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Validating prediction equations for mid-arm circumference measurements in adults: National Health and Nutrition Examination Survey, 2001–2012

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Abstract

Background—Accurate measurement of blood pressure (BP) requires choosing an appropriate BP cuff size.

Objectives—The objective of this study was to examine the validity of regression equations to predict mid-arm circumference (mid-AC) using 2001–2012 National Health and Nutrition Examination Survey height and weight data.

Methods—National Health and Nutrition Examination Survey uses a complex multistage probability sample design to represent the civilian, noninstitutionalized US resident population. The sample consisted of 29 745 participants aged 20 years and older.

Results—For both men and women, the correlations between the predicted and measured mid-AC values were as follows: $r = 0.91$ and 0.92, $P < 0.001$, respectively. For both sexes, the difference between the predicted and measured mid-AC mean values was less than 1.5 cm. The overall percent agreement for selecting the appropriate BP cuff, using the American Heart Association cuff size criteria and comparing the predicted mid-AC values with measured values, was 83.0% for men and 80.0% for women. The percent agreement for small adult cuff was 10.0% for men and 54.0% for women; for adult cuff it was 87.0% for men and 88.0% for women; for large adult cuff it was 82.0% for men and 80.0% for women; and for thigh cuff it was 84.0% for men and 74.0% for women. All agreement statistics were above chance (for men, $\gamma = 0.96$, and Kendall's Tau-b = 0.73; for women, $\gamma = 0.97$, and Kendall's Tau-b = 0.76).

Conclusion—When possible, mid-AC should be directly measured for appropriate BP cuffing; however, the results of this validation study suggest that the prediction equations for mid-AC estimations were highly correlated and had an overall 80.0% agreement with measured mid-AC.

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Conflicts of interest
There are no conflicts of interest.

All supplementary data is available directly from the corresponding author.

Keywords

arm circumference; blood pressure cuff size; National Health and Nutrition Examination Survey (NHANES)

Introduction

An estimated 29.1% of adults aged 18 years and older in the USA have hypertension defined as blood pressure (BP) greater than or equal to 140/90 mmHg or taking antihypertensive medications [1]. Although hypertension is a significant risk factor for cardiovascular disease and mortality, it is a modifiable risk factor [1–4]. Effective BP management, resulting in a reduction in BP, has shown to greatly decrease the incidences of stroke, heart attack, and heart failure [2,5,6]. Therefore, accurate measurement of BP is critical for hypertension screening, as well as for disease management. To accurately measure BP, a BP cuff with the appropriate bladder width must be used. Although there are guidelines for appropriate cuff size selection, there are differences in cuff size ranges. According to the American Heart Association (AHA), an ‘ideal’ bladder width that covers 40% of an individual’s arm circumference (AC) is needed for accurate BP assessment [7]. 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 [8,9].

Alpert [10], in a recent editorial, estimated that ‘improper cuffs are used at least 30–50% of the time’. McKay *et al.* [11] showed that only 29 doctors out of 114 (25.4%) surveyed had a large BP cuff available in their practice for patients requiring such a cuff, and only 13 doctors out of 114 (11.4%) surveyed had the full complement of BP cuffs (small adult, adult, large adult, and thigh) in their practice. In addition, on the basis of a sample of 831 healthcare providers, Wingfield *et al.* [12] reported that only 27% of doctors and 32% of nurses used the appropriate BP cuff size.

Considering the importance of appropriate BP cuff size to accurately obtain BP, Ostchega and colleagues calculated prediction equations for mid-AC estimation by sex using age, height, and weight as regressors on the basis of the National Health and Nutrition Examination Survey (NHANES) III (1988–1994) and NHANES 1999–2000 data. Using these predicted estimations, one can select an appropriate BP cuff size to correctly obtain BP readings without directly measuring mid-AC [13]. The objective of the current study was to validate the aforementioned mid-AC regression equations using 2001–2012 NHANES data. Specifically, we compared measured mid-AC with predicted mid-AC by sex and the corresponding recommended BP cuff sizes.

Methods

Survey description

NHANES uses a complex multistage probability sample design to select participants who are representative of the civilian, noninstitutionalized US resident population. Participants are interviewed in their homes and 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 to conduct the interview and examination have been previously described [14]. The National Center for Health Statistics Research Ethics Review Board approved the NHANES protocol. Informed consent was obtained from all participants.

Sample

A total of 44 555 individuals aged 20 years and older were sampled during NHANES 2001–2012. Of these, 33 144 (74.0%) individuals were interviewed and 31 627 (71.0%) were examined. Of those examined, 1882 individuals were excluded for the following reasons: 133 had a mid-AC measurement less than 22 cm, which falls outside the smallest available adult cuff size; 1501 missed the mid-AC measurement during the anthropometry exam in the MEC; and 248 had missing height and/or weight data. These exclusions resulted in a final analytic sample of 29 745 participants aged 20 years and older (14 430 men and 15 315 women).

Outcome variables

Measured mid-arm circumference—During the anthropometry exam, the participant's right AC was measured by a trained examiner at the level of the upper arm midpoint mark. The examiner made this mark on the posterior surface of the arm immediately after measuring the upper arm length. The arm midpoint mark was the level at which the measurement was taken to the nearest 0.1 cm using a steel measuring tape. The measuring tape fit snugly against the skin, encircling the whole circumference of the arm without indenting the skin. For more details, see the Anthropometry (Body Measurements) Procedures Manual on the NHANES website [15].

Predicted mid-arm circumference equations—The following equations were proposed by Ostchega and colleagues using the NHANES III and NHANES 1999–2000 data to predict mid-AC:

$$\begin{aligned}\text{Men}: &\ \text{Estimated mid-AC}\\ &= 31.76749 + 0.22626 \times \text{weight} - 0.10109 \times \text{height} + 0.05092\\ &\times \text{age} - 0.00081813 \times (\text{age}^2),\end{aligned}$$

$$\begin{aligned}\text{Women}: &\ \text{Estimated mid-AC}\\ &= 39.29946 + 0.2641 \times \text{weight} - 0.1823 \times \text{height} + 0.01972\\ &\times \text{age} - 0.00104 \times (\text{age}^2) + 0.00045901 \times (\text{weight} \times \text{age})\\ &+ 0.00037509 \times (\text{height} \times \text{age}).\end{aligned}$$

The R^2 of the regression models were 0.80 for men and 0.86 for women.

Independent variables

Height in centimeters and weight in kilograms were measured in the MEC during the anthropometry exam. Age was self-reported in years. For more details, see the

Anthropometry (Body Measurements) Procedures Manual on the NHANES website [15]. Table 1 shows the mean values of these three variables for the 2001–2012 NHANES data.

BP cuff sizes

Because the cuff size recommendations can vary by the manufacturer, the AHA scientific statement definitions for recommended BP cuff sizes was used [7]. Specifically, the mid-AC ranges for the cuffs were as follows: small adult (dimensions: 12 cm bladder width by 22 cm length) is 22–26 cm; adult (dimensions: 16 cm bladder width by 30 cm length) is greater than 26–34 cm; large adult (dimensions: 16 cm bladder width by 36 cm length) is greater than 34–44 cm; and thigh (dimensions: 16 cm bladder width by 42 cm length) is greater than 44–52 cm. A measured mid-AC less than 22 cm corresponded to a recommended pediatric cuff size, which represented 0.004% (133 individuals) of examined NHANES participants, who were excluded from the analysis.

Statistical analyses

MEC examination weights and appropriate sample design variables were used in the analysis. The MEC examination sample weights account for the complex survey design, oversampling, and survey nonresponse, and they are poststratified to obtain nationally representative estimates of the US civilian noninstitutionalized resident population. Statistical analyses were conducted using SAS (version 9.3; SAS Institute, Cary, North Carolina, USA) and SAS-callable SUDAAN (version 11.0; Research Triangle Institute, Research Triangle Park, North Carolina, USA).

The predicted mid-AC values were calculated using the sex-specific regression equations from the study by Ostchega and colleagues. The measured mid-AC and the cuff size associated with measured mid-AC were treated as the gold standard.

The differences between the predicted and the measured mid-AC (predicted – measured) were derived for the means and the selected percentiles (1, 10, 25, 50, 75, 90, 95, and 99%). Smoothed weighted distributions of both predicted and measured mid-AC by sex were graphically displayed using Proc SGPLOT SAS 9.3 (version 9.3; SAS Institute, Cary, North Carolina, USA).

Overall percent agreement and percent agreement for specific cuff sizes (small adult, adult, large adult, and thigh) determined by measured and predicted mid-AC were computed. In addition, a number of summary agreement statistics, including γ-statistics and Kendall's Tau-b statistics, to test the monotone trend of association between two BP cuff measurements were computed [16]. These statistics evaluate the strength of agreement differently. γ assesses the agreement of ordinal variables based on concordant and discordant pairs of observations. It ignores tied pairs. Kendall's Tau-b is similar to γ-statistics; however, it uses a correction for ties. The absolute values of the above statistics are from 0 to 1, where 1 represents complete agreement and 0 implies independence [17,18]. All agreement statistics were calculated by sex.

Results

Comparing the predicted with the measured mid-AC values

Table 2 presents the means and selected percentile values for measured and predicted mid-AC. For both men and women, the correlation between predicted and measured mid-AC values was statistically significant ($r = 0.91$ and 0.92, $P < 0.001$, respectively). All percentiles and mean differences were less than or equal to 1 cm, except for the first percentile for men and the 99th percentile for women, which were 1.32 and 1.05 cm, respectively.

Figures 1 and 2 present the smoothed distribution graphs of the measured and the predicted mid-AC by sex. The figures show that the predicted values closely approximated the measured values, with a right shift in the distribution of the predicted mid-AC at 24–26 cm for men. There are clear points at which the equation overpredicted and underpredicted along the curve. This mid-AC range coincides with a small adult cuff. As the predicted values were greater than the measured values at this range, a larger percentage of men requiring a small adult cuff size were categorized into the adult cuff size. However, starting at the 28-cm mark, there is a left shift in the distribution of the predicted mid-AC. Among women, the figure also shows that the predicted values closely approximated the measured values, with ~ 1–2-cm right shift in the distribution of the predicted mid-AC.

BP cuff classification agreement

We used the AHA scientific statement definitions for recommended BP cuff size selection [7]. Table 3 shows the percent agreement between cuff size classification using the predicted mid-AC values and the measured mid-AC values by sex. The prediction equation assigned 83.0% of men to the correct cuff size (the size associated with measured AC). However, only 10.0% of men who should have been assigned a small adult cuff were correctly assigned this cuff using the prediction equation, with 90.0% overcuffed to an adult cuff size. For all other cuff sizes for men, the agreement was greater than 80.0%. However, 14.0% of men were undercuffed to an adult cuff from a large adult cuff and 16.0% were undercuffed from a thigh cuff to a large adult cuff. In addition, 13.0% were overcuffed to a large adult from an adult cuff and 4.0% were overcuffed to a thigh cuff from a large cuff.

Similarly, the prediction equation assigned 80.0% of women to the correct cuff size. Fifty-four percent of women were correctly assigned a small adult cuff by the prediction equation, with the remaining 46.0% overcuffed to an adult cuff size. The prediction equation correctly assigned 80.0% of women who needed an adult cuff and 74.0% of women who needed a thigh cuff. However, among women, 1.0% were undercuffed to a small adult from an adult cuff, 13.0% were undercuffed to an adult cuff from a large adult cuff, and 26.0% were undercuffed from a thigh cuff to a large adult cuff. In addition, 11% of women were overcuffed to a large adult cuff from an adult cuff and 7% were overcuffed to a thigh cuff from a large adult cuff.

We calculated the overall agreement of the measured and the predicted BP cuff selection (for men: $\gamma = 0.96$, and Kendall’s Tau-b = 0.73; for women: $\gamma = 0.97$, and Kendall’s Tau-b = 0.76). γ-statistics and Kendall’s Tau-b statistics test the monotone trend of association between two BP cuff measurements. A γ greater than 0.90 and a Kendall's Tau greater than 0.70 indicate a strong positive association of cuff selection between the predicted measure and the direct measure of the mid-AC [17,18].

Discussion

National organizations such as the American Medical Group Association have strongly encouraged providers to accurately identify individuals with hypertension to effectively manage BP among those with hypertension [19]. If inaccurate BP readings are obtained because of wrong cuff size selection, this goal will be unattainable. Measuring mid-AC is necessary for proper selection of the appropriate BP cuff and thus proper BP measurement. Measuring mid-AC is not technically difficult, but it is not routinely performed in clinical practice, nor do clinicians routinely check the fit of the 'index line' marked on the BP cuff to determine whether the BP cuff size is appropriate for the patient [20].

The objective of this study was to validate the regression equations predicting mid-AC using NHANES 2001–2012 measured mid-AC data. To date, this is the first report to validate the regression equations using a large data set.

Our results showed a strong positive relationship between the predicted and measured mid-AC values. The values correlated well and the overall mean difference between predicted and measured mid-AC was less than 1 cm. When examining cuff selection, regardless of sex, the percent agreement between the cuff selected with the measured mid-AC and the predicted mid-AC was at or greater than 80% for adult and large adult cuff sizes. An overwhelming majority of the cuffs used to measure BP in the USA are the adult and large adult cuffs. In the NHANES 2007–2010 sample, 95.6% of adult men needed an adult or large adult cuff to be correctly cuffed, and 84.0% of women needed an adult or large adult cuff size to be correctly cuffed [21]. Conversely, our findings indicated a low percent agreement in two cuff size categories when using the mid-AC regression-derived values. This mostly occurred with overcuffing in the small adult cuff size category for men and women and undercuffing in the thigh cuff category, especially among women (men: 16.0%; women: 26.0%).

In 2007–2010, men needing a small adult or thigh cuff size represented less than 5.0% of the cuff distribution (2.6 and 1.9%, respectively), whereas women needing a small adult or thigh cuff size represented 13.5 and 2.8%, respectively, of the cuff distribution [21]. A closer examination of the data showed that 1655 individuals (men = 531; women = 1124) fell into this category of miscuffing from a small adult to an adult cuff category. The mean difference between measured mid-AC and predicted mid-AC for both sexes was less than 2.5 cm (men: measured = 25.7 cm, predicted = 28.0 cm; women: measured = 25.8 cm, predicted = 27.7 cm). As for undercuffing from thigh to large BP cuff (men = 36; women = 95), the average difference for both sexes was about 5 cm (men: measured = 46.1 cm, predicted = 42.5 cm; women: measured = 46.9 cm, predicted = 42.0 cm).

The equations are not good in classifying those who have a mid-AC less than or equal to 26 cm. Some caution should also be exercised when using these regression equations for women needing a thigh cuff, because the equations may assign a smaller cuff size when a larger one is needed (happens one-quarter of the time). However, the equations provide a good estimate of mid-AC in those needing an adult and large adult cuff size.

The findings in this report are subject to some limitations. We chose the AHA-recommended BP cuff sizes as the basis of our analysis [7]. To assess the applicability of the regression equations to other cuffs beyond the AHA recommendations, the regression equations were compared with the manufacturer's cuff guidelines, specifically the commercially available Bauman cuff. Results show that the regression equation for men correctly chose 2.1% of the small adult cuff size ($n = 6$), 83.0% of the adult cuff size ($n = 6568$), 87.6% of the large adult cuff size ($n = 5577$), and 78.9% of the thigh cuff size ($n = 89$). For women, the regression equation correctly chose 22.3% of the small adult cuff size ($n = 183$), 89.5% of the adult cuff size ($n = 8278$), 86.4% of the large adult cuff size ($n = 4164$), and 71.9% of the thigh cuff size ($n = 156$) (see Supplementary Tables).

Although the AHA recommendations are widely accepted in the USA, they are subject to continuing scientific debate. For example, the AHA recommendation suggests that an ideal bladder width covers 40.0% of an individual's AC for accurate BP assessment; others recommend a 46.0% ratio as an ideal bladder width [7,22]. Other sources of discrepancy can relate to the selection of cutoff points and the design of the BP cuffs themselves. Actually, Palatini and colleagues examined whether the shape of the upper arm and the cuff affected BP. Results showed that troncoconical cuff fit better on those with large mid-AC than rectangular cuffs [23].

Conclusion

Previous studies have shown that proper cuff selection is a critical part of BP measurement; nonetheless, mid-AC is a neglected measure [8–10]. The use of regression equations offers a practical way to measure mid-AC. Although the percent agreement does not reach 90% when using the Ostchega and colleagues regression equations, these equations could be useful in multiple settings, especially in which mid-AC is difficult to measure. An example in which the equations would be helpful is in epidemiological surveys, public BP screening settings, or clinical settings in which providers are alerted through electronic health records the predicted cuff size needed for a patient. To this effect, a recent study nested in the NHANES program with 130 participants (Health Measures At Home Study) compared BP measurements taken in a home setting. In the home, the regression equations were used to determine appropriate cuff size before taking BP measurements. Results from the study showed that there was 81.3% agreement for the adult size cuff, 91.9% agreement for the large adult, and 100% agreement for the extra-large cuff size between the cuff size assigned by the regression equation and the cuff size determined by direct measurement [24].

Another growing phenomenon is the proliferation of BP kiosks in pharmacies and supermarkets; it is estimated that 25 000 units are currently operational in the USA [25]. In a recent article, Alpert *et al.* [26] emphasized the use of out-of-office BP measurement in the clinical management of hypertension and other medical conditions; however, the authors underscored two major criteria: proper validation testing of the device and a suitable cuff for a particular AC. Indeed, according to Graves [27], cuff sizes of kiosk BP units are too small for the majority of hypertensive patients, hence providing wrong readings. These regression equations may be used in these settings for the majority of US adults who require an adult or large adult cuff for proper BP measurement. The equations have the greatest usefulness for producing valid mid-AC results in adults needing cuff sizes ranging from adult to thigh for men and adult to large adult for women. Although these equations are simple and use common inputs such as age, height, and weight to estimate a critical measure for BP accuracy, they are not substitutes for directly measuring mid-AC with a measuring tape. Although direct arm measurement is the 'gold standard', it is often not exercised, and these regression equations offer a unique opportunity to weave a critical step in the measurement of BP into clinical practice and routine screening tests. In addition, the equations could be used as a verification tool to confirm cuff size selection in physician offices. Another possible approach is to use the equations in terms of ruling out a particular cuff size. In this approach, the regression equations could be used to inform the clinician or observer about the cuff size that should not be used. Because hypertension is a frequent condition and often requires treatment over years, incorrect BP measurement and subsequent misdiagnosis of hypertension have major clinical and epidemiological effects [28]. Future research should examine the current practice for determining cuff size for BP measurements in different types of settings.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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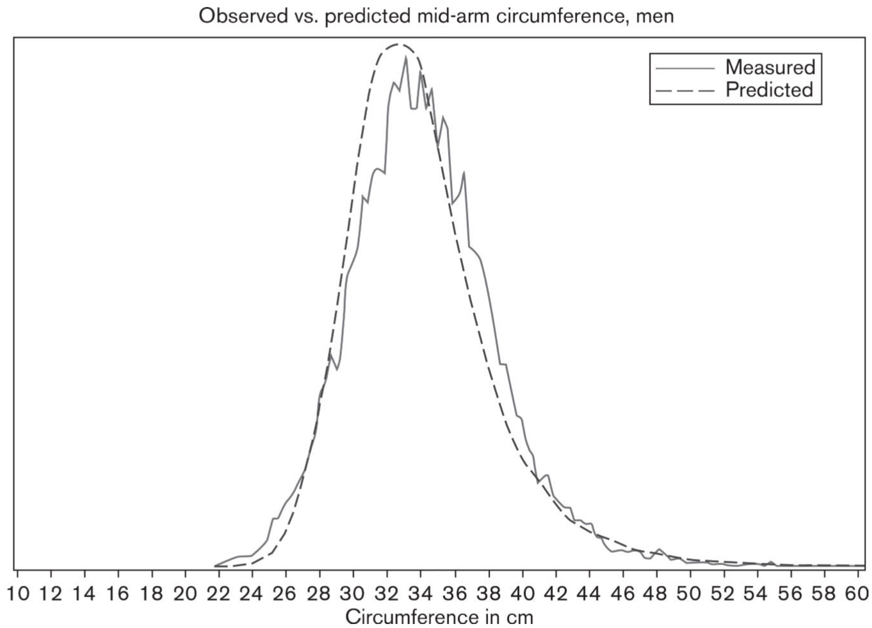

Fig. 1.

Model based on smoothed distribution for measured and predicted mid-arm circumference in men, NHANES 2001–2012. NHANES, National Health and Nutrition Examination Survey.

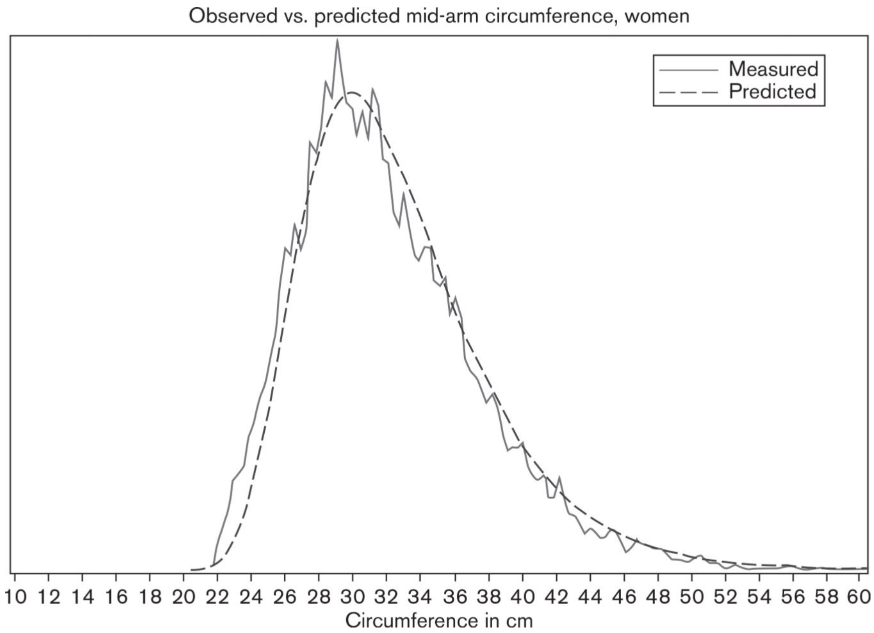

Fig. 2.

Model based on smoothed distribution for measured and predicted mid-arm circumference in women, NHANES 2001–2012. NHANES, National Health and Nutrition Examination Survey.

Table 1

Average age and measured height and weight of adults 20 years and older: NHANES 2001–2012

Sex	Sample size	Age in years Mean (SD)	Height in cm Mean (SE)	Weight in kg Mean (SE)
Men	14 430	49.5 (18.1)	176.1 (0.11)	88.2 (0.26)
Women	15 315	48.5 (18.2)	162.2 (0.10)	75.3 (0.25)

NHANES, National Health and Nutrition Examination Survey.

Table 2

Mid-arm circumference values computed from measured and predicted equations, mean with SE, and selected percentiles

Weighted mean and percentiles	Measured (cm)	Predicted (cm)	Predicted – measured (cm)
Men (*n*=14 430)			
Mean (SE)	34.15 (0.06)	34.33 (0.06)	0.18
1	25.20	26.52	1.32
10	28.93	29.21	0.28
25	31.20	31.01	−0.19
50	33.85	33.25	−0.6
75	36.63	35.94	−0.69
90	39.43	39.01	−0.42
95	41.69	41.30	−0.39
99	47.15	47.56	0.41
Women (*n*=15 315)			
Mean (SE)	32.00 (0.07)	32.41 (0.07)	0.41
1	22.91	23.66	0.75
10	25.84	26.05	0.21
25	28.14	27.95	−0.19
50	31.12	30.82	−0.3
75	35.06	34.77	−0.29
90	39.16	39.22	0.06
95	41.99	42.41	0.42
99	47.80	48.85	1.05

Note: r=0.91 for men and r=0.92 for women.

Table 3

Percent agreement for selecting a BP cuff according to AHA criteria using predicted mid-arm circumference values and measured mid-AC values by sex, NHANES 2001–2012

		Measured mid-AC				
	Sample size	**Small adult**	**Adult**	**Large adult**	**Thigh**	**Statistics**
Men	*n*=12 056					
Predicted mid-AC						
Small adult	632	**10.0**				
Adult	7117	90.0	**87.0**	14.0		
Large adult	4137		13.0	**82.0**	16.0	
Thigh	170			4.0	**84.0**	
						$\gamma = 0.96$
						Kendall's Tau-b=0.73
Women	*n*=12 056					
Predicted mid-AC						
Small adult	1944	**54.0**	1.0			
adult	7405	46.0	**88.0**	13.0		
Large adult	3133		11.0	**80.0**	26.0	
Thigh	320			7.0	**74.0**	
						$\gamma = 0.97$
						Kendall's Tau-b=0.76

Note: values in bold represent the percent of agreement for the same category. AHA, American Heart Association; BP, blood pressure; mid-AC, mid-arm circumference; NHANES, National Health and Nutrition Examination Survey.