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Mean mid-arm circumference and blood pressure cuff sizes for US children, adolescents and adults: National Health and Nutrition Examination Survey, 2011–2016

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Abstract

Background—Measuring blood pressure (BP) requires an appropriate BP cuff size given measured mid-arm circumference (mid-AC).

Objective—To provide mid-AC means and percentiles for US population aged more than 3 years and examine the frequency distribution of mid-AC cuffed by Baum and Welch Allyn cuff systems.

Patients and methods—The 2011–2016 National Health and Nutrition Examination Survey, a cross-sectional survey, was used to estimate mean mid-AC (n = 24 723).

Results—Mean mid-AC did not differ from 2011 to 2016(31.0 vs. 31.3 cm, $P > 0.05$). During 2011–2016, mean mid-AC was greater for males than females (32.0 vs.30.4 cm, $P < 0.001$) and was largest among adults40–49 years (34.0 cm). Non-Hispanic Black persons had the largest mean mid-AC (32.0 cm) and non-Hispanic Asian persons the smallest (28.4 cm). Increased BMI was associated with increased mean mid-AC for those 3–19 years (normal, 22.0 cm and obese, 31.5 cm, $P < 0.001$) and more than 20 years (normal, 28.2 cm and obese, 37.8 cm, $P < 0.001$). Among those aged 8–17 years, high BP status was associated with a larger mean mid-AC (normotensive 26.1 cm vs. high BP 28.2 cm, $P = 0.001$). Among adults aged 18 years and older, hypertension status was associated with a larger mean mid-AC (normotensive32.4 cm vs. hypertensive 34.2 cm, $P < 0.001$). Among those aged 12–19 years, 13.0% required a Baum large cuff (35–46.9 cm mid-AC) and 21.7% required a Welch Allyn large cuff (32–39.9 cm mid-AC). Among those aged more than 20 years, 33.2% required a Baum large cuff, 48.2% required a Welch Allyn large cuff, 1.3% required a Baum extra-large cuff (44–66 cm mid-AC), and 9.5% required a Welch Allyn extra-large cuff (40–55 cm mid-AC).

Conclusion—Currently, BP is obtained in clinic, pharmacy, home, and ambulatory setting using single or multiple cuffs. National Health and Nutrition Examination Survey mid-AC data should be considered for accurate cuffing avoiding cuff hypertension or hypotension.

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Conflicts of interest

There are no conflicts of interest.

Keywords

blood pressure cuff sizes; mid-arm circumference; National Health and Nutrition Examination Survey

Introduction

Accurate measurement of blood pressure (BP) requires a BP cuff with the appropriate bladder width. Recently, based on previous findings, it is suggested that the ratio of bladder width to mid-AC should be 40–47% of the arm circumference [1,2]. Using a cuff with a bladder width that is too narrow for the mid-arm circumference (mid-AC) tends to overestimate BP, which potentially results in 'cuff hypertension'. In contrast, a bladder width that is too wide for the mid-AC results in underestimates or incorrectly low BP readings [3–8].

This analysis is an update of previous analysis on the same topic [9,10]. Accordingly, the objectives of this analysis were two-fold. The first objective was to provide averages and selected percentiles of mid-AC (cm) for the noninstitutionalized US population aged 3 years and older by sex, age, race and Hispanic origin, BMI, high BP status (aged 8–17 years), and hypertension status (aged > 18 years). The second objective was to examine frequency distribution by selected age groups (3–5, 6–11, 12–19, and 20 years and older) of mid-AC to be cuffed by the Baum; W.A. Baum Co., Inc., Copiague, New York, USA (infant, child/small adult, adult, large adult, and extra-large adult) and by the Welch Allyn (small child, child, small adult, adult, large adult, and extra-large adult).

Patients and methods

Survey description

National Health and Nutrition Examination Survey (NHANES) uses a complex multistage probability sample design to select participants who are representative of the entire civilian, noninstitutionalized US population. Participants are interviewed in their homes where information is obtained on health history, health behaviors, and risk factors. Subsequently, they undergo a physical examination at a mobile examination center (MEC). The procedures to select the sample and conduct the interview and examination have been previously described [11,12]. The National Center for Health Statistics Research Ethics Review Board approved the NHANES protocol, and informed consent was obtained from participants aged 18 years and older, documented assent for aged 7–17 years, and parental permission for aged 3–6 years.

Sample

This analysis includes NHANES 2-year cycles 2011 through 2016. A total of 39, 488 persons aged 3 years and older were sampled. Of these, 27 036 (68%) were interviewed and 25 956 (66%) were examined. Of those examined, 1233 were excluded from this analysis owing to missing data on mid-AC. These exclusions resulted in a final analytic sample of 24 723 participants aged 3 years and older.

Outcome variables

Mid-arm circumference—During the physical examination, the participant's right arm circumference was measured by a trained examiner at the level of the upper arm mid-point mark. The examiner made this mark on the posterior surface of the arm immediately after measuring the upper arm length. The arm mid-point mark was the level at which the measurement was taken to the nearest 0.1 cm using a steel measuring tape. The measuring tape was placed to fit snugly against the skin around the whole circumference of the arm without indenting the skin. For more details, see the Anthropometry Procedures Manual on the NHANES website [13].

Blood pressure cuff sizes—The Baum cuff system was selected because it has been used to measure BP in the original landmark Framingham study and, presently, by NHANES [12,14]. The Welch Allyn (Welch Allyn Inc., Skaneateles Falls, New York, USA) cuff system was selected because it is currently used by two validated oscillometric automatic BP devices ProBP 3400 (Skaneateles Falls, New York, USA) and SureBP (Skaneateles Falls, New York, USA) [15,16]. Most importantly, these cuff systems provide a range of cuffs from infant/small child to extra-large cuff (thigh cuff). Lastly, the information about the Welch Allyn cuff systems was provided by manufacturers [17]. See Table 1 for Baum and Welch Allyn cuff dimensions.

Demographic variables—Age was categorized into the following groups: 3–5, 6–11, 12–19, 20–39, 40–49, 50–59, and 60 and over following NHANES Sampling subdomains classification of age ranges [11]. Age 3 was selected as a start point based on the American Academy of Pediatrics (2017) recommendation that BP should be taken starting at age 3 years [18].

Race and Hispanic origin was based on self-reported information and classified as Hispanic, non-Hispanic Black, non-Hispanic White, and non-Hispanic Asian. Participants not fitting the aforementioned self-classification were classified as 'other'. Data for the 'other' group, including persons who reported multiple races, were included in the total sample results but are not reported separately in the data tables.

Other covariates—BMI was calculated as measured weight in kilograms over measured height in meters squared. For children and adolescents aged 3–19 years, BMI was based on the Centers for Disease Control and Prevention's sex specific 2000 BMI-for-age growth charts for the USA. Age in months at examination was used to match age in months from BMI growth chart data, separately for males and females. BMI for these age groups were categorized as underweight (BMI < 5th percentile), normal weight (BMI 5th to <85th percentiles), overweight (BMI 85th to <95th percentiles), and obese (BMI ≥ 95th percentile) [19]. For adults aged 20 years and older, BMI was categorized using criteria established by the National Institutes of Health as underweight (< 18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2), and obese (≥30.0 kg/m^2) [20]. Owing to the relatively small number of participants in the underweight category, the underweight category was combined with the normal weight category after a sensitivity analysis showed

little difference in the results when excluding the underweight category or when including it in the normal weight category.

All BP readings were obtained from individuals aged 8 years and older during a single examination visit. Trained physicians followed a standard protocol measuring BP at the MEC using a Bauman true gravity mercury wall model and standard Bauman cuffs. Appropriate BP cuff sizes were based on the measurement of the participant's mid-AC. After a 5-min rest, participants had their systolic and diastolic BPs (onset of K1 and fading of K5) measured; systolic and diastolic BP measurements were taken 30 s apart [12].

According to the new clinical practice guideline for screening and management of high BP in children and adolescents, definition of hypertension requires defined elevated office BP for 1 year or more, or defined stage 1 hypertension over three clinic visits. Because BP determinations in the MEC were obtained only once in children aged 8 years and older, stage 1 hypertension was redefined in this paper as high BP. Specifically, high BP in aged 8–17 years old was defined as systolic BP at least 130 mmHg or 95th percentile (whichever is lower), or diastolic BP at least 80 mmHg or 95th percentile (whichever is lower), or the participant reported currently taking medication to lower high BP, where the 95th percentiles of diastolic BP and systolic BP are based on the normative BP table by age, sex, and height [18].

Using the new 2017 ACC/AHA guidelines, an individual adult was defined as having stage 1 hypertension if at least one of the following conditions was satisfied: systolic BP of 130 mmHg or greater, diastolic BP of 80 mmHg or greater, or the participant reported currently taking medication to lower high BP [21].

Statistical analyses

All statistical analyses were performed using SAS 9.4 for Windows (SAS Institute Inc., Cary, North Carolina, USA) and SAS-callable SUDAAN 11.0 software (Research Triangle Institute, Research Triangle Park, North Carolina, USA). All estimates were weighted using the MEC sample weights and incorporated sampling design information; the sample weights accounted for the unequal probabilities of selection resulting from the complex sample design, survey nonresponse, and the planned oversampling of selected population subgroups.

Weighted mean mid-AC values and selected percentiles (5th, 25th, 50th, 75th, 90th) were calculated overall and for covariate subgroups. Mean mid-AC values were compared across covariate subgroups using a Satterthwaite adjusted *F*-test for equality. A *P*-value of less than 0.05 was used to indicate statistical significance. For subgroups with small sample sizes, reliability of 5th and 95th percentile estimates were checked using National Center for Health Statistics data presentation standard for proportions [22]. Specifically, using 5th and 95th percentile estimates as cutoff values, two binary variables (≤ 5th percentile or not, and ≥ 95th percentile or not) were created, and the proportion estimates of these two variables and their corresponding confidence intervals were calculated. Relative confidence interval width (absolute confidence interval width divided by the proportion estimate) greater than 1.3 was deemed as unreliable and the corresponding percentile estimate would be suppressed [22]. Weighted cumulative frequency distribution (CFD) plots were generated to

show the distribution of mid-AC by age groups 3–5, 6–11, and 12–19 years. The age groups 20–39, 40–49, 50–59, and 60 years or more were combined because they overlaid, and it was difficult to distinguish the age groups.

Results

Table 2 presents the mean values and selected percentiles by survey periods, sex, age groups, race and Hispanic origin, and BMI. For survey years 2011–2016, the overall mean mid-AC was not statistically significantly different across the three 2-year survey periods, from 31.0 cm during 2011–2012 to 31.3 cm during 2015–2016. From 2011–2016, mean mid-AC was greater for males than for females (32.0 vs. 30.4 cm, $P < 0.001$). Mean mid-AC varied by age groups and was smallest among children 3–5 years (17.5 cm) and largest among adults 40–49 year (34.0 cm). Among self-reported race and Hispanic groups, non-Hispanic Black persons had the largest mean mid-AC (32.0 cm) and non-Hispanic Asian persons had the smallest mean mid-AC (28.4 cm). Among children and adolescents aged 3–19 years, those classified as having a normal weight or being underweight had the smallest mean mid-AC (22.0 cm) and those with obesity had the largest mean mid-AC (31.5 cm). Similarly, for adults aged 20 years and older, normal weight was associated with the smallest mean mid-AC (28.2 cm) and obesity with the largest mean mid-AC (37.8 cm). Among adults aged 18 years and older, adults with normal BP (< 130/80 mmHg and not medicated for hypertension) had a smaller mean mid-AC (32.4 cm) than adults with hypertension (≥130/80 mmHg or medicated for hypertension) (mean mid-AC = 44.2 cm). Similar pattern was observed for children and adolescents aged 8–17 years old, where children with normal BP had a smaller mean mid-AC (26.1 cm) than children with high BP (mean mid-AC = 28.2 cm).

Figure 1 describes the CFD plot for mid-AC for specific age groups (3–5, 6–11, 12–19, and 20 years and more). The age specific CFD are further described in Table 3 by Baum and Welch Allyn cuff systems. Among children aged 3–5 years old, an estimated 91.7% had a mid-AC ranging from 10 to less than 20 cm and required a cuff that could accommodate this range, such as the Baum infant cuff (66.6%) and Welch Allyn child cuff (88.2%). Among children aged 6–11 years old, greater than 20% needed an adult or larger cuff sizes (Baum or Welch Allyn) accommodating a mid-AC at least 25 cm. Among adolescents ages 12–19 years old, an estimated 13.0% of this age group required a 35 to less than 47 cm mid-AC range cuff, like the Baum large adult cuff; an estimated 21.7% required a 32 to less than 40 cm mid-AC range cuff, like the Welch Allyn large adult cuff; and an additional 3.7% required a 40–55 cm mid-AC range cuff, like the Welch Allyn extra-large adult cuff. For adults aged 20 years and older, greater than 33% of this age group required at least 35 cm mid-AC cuff like the Baum large adult cuff and extra-large adult cuff, and more than an estimated 50% required at least 32 cm mid-AC range cuff like the Welch Allyn large adult cuff and extra-large adult cuff.

Discussion

From 2011–2012 to 2015–2016, there was no significant change in the mean mid-AC. During 2011–2016, there were significant differences in mean mid-AC by sex, age groups,

race and Hispanic origin, hypertension status, and BMI status. Increased BMI represents a challenge for appropriate cuff-bladder sizes, and as previously shown that even after adjusting for all covariates, BMI was significantly associated with BP cuff sizes [10].

During 2011–2016, more than 13.0% of noninstitutionalized adolescents aged 12–19 years and older, either being cuffed by the Baum or Welch Allyn cuff system, required a large adult BP or extra-large adult cuff to be correctly cuffed. Moreover, more than 33.0% of noninstitutionalized adults aged 20 years and older, either being cuffed by the Baum or Welch Allyn cuff system, required a large adult BP or extra-large adult cuff to be correctly cuffed.

Although this analysis (2011–2016) is an update of previous analyses (1999–2010), we felt that there is a value in the update [9,10]. First, and most importantly, currently there is a wide use of single cuff in home BP devices and kiosk BP devices, also known as wide-range cuffs, which are mostly used with automated systems; therefore, additional care must be taken in validating the results obtained, but wide range cuffs should not be used for manually taken BP. One example of validating a wide-range cuff in a kiosk setting is the validation of Pharma-Smart PS-2000 cuff (Pharmasmart International Inc., Rochester, New York, USA) using AAMI/ISO validation criteria [23]. Second, this paper examines the association of the new high BP and hypertension guidelines for children and adolescents aged 8–17 years and adults aged 18 years and older and mid-AC values [18,21]. Third, the current analysis includes BMI as a covariate. Very recent analysis of obesity and severe obesity comparing NHANES survey years 2007–2008 to 2015–2016 shows that obesity and severe obesity rates have not changed for children and adolescents aged 2–19 years. However, they increased significantly in adults; thus, BMI was added to account for that increase [24]. Finally, although in the previous analyses we provided means and standard error by demographic covariates, in the current analyses (in addition to mean mid-AC and standard error), we are providing percentages (5th to 95th) to help with further data interpretation. Finally, this analysis associates mid-AC values with two known BP cuff systems.

There are a number of clinical implications to our report. Overall, in 2011–2014, ~ 36 million (17%) persons engaged in monthly or more frequent home BP monitoring [25,] and as Graves reported, of 124 websites offering home BP devices, only 53% offered more than one cuff size to measure BP [26]. Moreover, Omron (OMRON Corporation, Kyoto, Japan) upper arm home BP devices systems, 5–10 series, offer a one-cuff system with cuffing range 22–42 cm [27]. Using our current mid-AC data to assess the accuracy of BP measurements of the Omron systems suggests that as prescribed, by the manufacturer, mid-AC range, it would miss-cuff 5% of the adult population ages 20 years and older (Fig. 1) and more than 5% of the obese adult and hypertensive population (Table 2). In addition, our data suggested that children and adolescents aged 8–17 years observed to have high BP during the MEC examination on average need an adult BP cuff for accurate BP determination and large adult cuff for those with high BP and in the 95% range.

Ubiquitous in any local pharmacy is the BP kiosk with one BP cuff ‘one size fits all’. Indeed, it is speculated that ~30 000 BP kiosks are located in pharmacies and work places and the concern is what effect does the one cuff has on the accuracy of obtained BP [23]. For

example, Pharma-Smart PS-2000 (one cuff system; mid-AC range 22–38 cm) and Vita-Stat 90550; Medical Screening Services, Inc., Niles, Illinois, USA (one cuff system; mid-AC range 23–33 cm), both are public-use BP monitors [23,28]. Using our current mid-AC data to assess the accuracy of BP measurements of those devices suggests that as prescribed, by the manufacturer, mid-AC ranges, the former would miss-cuff at least 15% of the adult population ages 20 years and older (Fig. 1) and more than 25% of the obese adult population (Table 2), whereas the latter would miss-cuff more than 50% of the adult population ages 20 years and older (Fig. 1) and more than 75% of the obese adult population (Table 2).

There are a number of strengths underlining this report. First, mid-AC data were collected by highly trained health technicians, observed frequently for quality control, and using the same strict protocol to measure mid-AC since NHANES III [13]. Second, previously we chose the National High Blood Pressure Education Program Working Group on High Blood Pressure in Children (4th report) and the American Heart Association (7th report) recommended BP cuff sizes as the basis of our analysis; however, those recommended BP cuff sizes are considered ‘theoretical’. Therefore, we felt that by selecting the Baum and Welch Allyn cuff system as demonstration cuff systems we provided more practical reference cuff sizes [29,30].

The limitations to our current report are the fact that we did not consider other manufacturers cuff systems, such as the Omron HEM-907XL for cuff sizes or other manufacturers, such as GE (GE Healthcare, Chicago, Illinois, USA) or Philips (Philips Healthcare, Andover, Massachusetts, USA). Moreover, we measured the mid-AC on the right arm. There is a chance that the left mid-AC may be larger or smaller than the right mid-AC.

Conclusion

Mid-AC is an essential factor in accurately measuring BP. Accurate mid-AC should be obtained to select the appropriate BP cuff to avoid overestimating or underestimating actual BP levels [7]. This report provides the latest data on mid-AC values, which should be noted for their effects on the accuracy of measurements obtained by BP devices to avoid cuff hypertension/hypotension.

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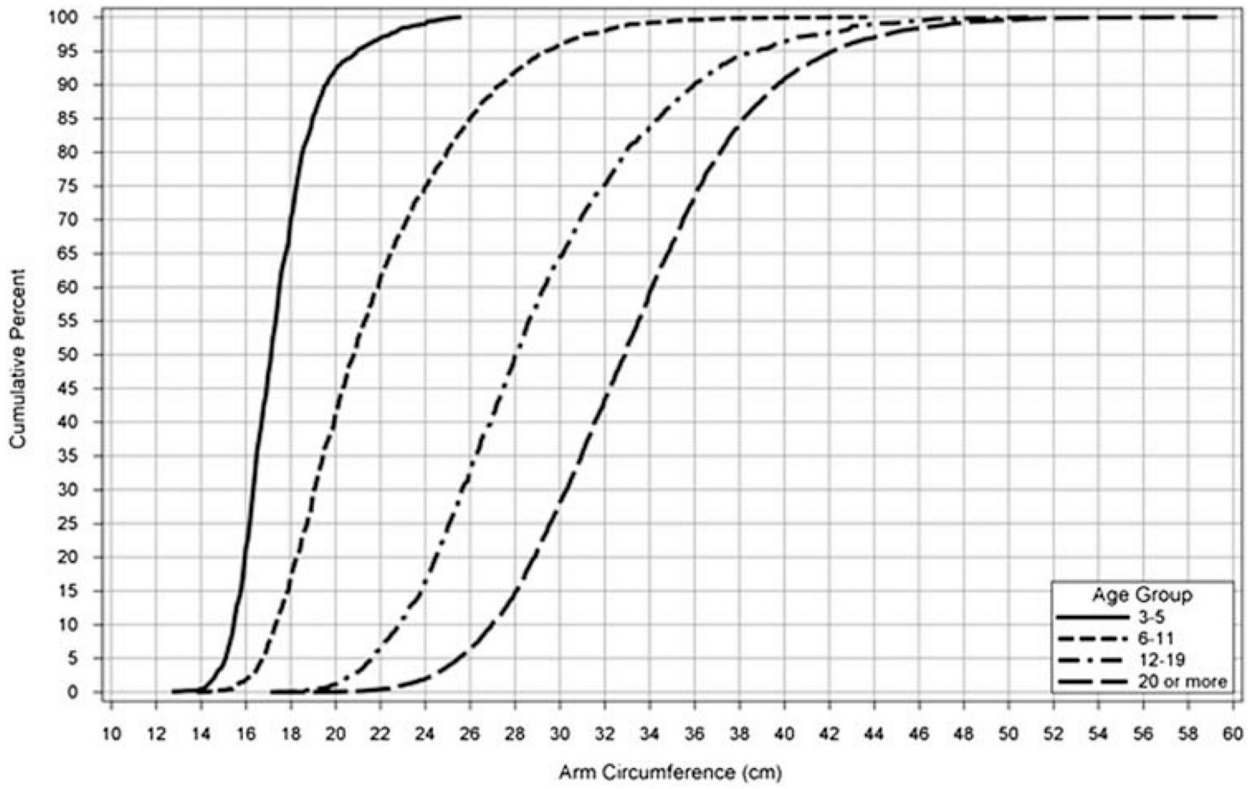

Fig. 1.

Cumulative frequency percent distribution plot for mid-arm circumference (cm) by age groups: National Health and Nutrition Examination Survey 2011–2016.

Table 1

Baum and Welch Allyn bladder dimensions and mid-arm circumference range in cm to be cuffed as designated on the cuff and modified[a]

Cuff system	Bladder[b] dimensions (width × length) (cm)	Mid-arm circumference range as designated on the cuffs	Modified mid-arm circumference range[a]
Baum			
Infant	6 × 12	10–19	10 to <18
Child/small adult	9 × 18	18–26	18 to <25
Adult	12 × 23	25–35	25 to <35
Large adult	15 × 33	33–47	35 to <47
Extra-large adult[c]	18 × 36	46–66	47–66
Welch Allyn			
Small child	6 × 17	12–16	12 to <15
Child	8 × 22	15–21	15 to <20
Small adult	10 × 22	20–26	20 to <25
Adult	13 × 28	25–34	25 to <32
Large adult	16 × 35	32–43	32 to <40
Extra-large adult[c]	20 × 45	40–55	40–55

[a] Modified with no overlap to sum-up to 100%.

[b] For Welch Allyn the bladder is integrated into the cuff.

[c] At times referred to as ‘thigh cuff’.

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Table 2

Mid-arm circumference (cm) among persons aged 3 years and older

			Percentile				
	n	**Mean (SE)**	**5th**	**25th**	**50th**	**75th**	**95th**
Survey period							
2011–2012	8044	31.0 (0.1)	18.4	27.4	31.3	35.2	41.0
2013–2014	8513	31.2 (0.1)	18.5	27.3	31.5	35.4	41.7
2015–2016	8166	31.3 (0.2)	18.6	27.3	31.4	35.5	41.8
P value[1]		0.355					
Sex							
Males	12247	32.0 (0.1)	18.2	28.7	32.7	36.0	41.5
Females	12476	30.4 (0.1)	18.9	26.4	30.1	34.3	41.5
P value[1]		< 0.001					
Age group (years)							
3–5	1693	17.5 (0.1)	15.1	16.2	17.1	18.3	21.0
6–11	3749	21.7 (0.1)	16.8	18.7	20.8	24.0	29.4
12–19	3742	28.9 (0.1)	21.6	25.1	28.0	32.0	38.8
20–39	5407	33.2 (0.1)	25.2	29.3	32.7	36.4	42.6
40–49	2670	34.0 (0.2)	26.4	30.5	33.8	36.9	42.8
50–59	2596	33.6 (0.2)	25.9	30.0	33.2	36.6	42.6
> 60	4866	32.5 (0.1)	25.0	29.2	32.1	35.3	40.6
P value[1]		< 0.001					
Race/Hispanic origin							
Hispanic	6800	30.6 (0.1)	17.7	26.4	31.2	35.1	40.7
Non-Hispanic White	8125	31.4 (0.1)	19.2	27.8	31.6	35.4	41.4
Non-Hispanic Black	5896	32.0 (0.1)	18.2	27.4	32.4	36.8	43.8
Non-Hispanic Asian	2835	28.4 (0.1)	17.9	25.3	28.5	31.6	36.2
P value[1]		< 0.001					
BMI category[2]							
3–19 years of age							

			Percentile				
	n	**Mean (SE)**	**5th**	**25th**	**50th**	**75th**	**95th**
Normal/underweight	5898	22.0 (0.1)	15.9	18.0	21.4	25.5	29.8
Overweight	1496	26.4 (0.2)	17.9	21.8	27.0	30.7	34.1
Obese	1746	31.5 (0.2)	20.1	26.4	31.9	36.2	42.8
P value[1]		< 0.001					
> 20 years of age							
Normal/underweight	4621	28.2 (0.1)	23.6	26.4	28.3	30.0	32.6
Overweight	4966	32.5 (0.0)	28.4	30.7	32.4	34.2	36.7
Obese	5891	37.8 (0.1)	32.1	34.9	37.1	39.9	45.4
P value[1]		< 0.001					
High blood pressure among children and adolescents aged 8–17 years of age[3]							
Yes	240	28.2 (0.6)	NA[4]	22.8	27.9	31.2	42.8
No	4896	26.1 (0.1)	18.6	22.2	25.5	29.2	35.9
P value[1]		0.001					
Stage one hypertension among adults ages 18 years and older[5]							
Yes	7559	34.2 (0.08)	26.0	30.5	33.9	37.2	44.0
No	8242	32.4 (0.1)	25.1	29.0	31.9	35.3	40.6
P value[1]		< 0.001					

National Health and Nutrition Examination Survey 2011–2016.

NA, not available; SE, standard error.

[1] *P* value from Satterthwaite adjusted *F*-test of equality among subgroups.

[2] For 3–19 year olds BMI category was defined using the variable BMDBMIC. For those 20 or more years of age, normal/underweight was defined as a BMI less than 25, overweight was defined as a BMI of 25 to less than 30, and obese as a BMI of 30 or more.

[3] Systolic blood pressure of at least 130 mmHg or 95th percentile (whichever is lower), or diastolic blood pressure at least 80 mmHg or 95th percentile (whichever is lower), or the participant reported currently taking medication to lower high blood pressure, where the 95th percentiles of diastolic blood pressure and systolic blood pressure are based on normative blood pressure tables by age, sex, and height [18].

[4] Results not shown due to unreliable percentile estimates based on National Center for Health Statistics data presentation standards [22].

[5] Systolic blood pressure of 130 mmHg or greater, or diastolic blood pressure of 80 mmHg or greater, or the participant reported currently taking medication to lower high blood pressure.

Table 3

Frequency distribution by cuff systems and age groups

Cuff system	Modified mid-arm circumference range	Age groups (%)			
		3–5 years	6–11 years	12–19 years	> 20 years
Baum					
Infant	10 to <18	66.6	15.1	0.1	-
Child/small adult	18 to <25	33.2	64.3	23.1	3.5
Adult	25 to <35	0.2	20.0	63.6	62.0
Large adult	35 to <47	-	0.6	13.0	33.2
Extra-large adult[a]	47–66	-	-	0.2	1.3
Welch Allyn					
Small child	12 to <15	3.5	0.2	-	-
Child	15 to <20	88.2	39.0	1.1	-
Small adult	20 to <25	8.1	40.1	22.1	3.5
Adult	25 to <32	0.2	18.5	51.5	38.7
Large adult	32 to <40	-	2.1	21.7	48.2
Extra-large adult[a]	40–55	-	0.1	3.7	9.5

[a]At times referred to as ‘thigh cuff’.