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Reliability of resting blood pressure measurement and classification using an oscillometric device in children with chronic kidney disease

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Abstract

Objective—To compare the reliability of blood pressure (BP) readings obtained by an oscillometric device to those obtained by auscultation and assess for differences in BP status classification based upon the two techniques.

Study design—Resting BP was measured by auscultation and with an oscillometric device at the same encounter in 235 subjects enrolled in the Chronic Kidney Disease in Children study. Resting auscultatory BP's were averaged and compared with averaged oscillometric readings. BP agreement by the two methods was assessed using Bland-Altman plots, and BP status classification agreement was assessed by calculation of Kappa statistics.

Results—Oscillometric BP readings were higher than auscultatory readings, with a median paired difference of 9 mmHg for systolic BP (SBP) and 6 mmHg for diastolic BP (DBP). Correlation for mean SBP was 0.624 and for mean DBP was 0.491. The bias for oscillometric BP measurement was 8.7 mmHg for SBP (P<0.01) and 5.7 mmHg for DBP (P<0.01). BP status classification agreement was 61% for SBP and 63% for DBP, with Kappas of 0.31 for SBP and 0.20 for DBP.

*A list of members of the Chronic Kidney Disease in Children (CKiD) Study Group is available at www.jpeds.com (Appendix).

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Conclusions—Compared with auscultation, the oscillometric device significantly overestimated both systolic and diastolic BP, leading to frequent misclassification of BP status.

Reference values for childhood blood pressure (BP) have been issued on four occasions since the 1970s by the National High Blood Pressure Education Program. These values are based upon a database of BP readings obtained by auscultation in normal children from a nationally representative sample. Consensus recommendations for measuring BP and classifying hypertension status in children and adolescents state that auscultation is the preferred method of BP measurement in the young. It is further recommended that elevated BP values obtained by another method such as an oscillometric device should be re-measured by auscultation.¹

Despite this recommendation, many clinicians routinely use oscillometric devices for BP measurement in children and adolescents given their convenience and ease of use. Frequent use of oscillometric devices occurs even among pediatric nephrologists, 70% of whom stated that they routinely use oscillometric devices to measure BP². At the same time, it has been shown that oscillometric devices may not yield BP readings that are as accurate or reproducible as those obtained by auscultation.³ This problem may be amplified in children who may not cooperate well with oscillometric devices, thus resulting in greater and more frequent inaccuracies⁴.

We have recently shown that among children with chronic kidney disease (CKD), elevated BP is common, is frequently missed, and is often under-treated⁵. Although the reasons for this are unclear, it is important to understand whether the use of oscillometric devices rather than auscultation may introduce systematic errors in BP measurement which may lead to misclassification of hypertension status. To the best of our knowledge, no data comparing BP measurement and classification by these two methods is available in children with CKD.

We therefore compared paired resting BP values obtained by auscultation and oscillometry in children enrolled in the Chronic Kidney Disease in Children (CKiD) cohort study to better understand the comparability of BP values obtained by the two techniques, and the effect of these different techniques upon classification of BP status.

Methods

The CKiD study is an observational cohort study of 586 children with CKD being conducted at 46 pediatric nephrology centers in North America; the study design and objectives have previously been published⁶. The CKiD study protocol has been reviewed and approved by the Institutional Review Boards of each participating center (Appendix).

Eligibility criteria for enrollment in CKiD include: age 1–16 years, estimated GFR⁷ 30 – 90 ml/min/1.73m², and signed written informed consent by a parent or guardian, plus signed assent according to local requirements. Exclusion criteria include: solid organ, bone marrow or stem cell transplant, dialysis within 3 months of enrollment, cancer/leukemia or HIV treatment within the past year, pregnancy within the past year, inability to complete protocol procedures, enrollment in a randomized clinical trial in which treatment is masked, or plans to move away from the participating center in the near future.

The present study is a cross-sectional analysis of resting BP measurements obtained by a standard BP measurement protocol⁵ across all sites at follow-up visits at which subjects underwent resting BP measurement by auscultation and also with an oscillometric device. Analysis was restricted to children with both auscultatory and oscillometric blood pressure measurements obtained on the same day.

Resting Blood Pressure

Auscultatory measurement—The protocol for auscultatory BP measurement in the CKiD study has been described⁵. Briefly, after 5 minutes of rest and after measurement of the child's upper arm, an appropriately sized cuff¹ is selected. Following this, the peak inflation pressure is determined and then three BP measurements at 30-second intervals are obtained by auscultation of the brachial artery using an aneroid sphygmomanometer (Mabis MedicKit 5, Mabis Healthcare, Waukegan, IL). The first Korotkoff sound is recorded for systolic BP (SBP) and the fifth Korotkoff sound for diastolic BP (DBP). All participating clinical sites have been provided the same aneroid device by the CKiD Clinical Coordinating Centers (CCC's). The CCC's also provide standardized training and certification in the auscultatory BP measurement protocol to all study personnel responsible for casual BP measurement. Recertification in auscultatory BP measurement technique and calibration of each center's aneroid device occurs annually.

For this analysis, auscultatory BP values (SBP and DBP, respectively) were calculated as the mean of the three auscultatory BP measurements.

Oscillometric measurements—The CKiD study protocol includes ambulatory BP monitoring (ABPM) at the first follow-up study visit using a SpaceLabs 90217 oscillometric device (SpaceLabs Healthcare, Issaquah, WA). Monitors are programmed centrally at the ABPM Center (University of Texas at Houston), shipped to the clinical sites, and placed on the subject's non-dominant arm. The child's arm circumference is measured locally and an appropriately-sized cuff is selected according to Fourth Report recommendations¹. Monitor placement occurs at the end of the study visit, after the auscultatory readings have been obtained. All participating clinical sites receive annual training in monitor placement from the ABPM Center.

At the time of monitor placement, the CKiD protocol calls for three resting BP's to be obtained using the SpaceLabs device to ensure that the monitor is fitted and working properly. For the current analysis, oscillometric SBP and DBP measurements were calculated as the mean of these resting oscillometric BP measurements, excluding the first reading. The first reading was excluded to account for the fact that the cuff inflation process is automated, and may overinflate on the first reading, leading to inaccurate BP measurements. The first auscultatory BP reading was not excluded because determination of the peak inflation pressure as previously described⁵ avoids overinflation.

Definitions/Classification of BP status

For this report, participants' SBP and DBP statuses, respectively, were classified according to the National High Blood Pressure Education Program (NHBPEP) Fourth Report on the diagnosis, evaluation, and treatment of high BP in children and adolescents¹: individuals with resting BP <90th percentile were categorized as normotensive, ≥90th and <95th percentiles as pre-hypertensive, and ≥95th percentile as hypertensive. This classification scheme was applied to resting BP values obtained by auscultation and by the oscillometric device. BP status categorization was applied to BP measurements whether children were taking antihypertensive medications or were blood pressure medication naïve.

Other variables

To describe the clinical characteristics of the study population, the following variables are also reported: age, sex, race, ethnicity, glomerular filtration rate (GFR), CKD diagnosis, body mass index (BMI) percentile, and use of antihypertensive medication. All clinical measurements and biologic samples were collected concomitantly at the time of the study visit. GFR was determined by plasma iothexol disappearance as previously described⁸.

Demographic and medical history information was collected at the participating clinical sites using standardized forms. Anthropometric measurements were obtained via a standardized physical examination. Age- and sex-specific height, weight and BMI percentiles were calculated using standard growth charts for United States children⁹. Blood samples were analyzed at the CKiD central laboratory (University of Rochester, Rochester, NY).

Participant's CKD diagnosis was classified as either glomerular or non-glomerular as previously published⁵. Overweight was defined as a BMI > 85th percentile.

Statistical Analysis

Clinical, demographic and anthropometric characteristics of the study population were summarized using medians (interquartile ranges, IQR) for continuous variables and percent (frequency) for categorical variables.

Agreement of paired Oscillometric and Auscultatory BP Measurements—The statistical methods described below were performed for the analysis of both SBP and DBP. To quantify the agreement (reliability) between the paired BP measurements - auscultatory and oscillometric - scatterplots and Bland-Altman plots were developed as graphical summaries. Paired *t*-tests were used to test for differences between the two BP measurement methods. Using Analysis of Variance, an Intraclass Correlation Coefficient (ICC) was calculated to quantify the proportion of the total variability that comes from between individual differences. ICC values close to 1 indicate good agreement.

The Bland-Altman plots present the difference between the two paired measurements (ΔBP_{O-A}) plotted against the mean of the two measurements ($\overline{BP}_{AO}$). In addition to plotting these quantities, we also regressed the paired differences on the means of the pairs to obtain metrics that quantify agreement. The resulting parameter estimates from the regression provided a measure of the bias (intercept term) and a measure of the ratio of standard deviations (the slope term). If the variance of the first measurement (oscillometric BP) is similar to that of the second (auscultatory BP), the slope will be close to zero. With increasing differences in the variance of the two measurement methods, the slope will move away from zero. Additionally, the magnitude of the residual error resulting from the regression is related to the correlation between measurements. As such, smaller residuals and a smaller mean square error indicate stronger correlation.

Comparison of BP Status Classification—To examine how discrepancies in paired resting BP measurements might affect the agreement of BP status classification, classification by the two BP devices was summarized in 3×3 contingency tables, one for SBP and one for DBP. Classification agreement by the two devices was summarized statistically by calculating the percent agreement and a Kappa Statistic.

In the presence of a quantified bias associated with oscillometric BP measurement, it might be possible to improve the agreement of BP status classification between the two BP measurement methods by subtracting the bias from each of the oscillometric measurements and in turn classifying the "corrected" oscillometric BPs. To see if agreement of hypertension classification improved after correcting for the bias between the two devices, we compared classification by 'bias-corrected' oscillometric measurements to the auscultatory measurements, again using contingency tables, percent agreement and Kappa Statistics. This analysis was performed for classification of both SBP and DBP.

All analyses were performed using SAS 9.2 (SAS Institute, Cary, NC). Scatterplots and Bland-Altman Plots were generated using S-Plus 8.0 (Insightful Corp., Seattle, WA). Significance tests with a *p*-value less than 0.05 were considered statistically significant.

Results

Restricting analysis to children with both auscultatory resting BP measurements and 2 or more resting oscillometric BP measurements obtained by study personnel on the same day, data from 235 children were available for analysis (one set of paired BP measurements per child). The remaining 351 subjects either never underwent ABPM ($n=152$), had an insufficient number of oscillometric BP readings ($n=133$), did not have auscultatory BP values obtained ($n=8$) or had their ABPM study performed on a different day than the study visit at which the auscultatory BP values were obtained ($n=58$).

Clinical, anthropometric, and demographic characteristics for these 235 children are presented in Table I. They were predominantly male (57%), Caucasian (71%), and non-Hispanic ethnicity (84%); the median age was 12 years (interquartile range [IQR]: 9, 15 years). Median GFR was 43 ml/min/1.73 m²; a minority had a glomerular CKD diagnosis (20%). Current use of antihypertensive medication was common (72%). The 351 excluded children were similar in all characteristics at CKiD study enrollment except for a higher percentage of males (66%), a higher percentage of African-Americans (25%), a slightly lower rate of antihypertensive use (59%), and higher baseline systolic BP (data not shown).

Table II provides statistical summaries for the distribution of SBP and DBP as measured oscillometrically and by auscultation, as well as the distribution of the pairwise (within individual) differences between the two measurement methods. For SBP, the mean of the oscillometric measurements was 115 mm Hg (95% CI: 113, 117 mm Hg) compared to 106 mm Hg (95% CI: 105, 108) for auscultatory measurements; for DBP, the mean oscillometric measurement was 71 mm Hg (95% CI: 70, 73) compared to 66 mm Hg (95% CI: 64, 67) for auscultatory measurements. Significant pairwise differences between the two measurement methods were seen for both SBP and DBP. Oscillometric SBP measurements were on average 9 mm Hg higher (95% CI: 7, 10 mm Hg, $p<0.001$) than their paired auscultatory measurements; for DBP, oscillometric measurements were on average 6 mm Hg higher (95% CI: 4, 7 mm Hg, $p<0.001$) than their paired auscultatory measurements.

For SBP, the ICC for assessing reliability between the two measurement methods was 0.45 (95% CI: 0.34, 0.54); for DBP it was 0.40 (95% CI: 0.29, 0.50). ICC's of this magnitude suggest only fair reproducibility of the auscultatory BP measurement by the oscillometric device. The ICC is a measure of the percent of total variability across all BP measurements (SBP or DBP) attributable to between individual variability. As such, approximately 55% of the total variability in the SBP measurements was within individual variability; for DBP, 60% of the total variability stemmed from within individual differences in measurements.

Agreement between the oscillometric and auscultatory measurements for SBP and DBP are depicted graphically in Figures 1 and 2. Figures 1, A and 2, A are scatterplots of the SBP and DBP oscillometric measures against their respective auscultatory measures. Additionally, each scatterplot includes a fitted least-squares regression line of the data as well as a 45° line of unity (representing perfect agreement between the two measurements). For both SBP and DBP, the scatterplots show significant departure from the line of unity. There are two primary sources for this lack of agreement. The first is poor correlation between the two measurements. For SBP, the correlation between the auscultatory and oscillometric measurements was $r=0.62$, and for the DBP measurements it was $r=0.49$. The second is a systematic bias by which the oscillometric measurements – SBP and DBP – tend to overestimate their respective auscultatory measures.

This second point is more clearly shown in the Bland-Altman plots. In Figures 1, B and 2, B, a least squares regression line (dashed line) of the paired difference (oscillometric-auscultatory) against the paired mean ((oscillometric+auscultatory)/2) shows that

the oscillometric measurements overestimate the auscultatory measurements. For SBP, the oscillometric measurements were on average 8.6 mm Hg higher than their respective auscultatory values ($p < 0.01$). This bias is depicted graphically in Figure 1, B by the vertical distance between the dashed regression line and the x-axis at the mean value of the paired means (represented by the solid vertical line). As a function of the overall variability of the SBP measurements, this bias is equivalent to 76% of the standard deviation of the distribution of SBP paired means. The slope of this regression line is not significantly different from zero, suggesting that there is no difference in the dispersion (variability) of SBP measurements by the two methods. This is supported by the fact that the ratio of the oscillometric SBP standard deviation to that of the auscultatory SBP is approximately 1 ($p = 0.72$ under the null hypothesis that the ratio of standard deviations is 1).

The results for the DBP measurements were qualitatively similar to those for SBP. DBP measurements using the oscillometric device were on average 5.7 mm Hg higher than the auscultatory values ($p < 0.01$). As a function of the overall variability of the DBP measurements, this bias is equivalent to 60% of the standard deviation of the distribution of DBP paired means. As with SBP, the slope of the regression line was not significantly different from zero suggesting little difference in the variability of the oscillometric DBPs compared with the auscultatory DBPs. As such, the ratio of the oscillometric DBP standard deviation to that of the auscultatory DBP was approximately 0.9 ($p = 0.201$).

Of the 235 subjects included in this analysis, 8 were missing height percentiles and therefore could not have their BP status classified. Comparisons of SBP and DBP status classification for the remaining 227 subjects by auscultatory and oscillometric measurements are presented in Table III. By auscultatory measurement, 9% of subjects were classified as systolic hypertensive (sHTN), 13% as systolic pre-hypertensive (sPHTN), and 78% as normotensive. A greater percentage of subjects were classified as hypertensive (30%) by the oscillometric device, and fewer children were classified as normotensive (53%). Sixty-one percent of subjects received the same systolic classification by each method; taking account of chance agreement yielded a kappa statistic of 0.27 (95% CI: 0.18, 0.36).

Agreement of diastolic classification between the two methods was 63%, with a kappa statistic of 0.20 (95% CI: [0.10, 0.30]). As with systolic measurements, the oscillometric device yielded a larger percentage of diastolic hypertensive children and a smaller percentage of normotensive children compared with the auscultatory measurements. Eleven percent of subjects were diastolic hypertensive by auscultatory measurements compared with 27% by oscillometric methods; 81% were normotensive by auscultation and only 62% were normotensive by oscillometric methods.

To determine the extent to which the upward bias of the oscillometric measurements contributed to disagreement between the two methods, we classified bias-corrected oscillometric BP measurements and compared them with the auscultatory measurement classifications. To do this, we used the bias estimates shown in Table III and the Bland-Altman figures: 9 mm Hg for systolic and 6 mm Hg for diastolic. A comparison of the bias-corrected SBP and DBP oscillometric classifications to the auscultatory measurements are shown in smaller, italicized font in Table III. For systolic BP, after correcting for the bias, 12% (reduced from 30%) of children were classified as hypertensive and 77% (increased from 53%) as normotensive. The overall agreement was 74% with a kappa statistic of 0.31 (95% CI: [0.19, 0.43]).

Among the bias-corrected oscillometric diastolic BP measurements, 10% (decreased from 27%) were classified as hypertensive and 80% (increased from 62%) as normotensive.

Overall agreement between the bias-correct oscillometric measurements and the auscultatory measurements was 75% with a kappa statistic of 0.27 (95% CI: 0.14, 0.40).

Discussion

Control of hypertension has been shown to play an important role in the prevention of CKD progression. To assure that BP is being adequately controlled and patients properly classified as normotensive or hypertensive, accurate BP measurement is crucial. In this population of children with CKD, there was significant bias in resting BP values obtained using an oscillometric device compared with those obtained by auscultation, with the oscillometric device overestimating both systolic and diastolic BP. This overestimation led to significantly more children being classified as hypertensive if such classification were based upon the oscillometric BP values instead of upon BP values obtained by auscultation. Given these findings, auscultation should be used to measure and classify BP in children with CKD.

We have previously demonstrated that hypertension is common in children with CKD, even among those cared for at referral centers.⁵ Given the important contribution of BP elevation to the progression of pediatric CKD^{10–12}, careful, accurate blood pressure measurement constitutes a crucial component of office visits for follow-up of CKD. Although ambulatory BP monitoring has been shown to provide much more complete information about blood pressure, particularly in special populations such as CKD¹³, in practice, most physicians rely upon office measurement of casual BP, as recommended in recent clinical practice guidelines¹⁴. Furthermore, although we have shown that a standardized protocol utilizing an aneroid device can result in reproducible auscultatory BP measurements⁵, it has been demonstrated that pediatric nephrologists commonly utilize a wide variety of devices, frequently both oscillometric and auscultatory in the same setting². Thus, it is likely that the management of hypertensive children with CKD may often be based upon BP measurements obtained using oscillometric devices.

Our study suggests that reliance upon oscillometric devices alone to measure BP in children with CKD may not be advisable. There was significant overestimation of both systolic and diastolic BP using the oscillometric device compared with the auscultatory technique, with a bias of approximately 9 mmHg for systolic BP and 6 mmHg for diastolic BP. Thus, it is not surprising that many more children were classified as hypertensive using the oscillometric BP values than using the auscultatory values. Further, ‘correction’ of the oscillometric values by subtracting the bias did not result in significant improvement in agreement of classification by the two methods.

There is a potential biologic explanation for the BP difference between the two methods. Vascular stiffness has been shown to affect the validity of BP readings in adults, leading to systematic overestimation of BP by the oscillometric technique.¹⁶ Chronic kidney disease is known to increase vascular stiffness,^{17,18} probably due to disordered calcium-phosphorus metabolism, among other factors.^{18,19} Given this, it is possible that the bias in the oscillometric readings in this study reflect alterations of vascular function present already in this young population with CKD.

Our study has some potential limitations. Different personnel were involved in obtaining the auscultatory readings at the different centers. In spite of the personnel in each center undergoing the same annual recertification⁵, it is possible that this unavoidable aspect of this multi-center study might have introduced some variability in the accuracy of the auscultatory readings among centers. Although true, it would, if anything, increase noise and reduce our ability to detect a difference.

In validation studies of BP measurement devices, readings are taken with the test device and the reference device simultaneously, or in randomized order. By contrast, we analyzed BP readings obtained by two different devices at different times on the same day, which was an unavoidable aspect of our study design. There is a possibility that this design introduced bias that could have contributed to the observed differences in the auscultatory and oscillometric measurements. However, our protocol called for the oscillometric measurements to be done at the end of the study visit, well after the auscultatory BPs. Repeated BP measurements are typically lower than initial measurements. Thus, any bias created by our study design should have led to lower oscillometric BP values, not higher. Given that we found the opposite, we do not believe that our study design introduced significant bias.

Digit preference is a known drawback of auscultatory BP measurement.²⁰ To assess whether digit preference may have affected the auscultatory BP readings in this study, we examined the frequency of auscultatory BP values according to the terminal digit (data not shown). As expected given the sphygmomanometer used in the study, odd-numbered BP values constituted <2% of readings. Proportions of even-numbered terminal digits (i.e., 0, 2, 4, 6, and 8) ranged from 16–27% and were similar for systolic and diastolic BP. Given the lack of significant deviation from the expected random distribution of 20% for each even-numbered terminal digit, it is unlikely that digit preference contributed significantly to the observed difference between the auscultatory and oscillometric BP values.

Another potential limitation of our findings is the specific oscillometric device used. Although the SpaceLabs 90217 device is recommended as acceptable for measuring ambulatory BP in adults,²¹ specific validation of this model in children is lacking²² and a similar model by the same manufacturer was found to perform acceptably in measurement of systolic, but not diastolic BP.²³ However, given the known inaccuracies of oscillometric devices overall,^{4,16} it is likely that the biases in BP values obtained using this device compared with auscultation are generally representative of biases in BP values using other oscillometric devices as well. Furthermore, it was not the aim of the study to validate data obtained by this specific device, but to examine if, in general, oscillometric BP readings can be relied upon in this patient population. Our results indicate that careful BP measurement by auscultation should be preferred for assessment and classification of BP in children with CKD.

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Figure 1. Scatterplot (a) of the SBP oscillometric measures against their respective auscultatory measures; and Bland-Altman plot (b) of the least squares regression line (dashed line) of the paired difference in SBP (oscillometric-auscultatory) against the paired mean ((oscillometric + auscultatory)/2) in SBP.

Figure 2. Scatterplot (a) of the DBP oscillometric measures against their respective auscultatory measures; and Bland-Altman plot (b) of the least squares regression line (dashed line) of the paired difference in DBP (oscillometric-auscultatory) against the paired mean $((\text{oscillometric} + \text{auscultatory})/2)$ in DBP.

Table I

Characteristics of the study participants, N=235

Characteristic	Median [IQR] or %(n)
Age, years	12 [9, 15]
Male, %	57% (133)
Race	
Caucasian	71% (166)
African-American	13% (31)
Other/multi-racial	16% (38)
Hispanic Ethnicity	16% (37)
GFR, ml/min/1.73m ²	43 [31, 58]
Glomerular CKD, %	20% (46)
Height, cm	147 [127, 160]
BMI percentile, %	59 [33, 87]
BMI > 85th percentile	27% (61)
Current antihypertensive use, %	72% (169)

BMI, body mass index; CKD, chronic kidney disease; IQR, Interquartile range; GFR, glomerular filtration rate

Table 2

Summary Statistics of Paired Oscillometric and Auscultatory Blood Pressure measurements, N=235

	Oscillometric, mm Hg mean (95% CI)	Auscultatory, mm Hg mean (95% CI)	Paired difference, mmHg mean (95% CI)	p-value for paired difference
Systolic BP	115 (113, 117)	106 (105, 108)	9 (7, 10)	<0.001
Diastolic BP	71 (70, 73)	66 (64, 67)	6 (4, 7)	<0.001

Table 3

Blood Pressure Classification: Oscillometric v. Auscultatory, N=227*

		Auscultatory SBP			
		Normotensive	Pre-HTN	HTN	Total
Oscillometric SBP	Normotensive	111 (49%) 153 (68%)	5 (2%) 13 (6%)	4 (2%) 7 (3%)	120 (53%) 173 (77%)
	Pre-HTN	28 (12%) 13 (6%)	11 (5%) 8 (4%)	0 (0%) 6 (3%)	39 (17%) 27 (12%)
	HTN	39 (17%) 12 (5%)	13 (6%) 7 (3%)	16 (7%) 7 (3%)	68 (30%) 26 (12%)
	Total	178 (78%) 178 (79%)	29 (13%) 28 (12%)	20 (9%) 20 (9%)	227 226
		Auscultatory DBP			
		Normotensive	Pre-HTN	HTN	Total
Oscillometric DBP	Normotensive	126 (56%) 158 (70%)	6 (3%) 11 (5%)	8 (4%) 12 (5%)	140 (62%) 181 (80%)
	Pre-HTN	21 (9%) 14 (6%)	3 (1%) 5 (2%)	2 (1%) 4 (2%)	26 (11%) 23 (10%)
	HTN	36 (16%) 11 (5%)	11 (5%) 4 (2%)	14 (6%) 8 (4%)	61 (27%) 23 (10%)
	Total	183 (81%) 183 (81%)	20 (9%) 20 (9%)	24 (11%) 24 (11%)	227 227

* Non-italicized values are the bi-variate distribution of either systolic or diastolic BP classification by auscultatory and uncorrected oscillometric BP values. The italicized values are the bi-variate distribution of either systolic or diastolic BP classification by auscultatory and bias-corrected oscillometric BP values.