retraining of all physicians, and monitoring of equipment and equipment repair. Blood pressure certification consisted of video test recognition of Korotkoff sounds and measurement performance on live volunteers. The physician selected 1 of 5 (infant, child, adult, large adult, and thigh) cuff sizes for blood pressure measurement based on the size of the participant's arm. The inside cuff was marked with an index and range line. If the index line fit within the range line, the cuff size was considered correct. If the index line did not fit or the cuff was barely large enough, the next smaller or larger cuff was attempted until an appropriately fitting cuff was identified. Details regarding blood pressure measurement and quality control procedures are provided in the NHANES III and NHANES 1999-2000 manuals of operation.[12]

The protocols for conduct of NHANES III and NHANES 1999-2000 were approved by the institutional review board of the National Center for Health Statistics, Centers for Disease Control and Prevention.[13] Informed consent was obtained from all participants or from the participant's guardian.[13]

Statistical Methods

The current analysis was limited to children and adolescents in NHANES III (n = 3496) and NHANES 1999-2000 (n = 2086) with 3 valid systolic and diastolic blood pressure measurements and height and weight measurements. Findings were similar when children and adolescents with any valid blood pressure measurement were included. Characteristics of US children and adolescents aged 8 through 17 years were calculated using NHANES III (1988-1994) and NHANES 1999-2000.

For NHANES 1999-2000, sex-specific quantile regression models including third-order polynomials for age were used to assess the association between age and level (25th, 50th, 75th, 90th, 95th percentiles) of systolic and diastolic blood pressure. Additionally, age-specific mean systolic and diastolic blood pressure was determined for each race/ethnicity group (non-Hispanic white, non-Hispanic black, and Mexican American) and sex subgroup. Differences in mean blood pressure levels, adjusted for age only and subsequently for age and BMI, were assessed across race/ethnicity and sex groupings using multivariable linear regression. Increases in systolic and diastolic blood pressure with age from 8 to 17 years were assessed using linear regression models. Due to differences in the blood pressure slopes between boys and girls, the increase in blood pressure with age was analyzed separately for children aged 8 through 12 years and adolescents aged 13 through 17 years.

Age-, race-, and sex-standardized mean systolic and diastolic blood pressure levels were calculated for children and adolescents in NHANES III and NHANES 1999-2000. Blood pressure levels were also calculated for each period by sex, race/ethnicity, and age group (8-12 years and 13-17 years). Comparisons of mean blood pressure levels across the 2 surveys were achieved using *t* tests and took into account the complex survey design used in both the NHANES III and NHANES 1999-2000. Specifically, after determining the mean (SE) blood pressure level for each survey, we calculated the *t* statistic as the difference in blood pressure divided by the SE of the difference, calculated as the square root of the sum of each estimate's variance. Finally, the mean changes in systolic and diastolic blood pressure were calculated under the assumption that the BMI distribution remained constant between NHANES III and NHANES 1999-2000 using direct adjustment. This was accomplished by applying the distribution of BMI for children and adolescents aged 8 to 17 years from NHANES III by individual unit of BMI to the mean blood pressure levels observed in NHANES III and NHANES 1999-2000. All analyses were repeated and adjusted for height rather than BMI with markedly similar results observed (data not shown).

All calculations were weighted to the civilian noninstitutionalized population of the United States, aged 8 through 17 years, using SUDAAN statistical soft-

ware (version 8.0; Research Triangle Institute, Research Triangle Park, NC). Analyses included sample weights that account for the unequal probabilities of selection, oversampling, and nonresponse. The SEs were estimated for NHANES 1999-2000 by means of the delete–1 jackknife method and for NHANES III using the Taylor series linearization method.[16]

RESULTS

Mean age was similar among children and adolescents in the United States in 1988-1994 and 1999-2000 (TABLE 1). Additionally, the percentages by sex were similar in the 2 populations. The percentage of children and adolescents who were Mexican American compared with non-Hispanic white was higher in 1999-2000. The prevalence of those who were overweight also increased from 1988-1994 to 1999-2000.

Blood Pressure Levels in NHANES 1999-2000

In 1999-2000, the mean (SE) systolic blood pressure was 106.0 (0.3) mm Hg and the mean (SE) diastolic blood pressure was 61.7 (0.5) mm Hg. Among boys and girls, the entire distribution of systolic and diastolic blood pressure levels increased with age (FIGURE). This was true for each of the 6 race/ethnicity and sex groups (TABLE 2 and TABLE 3). Age- and race/ethnicity–adjusted mean systolic blood pressure was 3.2 mm Hg higher among boys compared with girls ($P<.001$). For girls, age-adjusted mean systolic blood pressure was 1.6 mm Hg higher for non-Hispanic blacks ($P=.11$) and 1.0 mm Hg higher for Mexican Americans ($P=.21$) compared with non-Hispanic whites. After further adjustment for BMI, systolic blood pressure was 0.5 mm Hg higher among non-Hispanic blacks ($P=.60$) and 0.1 mm Hg higher among Mexican Americans ($P=.86$) compared with non-Hispanic whites. For boys, age-adjusted mean systolic blood pressure was 2.9 mm Hg higher among non-Hispanic blacks ($P<.001$) and 2.7 mm Hg higher among Mexican-Americans ($P<.001$) compared with non-Hispanic whites. After adjustment for age and BMI, systolic blood pressure was 1.9 mm Hg higher among non-Hispanic blacks ($P=.02$) and 1.1 mm Hg higher among Mexican Americans ($P=.18$) compared with non-Hispanic whites. Differences in age- and BMI-adjusted diastolic blood pressure across race/ethnicity and sex were small and not statistically significant ($P=.20$).

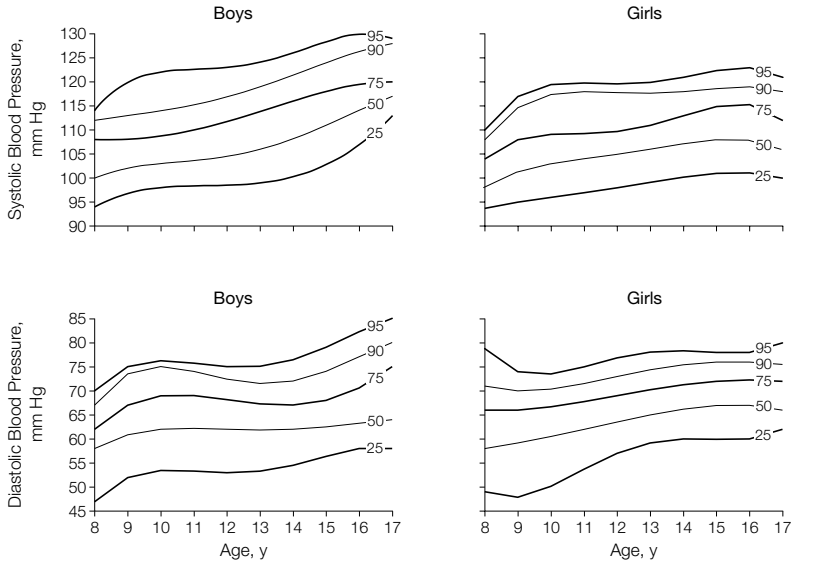
For children and adolescents aged 8 through 12 years, the increase in systolic blood pressure with each year of age was greater among girls (1.46 mm Hg) compared with boys (0.63 mm Hg) ($P=.01$). In contrast, among children and adolescents aged 13 through 17 years, the increase in blood pressure for each year of age was greater among boys (2.53 mm Hg) compared with girls (0.40 mm Hg) ($P=.08$). Similar patterns were seen for the increase in diastolic blood pressure with age. The increase in diastolic blood pressure between the ages of 8 and 12 years was 1.19 mm Hg for girls and 0.38 mm Hg for boys ($P=.24$) with each year of age. Between the ages of 13 and 17 years, the increase in diastolic blood pressure with each year of age was 0.23 mm Hg for girls and 1.54 mm Hg for boys ($P=.01$). After adjustment for BMI, the increase in systolic blood pressure with age was not significantly different between boys and girls. Among boys and girls aged 8 through 12 years, the increase in systolic blood pressure with age was greatest among Mexican Americans and lowest among non-Hispanic whites ($P=.08$ comparing Mexican American to non-Hispanic white boys). The increase in systolic blood pressure with age among boys 13 through 17 years was greater among non-Hispanic whites compared with Mexi-

Table 1. Characteristics of US Children and Adolescents Aged 8 Through 17 Years

Characteristic	US Population, Mean or % (SE) 1988-1994 (n = 3496)*	1999-2000 (n = 2086)†
Mean age, y	12.7 (0.1)	12.7 (0.1)
Male, %	51.1 (0.2)	49.5 (1.2)
Non-Hispanic black, %	16.3 (0.1)	16.8 (0.8)
Mexican American, %	9.2 (0.1)	12.0 (0.6)
At risk for overweight, %‡	16.5 (1.1)	15.5 (1.2)
Overweight, %§	11.7 (1.1)	16.3 (1.3)

*From the third National Health and Nutrition Examination Survey.
†From the National Health and Nutrition Examination Survey 1999-2000.
‡In the 85th to 94th percentile for age- and sex-specific body mass index based on the Centers for Disease Control and Prevention's 2000 growth charts.
§In the 95th percentile or higher for age- and sex-specific body mass index based on the Centers for Disease Control and Prevention's 2000 growth charts.

Figure. Systolic and Diastolic Blood Pressure Levels by Age and Sex Among Children and Adolescents Aged 8 to 17 Years in the United States, 1999-2000



Blood pressure levels are presented in 25th, 50th, 75th, 90th, and 95th percentiles.

can Americans ($P=.004$), while no significant differences were noted across race/ethnicity groups among girls. Among boys, the increase in diastolic blood pressure was similar across race/ethnicity groupings for those aged 8 to 12 years ($P>.60$) and greater among non-Hispanic whites compared with Mexican Americans aged 13 through 17 years ($P=.08$). Compared with non-Hispanic black girls aged 8 through 12 years, the increase in diastolic blood pressure with age was greater among non-Hispanic whites ($P=.11$) and Mexican Americans ($P=.08$). In contrast, no significant differences across race/ethnicity were noted among girls aged 13 through 17 years.

Blood Pressure Trends (1988-1994 to 1999-2000)

After adjustment for differences in age, race, and sex, mean systolic blood pressure was 1.4 mm Hg (95% confidence interval [CI], 0.6-2.2 mm Hg; $P<.001$) higher and diastolic blood pressure was 3.3 mm Hg (95% CI, 2.1-4.5 mm Hg; $P<.001$) higher in 1999-2000 com-

Table 2. Systolic Blood Pressure of US Children and Adolescents Aged 8 Through 17 Years

	Mean (SD) Systolic Blood Pressure, mm Hg					
	Boys			Girls		
	White	Black	Mexican American	White	Black	Mexican American
Age, y						
8	100 (2)	103 (2)	101 (1)	98 (2)	98 (2)	96 (1)
9	103 (2)	102 (2)	105 (2)	101 (3)	104 (2)	100 (2)
10	102 (2)	106 (2)	104 (2)	104 (2)	102 (1)	99 (2)
11	107 (2)	108 (1)	104 (1)	99 (2)	103 (2)	106 (2)
12	101 (2)	104 (2)	107 (1)	105 (2)	105 (2)	107 (1)
13	104 (2)	111 (2)	113 (1)	107 (2)	107 (1)	106 (2)
14	109 (2)	113 (2)	113 (1)	105 (2)	108 (2)	109 (1)
15	110 (2)	111 (1)	113 (2)	106 (2)	111 (1)	108 (2)
16	111 (1)	116 (2)	115 (2)	109 (2)	108 (2)	108 (1)
17	117 (2)	118 (2)	115 (2)	107 (2)	108 (1)	110 (1)
Change per year, mean (SE)						
Ages 8-12 y	0.44 (0.63)	0.87 (0.56)	1.11 (0.39)	1.17 (0.66)	1.29 (0.56)	2.83 (0.46)
Ages 13-17 y	2.90 (0.72)	1.79 (0.45)	0.63 (0.34)	0.37 (0.48)	0.35 (0.35)	0.48 (0.58)
P value*						
Ages 8-12 y	.48	.13	.007	.08	.03	<.001
Ages 13-17 y	<.001	<.001	.07	.44	.32	.42

**P* value for change in blood pressure per year of age.

Table 3. Diastolic Blood Pressure of US Children and Adolescents Aged 8 Through 17 Years

	Mean (SD) Diastolic Blood Pressure, mm Hg					
	Boys			Girls		
	White	Black	Mexican American	White	Black	Mexican American
Age, y						
8	57 (2)	55 (3)	60 (2)	59 (3)	60 (2)	58 (2)
9	60 (3)	57 (3)	61 (2)	56 (2)	62 (2)	58 (2)
10	62 (2)	62 (2)	60 (2)	59 (4)	57 (3)	62 (1)
11	59 (3)	60 (3)	64 (2)	59 (3)	59 (2)	61 (2)
12	59 (3)	62 (3)	59 (1)	64 (1)	61 (2)	63 (1)
13	59 (2)	61 (2)	61 (1)	62 (2)	66 (2)	63 (1)
14	61 (2)	61 (2)	64 (2)	67 (2)	66 (2)	64 (1)
15	62 (2)	62 (2)	63 (2)	63 (2)	66 (2)	64 (1)
16	66 (2)	63 (2)	63 (2)	62 (3)	66 (2)	63 (2)
17	66 (3)	64 (2)	64 (2)	68 (2)	62 (2)	65 (1)
Change per year, mean (SE)						
Ages 8-12 y	0.33 (0.65)	0.57 (0.87)	0.21 (0.42)	1.63 (0.81)	–0.13 (0.61)	1.32 (0.49)
Ages 13-17 y	1.81 (0.61)	0.85 (0.59)	0.34 (0.45)	0.62 (0.56)	0.40 (0.67)	0.28 (0.35)
P value*						
Ages 8-12 y	.61	.51	.63	.05	.84	.01
Ages 13-17 y	.005	.16	.46	.27	.55	.42

**P* value for change in blood pressure per year of age.

pared with 1988-1994 (TABLE 4 and TABLE 5). Between 1988-1994 and 1999-2000, mean systolic blood pressure levels increased 1.4 mm Hg among boys and 1.5 mm Hg among girls. During the same period, mean systolic blood pressure levels increased 1.9 mm Hg among non-Hispanic blacks, 2.3 mm Hg among Mexican Americans, and 1.9 mm Hg among children and adolescents 8 to 12 years of age. Systolic blood pressure among non-Hispanic whites ($P=.06$) and those aged 13 through 17 years ($P=.09$) was 1.0 mm Hg higher in 1999-2000 compared with 1988-1994. Increases in diastolic blood pressure between 1988-1994 and 1999-2000 were large and seen in all age, race/ethnicity, and sex subgroups investigated. After standardization to the BMI distribution from 1988-1994, the increase in mean systolic and diastolic blood pressure from 1988-1994 to 1999-2000 was reduced by 29% and 12%, respectively. Specifically, after BMI adjustment, systolic blood pressure was 1.0 mm Hg (95% CI, 0.2-1.8 mm Hg) higher among children and adolescents aged 8 through 17 years in 1999-2000 compared with 1988-1994 ($P=.01$). Diastolic blood pressure was 2.9 mm Hg (95% CI, 1.7-4.1 mm Hg) higher among children and adolescents in 1999-2000 compared with 1988-1994 ($P<.001$).

COMMENT

We provide estimates of systolic and diastolic blood pressure levels for US children and adolescents aged 8 through 17 years. Between the NHANES III and NHANES 1999-2000 surveys, systolic blood pressure levels increased an average of 1.4 mm Hg and diastolic blood pressure levels increased 3.3 mm Hg. Significant increases in blood pressure levels were observed in all subgroups for diastolic blood pressure and in most subgroups for systolic blood pressure (non-Hispanic blacks, Mexican Americans, boys, girls, and those aged 8-12 years).

The increase in diastolic blood pressure among children and adolescents from NHANES III to NHANES 1999-2000 was especially large. Several potential explanations were taken into consideration to ensure these results were accurate. Blood pressure distributions for each survey were examined and children and adolescents with zero values for diastolic blood pressure were excluded in all analyses. The blood pressure measurement protocols used in NHANES III and NHANES 1999-2000 were identical and the fifth Korotkoff sound was used for defining diastolic blood pressure in both surveys. Additionally, the training, certification, and quality-control procedures for blood pressure measurements used in NHANES III and NHANES 1999-2000 were rigorous; published data for NHANES 1999-2000 indicate no bias in the measurement and recording of blood pressure data.[17] Although we cannot rule out random measurement errors, it seems unlikely that any random errors would account for the large increase in diastolic blood pressure observed between the 2 surveys.

In the United States, non-Hispanic black adults have a higher prevalence and incidence of hypertension.[18] The age at which differences in blood pressure across race/ethnicity groups become apparent is uncertain.[19] In a recent pooled analysis of 8 epidemiological studies, systolic blood pressure was 1.0 mm Hg higher for white compared with black girls aged 5 through 12 years after adjustment for height.[20] However, among girls aged 13 to 17 years, black girls' systolic blood pressure was 1.1 mm Hg higher than that in white girls. In the current analysis, mean systolic blood pressure was 1.6 mm Hg higher among black

Table 4. Systolic Blood Pressure by Age, Race/Ethnicity, and Sex for Children and Adolescents Aged 8 Through 17 Years*

	Mean (SE) Systolic Blood Pressure, mm Hg			
	1988-1994†	1999-2000‡	Difference Between Years	*P* Value
Total	104.6 (0.36)	106.0 (0.26)	1.4 (0.43)	<.001
Boys	106.2 (0.48)	107.6 (0.37)	1.4 (0.55)	.03
Girls	102.9 (0.42)	104.4 (0.47)	1.5 (0.62)	<.001
Non-Hispanic				
White	104.3 (0.50)	105.3 (0.36)	1.0 (0.58)	.06
Black	105.6 (0.43)	107.5 (0.52)	1.9 (0.59)	<.001
Mexican American	104.8 (0.39)	107.1 (0.43)	2.3 (0.60)	<.001
Age group, y				
8-12	100.6 (0.46)	102.5 (0.54)	1.9 (0.68)	<.001
13-17	108.4 (0.42)	109.4 (0.34)	1.0 (0.52)	.09

*Standardized to the age (by year), race/ethnicity, and sex distribution of children and adolescents in the third National Health and Nutrition Examination Survey.
†From the third National Health and Nutrition Examination Survey.
‡From the National Health and Nutrition Examination Survey 1999-2000.

Table 5. Diastolic Blood Pressure by Age, Race/Ethnicity, and Sex for Children and Adolescents Aged 8 Through 17 Years*

	Mean (SE) Diastolic Blood Pressure, mm Hg			
	1988-1994†	1999-2000‡	Difference Between Years	*P* Value
Total	58.4 (0.40)	61.7 (0.46)	3.3 (0.61)	<.001
Boys	58.9 (0.50)	61.2 (0.59)	2.3 (0.77)	<.001
Girls	57.9 (0.45)	62.1 (0.62)	3.2 (0.77)	<.001
Non-Hispanic				
White	58.8 (0.51)	61.6 (0.62)	2.8 (0.80)	<.001
Black	57.6 (0.50)	61.7 (0.80)	4.1 (0.94)	<.001
Mexican American	57.6 (0.69)	62.0 (0.40)	4.4 (0.80)	<.001
Age group, y				
8-12	54.9 (0.54)	59.7 (0.76)	4.8 (0.93)	<.001
13-17	61.8 (0.50)	63.5 (0.49)	1.7 (0.70)	.02

*Standardized to the age (by year), race/ethnicity, and sex distribution of children and adolescents in the third National Health and Nutrition Examination Survey.
†From the third National Health and Nutrition Examination Survey.
‡From the National Health and Nutrition Examination Survey 1999-2000.

compared with white girls. Although the current results were not statistically significant, they are consistent with data from the National Heart, Lung, and Blood Institute Growth and Health Study in which systolic (1.4 mm Hg) and diastolic (1.0 mm Hg) blood pressure levels were significantly higher for black compared with white girls.[19,21]

Although a majority of the evidence supports the presence of a higher average blood pressure among black compared with white girls, the situation for boys is less certain. In the pooled analysis of 8 large studies,[20] systolic blood pressure was 0.9 mm Hg (95% CI, 0.6-1.3 mm Hg) higher among white boys compared with black boys. However, blood pressure was higher among black compared with white children and adolescents in several studies. The current study was consistent with these latter studies. In the current analysis, systolic blood pressure was 2.9 mm Hg higher among a nationally representative sample of non-Hispanic black compared with non-Hispanic white boys.

The Mexican American population in the United States has grown tremendously over the past 2 decades and a higher incidence of cardiovascular disease among Mexican American compared with non-Hispanic white adults has been reported.[22] A previous report comparing white and black children from the Bogalusa Heart Study with Mexican American children from Brooks County, Texas, in 1984-1985 found similar blood pressure levels in each race/ethnicity grouping.[23] Additionally, mean age-adjusted systolic and diastolic blood pressures from large cross-sectional studies in Minneapolis, Minn, conducted in 1986 and 1996 were similar among white, black, and Hispanic children (mean age, 12.1 years).[24] The data from NHANES 1999-2000 show a higher age-adjusted mean blood pressure among Mexican Americans compared with non-Hispanic whites. Although higher BMI explains the difference in systolic blood pressure between non-Hispanic white and Mexican American girls, systolic blood pressure remained 1.1 mm Hg higher among Mexican American compared with non-Hispanic white boys and diastolic blood pressure remained 0.6 mm Hg higher after age and BMI adjustment.

The strong association between BMI and systolic blood pressure among children and adolescents is worrisome because the US prevalence of overweight has been increasing over the past several decades. Ogden et al[11] have recently reported that the prevalence of overweight has increased from 11.3% to 15.5% for adolescent boys and 9.7% to 15.5% among adolescent girls between 1988-1994 and 1999-2000. After age, race/ethnicity, and sex standardization, the mean BMI among children and adolescents aged 8 through 17 years increased by 0.7 ($P<.01$). Mean BMI was nonsignificantly higher in 1999-2000 compared with 1988-1994 for children and adolescents who were normal weight (0.1), at risk for overweight (0.1), and overweight (0.3). In our analyses, a statistically significant, although reduced, increase in systolic blood pressure of 1.0 mm Hg and diastolic blood pressure of 2.9 mm Hg between 1988-1994 and 1999-2000 remained present even after standardization for the increase in BMI. This suggests that environmental factors other than an increase in BMI are responsible for at least part of the increase in blood pressure observed among children and adolescents in the current study. To better control blood pressure levels among children and adolescents, research to identify behavioral factors, such as diet composition and physical activity influencing blood pressure and intervention programs to address these factors are needed.

There are few published studies detailing temporal trends in blood pressure among children and adolescents. A single blood pressure measurement was obtained among children and adolescents aged 6 to 17 years in the NHANES during 1963 to 1965, 1966 to 1970, 1971 to 1974, and 1976 to 1980.[25] Among children and adolescents, blood pressure was lower in 1971-1974 and 1976-1980 compared with the earlier periods. However, the methods of performing blood pressure measurements in these earlier NHANES differed between surveys, making comparisons tenuous. Trends in blood pressure have been reported from biracial populations aged 7 to 9 years studied in the Bogalusa Heart Study. Two cohorts of children and adolescents, the first examined in 1973 and the second in 1984, were reexamined 8 years later. Systolic and diastolic blood pressure levels were similar at baseline in both cohorts with the exception that black boys in the 1984 group had slightly lower diastolic blood pressure (2 mm Hg).[26] At the 8-year follow-up visits, the 1984 cohort weighed significantly more than the 1973 cohort for all ethnic and sex groups except white girls. Nonetheless, the increase in systolic blood pressure during follow-up was 4 to 6 mm Hg less for the 1984-1992 cohort compared with the 1973-1981 cohort, suggesting that factors other than weight were influencing the secular trend. More recently, blood pressure levels were compared from 2 serial cross-sectional surveys of fifth- through eighth-grade public school children, aged 10 to 14 years, from Minneapolis, Minn, surveyed in 1986 (n=8222) and 1996 (n=10 241).[24] During the 10-year period, systolic blood pressure increased by 1.5 mm Hg among boys ($P<.001$) and 0.7 mm Hg among girls ($P<.001$). However, diastolic blood pressure decreased 1.5 mm Hg among boys ($P<.001$) and 2.1 mm Hg among girls ($P<.001$).

In 1996, the National Heart, Lung, and Blood Institute published "Update on the Task Force Report (1987) on High Blood Pressure in Children and Adolescents: A Working Group Report from the National High Blood Pressure Education Program," which is a comprehensive report on blood pressure in children and adolescents.[27] This report contains blood pressure norms for children and adolescents in the United States. The blood pressure norms in the National Heart, Lung, and Blood Institute report are specific to height, age, and sex and are based on measurements from 61 206 children from 10 large population-based epidemiological studies. The blood pressure norms were not compared with those obtained in the current analysis as they were

derived from a single blood pressure measurement that was obtained using variable techniques rather than the average of multiple measurements obtained using a standardized method.

Our analyses have some limitations. Although estimates of blood pressure levels were based on an average of 3 blood pressure measurements at a single visit, a more precise estimate of blood pressure levels would be obtained by averaging multiple blood pressure measurements obtained during several visits. Additionally, although blood pressure data are available for children and adolescents from previous NHANES studies, methods of blood pressure measurement differed between prior surveys (ie, NHANES I in 1971-1975 and NHANES II in 1976-1980) and NHANES III and NHANES 1999-2000, precluding analysis of trends over a longer period. Also, although we assessed the potential impact that the increase in BMI between 1988-1994 and 1999-2000 might have had on blood pressure levels, data on the secular trends for several other variables relevant to children and adolescents (eg, Tanner scale data, dietary intake of sodium) were not available from both surveys. Finally, caution should be used when drawing temporal conclusions from serial cross-sectional data.

Strengths of our study include the representativeness of the samples for the US general population. We had ample data to present analyses and results by race/ethnicity and sex. Additionally, identical methods were used for measuring blood pressure in children and adolescents in NHANES III and NHANES 1999-2000, providing confidence that the increase in blood pressure observed is not due to differences in the study protocols.

Systolic and diastolic blood pressure has increased substantially among children and adolescents in the United States. The increase in BMI during this same period accounted for some of the increase in blood pressure. Given the relationship between BMI and blood pressure and the high and unabated increase in the prevalence of overweight in the United States, the incidence of hypertension is likely to increase. Additionally, factors other than the increase in overweight among children and adolescents appear to have contributed to the increase in blood pressure over the previous decade. Confirmation of the trends observed in the current study is needed. Factors that have resulted in higher blood pressure levels among children and adolescents in the United States also need to be identified. Additionally, effective primary and secondary hypertension prevention programs aimed at children and adolescents that include prevention of overweight, weight loss, increased physical activity, and dietary modification need to be developed and implemented. Such interventions could have a profoundly positive impact on the prevalence of high blood pressure in the United States.

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Study concept and design: Muntner, He, Cutler.
Analysis and interpretation of data: Muntner, He, Cutler, Wildman, Whelton.
Drafting of the manuscript: Muntner, Cutler.
Critical revision of the manuscript for important intellectual content: Muntner, He, Cutler, Wildman, Whelton.
Statistical expertise: Muntner, He, Whelton.
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