Use of Automated Office Blood Pressure Measurement in the Evaluation of Elevated Blood Pressures in Children and Adolescents

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Objectives To determine the level of agreement between automated office blood pressures (AOBP), auscultated or manual office BP (manual office blood pressure), and 24-hour ABPM, and to explore the ability of AOBP and manual office blood pressure to correctly identify daytime ambulatory hypertension in children.

Study design We retrospectively compared BPs obtained by AOBP and manual office blood pressure to predict daytime hypertension on ABPM. Six BPs were taken by AOBP followed by manual office blood pressure. Office hypertension was defined by BPs ≥95th percentile for sex and height percentiles for those <13 years of age and a BP of ≥130/80 mm Hg for ages ≥13 years. Daytime ambulatory hypertension was diagnosed if mean wake BPs were ≥95th percentile and BP loads were ≥25%. Application of adult ABPM thresholds for daytime hypertension (130/80 mm Hg) was assessed in ages ≥13 years. Sensitivity and specificity were calculated considering ABPM as the reference.

Results Complete data were available for 187 patient encounters. Overall, the best agreement was found if both AOBP and manual office blood pressure showed hypertension, but owing to low sensitivity up to 49% of children with hypertension would be misclassified. The use of adult thresholds for ABPM did not improve agreement.

Conclusions Neither AOBP nor manual office blood pressure confirm or exclude daytime ambulatory hypertension with confidence. These results suggest an ongoing role for ABPM in evaluation of hypertension in children. *(J Pediatr 2020;227:204-11)*.

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Recent pediatric guidelines recommend that 24-hour ambulatory blood pressure monitoring (ABPM) should be performed to confirm the diagnosis of hypertension in children and adolescents identified as hypertensive based on clinic blood pressure (BP) measurements.[1] ABPM can identify patients with white coat hypertension who do not need extensive laboratory and imaging investigations, as well as those with high-risk BP patterns, such as masked hypertension.[2] However, wearing a BP monitor for a prolonged period is not always convenient or well-tolerated, and these monitors may not be readily available.[3-5]

Studies in adults suggest that a series of BP measurements by an automated oscillometric device without staff in attendance approximates mean daytime ambulatory BP.[6-8] It has been shown that the white coat effect is decreased by this approach allowing for enhanced office assessment of BPs.[8-10] This technique, called automated office BP (AOBP), is recommended by Hypertension Canada and supported by the American Heart Association and the European Society of Hypertension for obtaining office BP.[11-13] Recognizing that access to ABPM is variable, an alternative approach that can be conducted in the office and potentially decrease the need for out-of-office assessment would be advantageous.[14-16] However, whether AOBP can actually substitute for ABPM remains unclear.[17-19] A recent meta-analyses of adult studies showed variability in the reliability of automated office devices in predicting ABPM results.[17]

Few data have been published on the use of AOBP in children and no comparisons with ABPM have been reported.[20] The goal of this study was to determine the level of agreement between AOBP, auscultated or manual office BP and 24-hour ABPM, and explore the ability of AOBP and manual office blood pressure

AAP	American Academy of Pediatrics
ABPM	Ambulatory blood pressure monitoring
AHA	American Heart Association
AOBP	Automated office blood pressures
BMI	Body mass index
BP	Blood pressure
CPG	Clinical practice guidelines

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to correctly identify daytime ambulatory hypertension in children and adolescents referred for evaluation of elevated BP.

Methods

Records were reviewed for all patients <18 years of age seen in the hypertension clinic located on the main campus of Seattle Children's Hospital who were evaluated with all 3 BP modalities—AOBP, manual office blood pressure, and ABPM—between December 2016 and November 2018. Those with incomplete data or inadequate AOBP or ABPM data were excluded. Treatment with antihypertensive medications was not an exclusion criteria. Nine patients had 2 sets of complete data. Only 1 set of data was used for 1 patient owing to poor tolerance of the initial ABPM procedure. None of the repeat ABPMs were performed owing to inadequacy of the initial study. The Seattle Children's Institutional Review Board approved retrospective data collection for this study.

BP Measurement Protocol

In December 2016, unattended AOBP readings using the BpTRU device (BpTRU Medical Devices Ltd, Coguitlam, British Columbia, Canada) were incorporated into our protocol for BP assessment in the hypertension clinic for children ≥5 years of age. This device has been validated in children.[20] Per protocol, readings were obtained by the BpTRU, followed by measurement of auscultatory BPs. Patients were brought to the examination room and positioned sitting with back supported and feet on the floor and right arm supported at the level of the right atrium. Cuff size was selected based on measurement of the mid-arm circumference as detailed in the American Academy of Pediatrics (AAP) Clinical Practice guidelines (CPG).[1] The staff member then left the room after confirming the first reading was successful. As programmed by the factory, the BpTRU takes a series of 6 BPs; the first reading is discarded, and the remaining readings were averaged. Patients and their families were instructed to minimize talking, avoid use of electronic devices, and remain seated. Owing to the pediatric setting, those accompanying the patient (such as parents and siblings) were allowed to remain in the room. For patient comfort, the interval between inflations was set at 2 minutes. Those with <3 successful readings (after discard of first reading) were excluded. Between December 2016 and April 2018, the study protocol specified a 5-minute rest period before the AOBP device was initiated. In May 2018, the protocol was modified to eliminate the rest period; this revised protocol was used between May 2018 and November 2018.

At the completion of the AOBP series, 1-2 manual office blood pressure readings were taken by the nephrology clinic nurse or medical assistant using an aneroid sphygmomanometer (WelchAllyn, Skaneateles Falls, New York). Staff followed the technique for auscultatory measurements outlined in the AAP CPG.[1] manual office blood pressure were always taken after AOBP and staff were aware of AOBP results.

ABPM is performed routinely in our hypertension clinic for patients referred for evaluation of elevated BPs. Placement of ABPM occurred on the same day as the office visit or within 8 weeks of the visit. ABPM were occasionally placed on a different day than AOBP measurements per physician or patient request or availability of device at site of initial visit. ABPM was obtained using either the Space Labs 90217 or 90227 with cuff selection based on the mid upper arm circumference. Readings are obtained every 20 minutes while awake and every 30 minutes while asleep. Sleep/wake times were determined by patient diary or activity record. hypertension definitions are reviewed in detail below. Adequacy was determined by the reading provider according to the criteria in the 2014 American Heart Association (AHA) pediatric statement on interpretation of pediatric ABPM.[2] For the purposes of this study only wake readings were considered for the diagnosis of daytime hypertension. Thus, for this study the decision for inclusion was based on adequacy for the wake portion of the recording. Patients with inadequate wake recordings were excluded.

Definitions of Hypertension

AOBP and manual office blood pressure hypertension was defined according to the AAP CPG.[1] As outlined in the CPG, for adolescents ≥13 years, hypertension was defined by average BP levels ≥130/80 and 95th percentiles for height and age were used for those <13 years of age.

ABPM daytime hypertension was defined by a mean wake BP of ≥95 percentile and BP loads ≥25% based on the thresholds provided in the AHA Scientific Statement on ABPM.[2] Additionally, an alternative definition following the AHA threshold for adults of ≥130/80 mm Hg was assessed in patients ≥13 years of age as used for office readings.[21]

Statistical Analyses

Measures of performance (sensitivity, specificity, and overall agreement) were calculated based on considering manual office blood pressure as the reference when comparing manual office blood pressure to AOBP, and were calculated based on considering the mean daytime BP as the reference when comparing the ABPM with office blood pressure. Overall agreement was calculated as the percentage of total comparisons that were either true positives or true negatives. Sensitivity analyses were performed by age group (<13 years vs ≥13 years), body mass index (BMI) Z-score category (<2 vs ≥2), and for those undergoing office blood pressure and ABPM on the same day. BMI z-score was automatically calculated by Cerner EHR platform, Millennium. BMI Z-score of 2 was chosen to identify more severely obese children.

Between December 2016 and March 2018, differences between AOBP means calculated based on readings 2-4 and 2-5 were compared with 2-6 (complete set). Eight children were excluded from this analysis because they lacked a complete set of readings. Pearson correlation coefficients were

calculated when comparing different systolic and diastolic BP measurements. Bland-Altman plots were also generated to further demonstrate agreement between a complete set of readings and sets with fewer readings. All analyses were completed using R version 3.5.1 (The R Foundation, Vienna, Austria).

Results

Complete data were available for 187 patient encounters. Eight patients had a complete set of data in each version of the protocol (with or without a rest period). As shown in Table I (available at www.jpeds.com), the mean age was similar in the 2 groups. Almost three-quarters of the patients were ≥13 years of age and the population was primarily male. The majority of patients (69%) underwent AOBP and ABPM on the same day with another 16% completing the ABPM within 4 weeks of the office visit. Table I shows the median time and range in days between AOBP and ABPM. As noted in Table I, 12 unique patients were evaluated in 13 patient encounters while on ≥1 antihypertensive medications. All children were seen for evaluation or follow-up of elevated BPs except for 4 females with Turner syndrome referred to evaluate for masked hypertension. Comparison of patients undergoing the protocol with (120 encounters) and without (67 encounters) a rest period before AOBP showed no significant differences in demographic variables or performance measures across office blood pressure and ABPM; thus, the combined results are presented.

Comparison of BP Readings by Technique

AOBP readings significantly differed from manual office blood pressure readings as shown in Table II. The median BP difference was greater for systolic vs diastolic pressures. The median systolic BP was 4 mm Hg lower for AOBP compared with manual office blood pressure. Differences in median diastolic BP were modest. The correlation of systolic BP was superior to that of diastolic BP. Similar findings were noted when readings obtained with and without a rest period were compared (data not shown). Median AOBP, manual office blood pressure, and ABPM readings are shown in Table II. The daytime median ABPM systolic BPs were significantly higher than AOBP and manual office blood pressure. Diastolic differences were not statistically significant. The correlation between ABPM and AOBP systolic pressures was similar to the correlation between ABPM and manual office blood pressure.

Classification of Hypertension Based on Office Blood Pressure vs ABPM

For the initial analysis, the ABPM findings were categorized based on pediatric ABPM thresholds.[2] The performance measures of the overall group are displayed in Table III. The sensitivity was low for AOBP and manual office blood pressure at 51% and 67%, respectively. AOBP demonstrated better specificity, although the values were still low at 71% for AOBP and 55% for manual office blood pressure. The best overall agreement was seen if both AOBP and manual office blood pressure showed hypertension: the overall agreement was 65% for AOBP, 58% for manual office blood pressure, and 70% for both. As shown in Table III, 17 of 51 children with hypertension on ABPM had normal BPs by both techniques (false negatives). Similarly, 30 out of 56 children with hypertension by both AOBP and manual office blood pressure (false positives) had normal mean ambulatory BPs. These data are depicted in Figure 1, which demonstrates that 32% of children with hypertension on ≥1 office technique demonstrated hypertension on ABPM. Conversely, for those in whom both office techniques showed normal BP, 65 of 82 (79%) demonstrated normal ABPM; similarly, 106 of 131 (81%) with normal BP on 1 or both office techniques showed normal ABPM (Figure 2).

The effect of age on the agreement is addressed in Table IV and Table V (available at www.jpeds.com). As shown, better specificity was observed in those <13 years of age (Table IV), as compared with those ≥13 years (Table V) for both office techniques. The specificity when both AOBP and manual

Table II. Differences in systolic and diastolic BPs obtained with 3 techniques (n = 187)

Comparisons of interest	Difference, median [IQR]	r*	BP values, median [IQR]	
Comparison of AOBP and manual office blood pressure			**AOBP**	**Manual office blood pressure**
Δ Systolic AOBP - manual office blood pressure	−4 [−9 to 0]†	0.75	118 [111 to 127]	122 [114 to 133]
Δ Diastolic AOBP - manual office blood pressure	1 [−5 to 9]‡	0.52	73 [68 to 80]	72 [64 to 80]
Comparison of ABPM to AOBP and manual office blood pressure			**ABPM**	**AOBP or manual office blood pressure**
Δ Systolic ABPM - AOBP	9 [2 to 17]†	0.52	128 [120 to 135]	118 [111 to 127]
Δ Diastolic ABPM - AOBP	0 [−7 to 5]	0.51	74 [69 to 79]	73 [68 to 80]
Δ Systolic ABPM - manual office blood pressure	4 [−2 to 12]†	0.52	128 [120 to 135]	122 [114 to 133]
Δ Diastolic ABPM - manual office blood pressure	2 [−7 to 10]§	0.38	74 [69 to 79]	72 [64 to 80]

*Pearson correlation coefficient.
†$P < .001$.
‡$P < .01$.
§$P < .05$.

Table III. Comparison of Office hypertension and ABPM hypertension results for all participants*

Comparisons with ABPM	Patients with hypertension on ABPM (n = 51)		Patients with no hypertension on ABPM (n = 136)		Performance measures		
	Normal office BP (false negative)	Abnormal office BP (true positive)	Normal office BP (true negative)	Abnormal office BP (false positive)	Sensitivity	Specificity	Overall agreement (%)
AOBP	25 (49)	26 (51)	96 (71)	40 (29)	0.51	0.71	65.2
manual office blood pressure	17 (33)	34 (67)	75 (55)	61 (45)	0.67	0.55	58.3
AOBP or manual office blood pressure†	17 (33)	34 (67)	65 (48)	71 (52)	0.67	0.48	52.9
AOBP and manual office blood pressure‡	25 (49)	26 (51)	106 (78)	30 (22)	0.51	0.78	70.6

Values are number (%). Office hypertension defined by 2017 CPG.[1] Pediatric ABPM thresholds used.[2]
*Hypertension prevalence based on elevation of daytime ABPM mean BP. All participants, hypertension prevalence of 27.3%.
†For AOBP or manual office blood pressure: positive result is abnormal on either or both office BP, negative result is normal on both office BP.
‡For AOBP and manual office blood pressure: positive result is abnormal on both office BP, negative result is normal on either or both office BP.

office blood pressure showed hypertension was 86%, for those <13 years of age as compared with 74%, for the older group. Although sensitivity was low, overall agreement was better for younger vs older patients. The possible effect of severe obesity was also considered by comparing the performance values for those with a BMI z-score of <2 vs ≥2 (**Table VI** and **Table VII**, respectively; available at www.jpeds.com). AOBP showed better specificity though lower sensitivity in those with a BMI Z-score of <2 compared with those with BMI Z-score of ≥2. In contrast, better specificity and sensitivity were demonstrated for manual office blood pressure in patients in the higher vs lower BMI category. However, for both subgroups, the best agreement (70%-71%) was found if the office techniques were congruent in detecting hypertension. Overall agreement did not differ if only systolic BPs were used to determine classification as hypertensive (data not shown).

ABPM was performed on a different day than the date for the office BPs in 31% of patients owing to patient or physician request or availability of the AOBP device. The subgroup with same day ABPM were analyzed separately as shown in **Table VIII** (available at www.jpeds.com). Agreement between OBPs and ABPM was generally superior when this subgroup was compared with the overall group (**Table III**). The sensitivity, specificity, and overall agreement improved for AOBP alone and in combination with manual office blood pressure, whereas little change was observed for manual office blood pressure, which showed the lowest agreement.

Effect of Using Adult Thresholds for ABPM on Classification

Comparisons were also made using the AHA adult definition of daytime hypertension (130/80 mm Hg), for categorization of daytime hypertension in adolescents ≥13 years of age as shown in **Table IX** (available at www.jpeds.com).[21] This approach improved specificity, but decreased the sensitivity for AOBP and manual office blood pressure as compared with findings when pediatric ABPM thresholds were used,

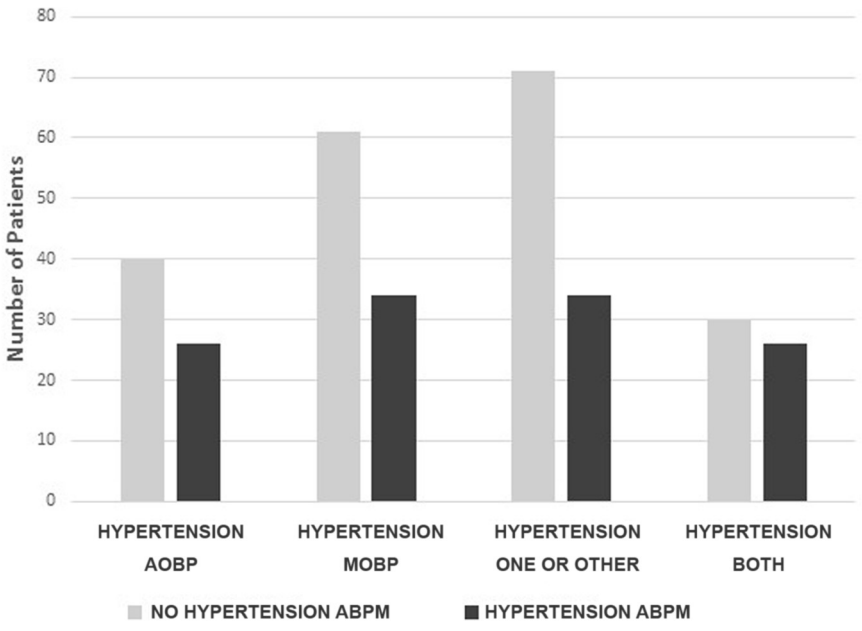

Figure 1. ABPM findings for patients with hypertension by AOBP, manual office blood pressure, and ≥1 or both techniques.

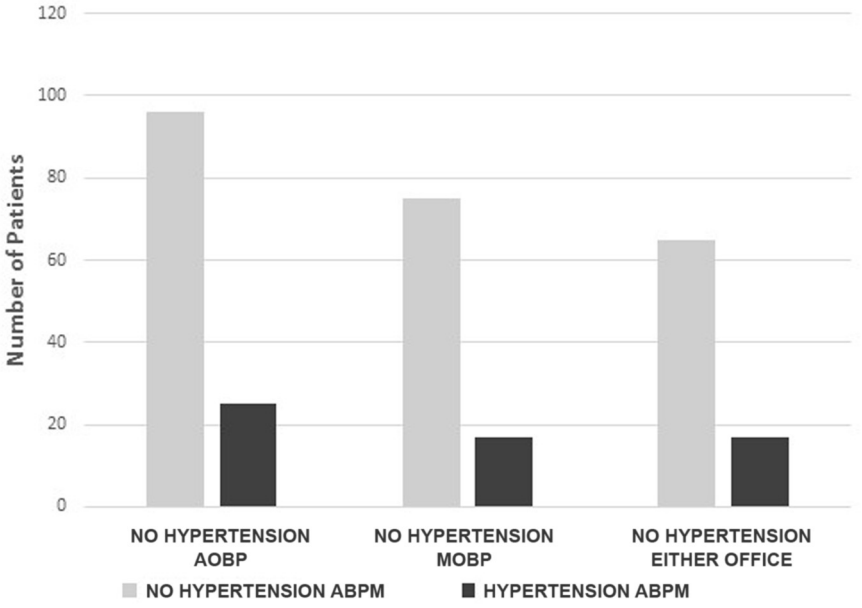

Figure 2. ABPM findings for patients with normal BPs by AOBP, manual office blood pressure, or both techniques.

as shown in Table V and Table IX.[2] When comparing AOBP with ABPM, overall agreement using the pediatric ABPM thresholds was 63% vs 58% with the alternative strategy. When comparing manual office blood pressure with ABPM, overall agreement using the pediatric ABPM guidelines was 58% but increased to 64% when the adult cut-points were used. If both office techniques were considered together, the overall agreement decreased from 67% to 60% when the adult cut-points were used.

Number of Required AOBP Readings

To determine the number of readings required for an accurate assessment, the average BP obtained with the full set of programmed readings on the automated device was compared with the average of fewer readings in a subset of patients. Individual readings were used to calculate the average obtained with readings 2-4 and 2-5. As shown in Figure 3 (available at www.jpeds.com), a review of individual readings demonstrated excellent correlation of the average of readings 2-6 (full set) with the average of readings 2-4 and 2-5 with correlation coefficients of 0.98 and 0.99, respectively, for systolic and diastolic BP. As shown in the Bland-Altman plots, the variance between the average of a full set of readings and 3 readings (2-4) was greater than observed with 4 readings for both systolic and diastolic pressures (Figure 4; available at www.jpeds.com).

Discussion

This study demonstrates that, although AOBP may aid in the diagnosis of daytime ambulatory hypertension, the low sensitivity of AOBP renders it less useful for diagnosis of white coat hypertension in children and adolescents. Generally, AOBP tended to be less sensitive and more specific than manual office blood pressure in the detection of daytime ambulatory hypertension. Our data show that AOBP performed best in combination with manual office blood pressure. Given a hypertension prevalence of 27%, if both office techniques show hypertension, ABPM can be anticipated to accurately confirm daytime hypertension approximately 46% of the time. If normal BPs are documented on both AOBP and manual office blood pressure, absence of daytime hypertension will likely be demonstrated in approximately 79% of patients.

Our data also demonstrate that the collection of repetitive BPs by an AOBP device is successful in most older children and adolescents. In a subset of patients, we found no difference between the average of BP readings 2-4 and 2-5 vs the complete set of 2-6. Although the device used here takes 6 readings, this particular device is no longer on the market; other commercially available machines average fewer readings. Our data suggest that BPs stabilized rapidly.

Studies in adults suggest that measurement of automated unattended office BPs approximates the average daytime ABPM, thus raising the question as to whether use of this technique may decrease the need to perform ABPM.[6-10,14-16] However, conflicting findings have been reported and these differences may hinge on details of the measurement protocol, including inclusion of a rest period, number of readings obtained, and the presence or absence of staff during BP measurement.[17,22-28] Studies have suggested that readings obtained by AOBP without staff in attendance were significantly lower than manual office blood pressure.[9,10,18,29] The possibility that AOBP might be able to replace ABPM at least in some circumstances is appealing owing to the challenges of providing ABPM on a wide scale in the pediatric population.

The recent AAP CPG strongly recommended confirming the diagnosis of hypertension in children and adolescents with ABPM.[1] Some experts have voiced concern that this testing may not be uniformly available.[3]

One concern with regard to implementation of AOBP in the office is the impact on clinic flow.[26] Previous studies with the specific device used here indicate that a rest period is not required and may result in underestimation of office blood pressure.[19,24,26,27] However, Andreadis et al using a different device suggested that a rest period may be helpful in those with higher office pressures.[28] Other investigators have also suggested that the relationship between AOBP and ABPM differs between lower and higher office pressures.[14,16,30] Although we did not assess for this effect, our results demonstrate that eliminating the rest period did alter the correlations between the techniques; however, overall agreement between the AOBP and manual office blood pressure for the classification of hypertension on ABPM did not differ significantly. Generally, AOBP performed better in the later version of our protocol that eliminated the rest period. Although these findings suggest a rest period may not be necessary, results may differ with other devices that obtain fewer readings.

Investigations have yielded mixed results as to the importance of having the AOBP measurements obtained while the patient is alone.[7,22-26,31-33] Owing to our underage population, we could not address this issue. Although staff were not present for the AOBP readings, those accompanying the patient (parents, siblings) remained in the room. As a result, our AOBP readings cannot truly be considered unattended. Manual office blood pressure readings were higher than AOBP even though the latter were obtained first in our protocol. This relationship has been reported by others and may reflect a white coat effect.[9,10,18,29] The superior specificity of AOBP compared with manual office blood pressure noted here suggests mitigation of the white coat effect by AOBP.

The significance of the superior results in younger children and children of healthy BMI noted here is of uncertain significance. Stergiou et al reviewed the need to validate oscillometric devices in children <12 years of age.[34] The device used here is no longer available and findings here may not apply if other AOBP devices such as the MicrolifeWatch BP (Microlife USA Inc, Clearwater, Florida) or Omron907XL (Omron Healthcare Inc, Kyoto, Japan) are used. Rinfret et al reported variation in measurements obtained when 2 devices were compared.[35] Correlation between devices may be impacted in part by variations in the number of readings and whether exclusion of the first reading is an option.

The inability of AOBP to predict daytime BP levels on ABPM in children and adolescents was anticipated because, in pediatrics, readings on ABPM commonly exceed office BP.[36-38] The reasons for this are somewhat unclear, but may be related to an overall higher activity level of children compared with adults. Studies have demonstrated that ABPM readings only begin to approximate office readings in early adulthood.[36] Consideration of an alternative threshold for ABPM based on age ≥13 years as adopted for office hypertension in the CPG did not consistently improve performance measures between office BPs and ABPM. Indeed, the data presented here show that generally the best agreement was found when AOBP was used with or without manual office blood pressure and daytime hypertension was defined based on pediatric ABPM thresholds.

This study has several limitations, including its retrospective design and limited number of children <13 years of age. Additionally, this study is limited to 1 academic center and may not predict findings in other types of practices or geographic locations. AOBP readings were always obtained first and staff were aware of the results as typical of a retrospective study. The approach taken here may have lessened the white coat effect for manual office blood pressure as there was a substantial lapse of time before taking manual office blood pressure readings. The period between initiations of readings for AOBP was set at 2 minutes and findings might differ if a shorter time (1 minute) were used. However, for those with elevated BPs, the time between readings can seem short if only 1 minute is used; thus, to maximize tolerability we elected to use the longer interval of 2 minutes. Most but not all patients wore the ABPM on the same day as the office visit. Although same-day assessment is ideal, it is not always practical in the clinical setting. Given that our study was conducted in minors, they were not alone during the AOBP procedure, although no staff were present. The impact of accompanying persons on readings obtained by AOBP is not known. Last, the applicability of a dataset based on auscultated BP measurements for oscillometric readings is not certain, particularly for diastolic BP.[1,39,40] Although these data were not presented, the overall agreement was similar if only systolic BP was considered. Despite these limitations, this study also has important strengths, including use of a standard BP measurement protocol for all types of BP measurements obtained, a relatively large sample size and application in a "real-world" clinical setting, which may improve generalizability, at least among pediatric referral centers.

In summary, the data reported here suggest that AOBP cannot be used with confidence to predict hypertension in children and adolescents owing to its poor sensitivity. Findings of hypertension on both AOBP and manual office blood pressure do not obviate the need for confirmation of hypertension with ABPM. In contrast, the absence of hypertension on both unattended AOBP and manual office blood pressure suggests that daytime BP will likely be normal on ABPM; however, approximately 20% of children with hypertension by ABPM will be misclassified. Although these data indicate that AOBP should not replace ABPM in pediatric patients, it may be useful when access to ABPM is limited, if used in combination with careful performance of auscultatory BPs. Although patients at greater risk for nocturnal hypertension would obviously be better assessed by ABPM, further study of the possible utility of AOBP in lower risk patients is warranted. ■

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Data Statement

Data sharing statement available at www.jpeds.com.

References

1. Flynn JT, Kaelber DC, Baker-Smith CM, Blowey D, Carroll AE, Daniels SR, et al. Clinical practice guidelines for screening and management of high blood pressure in children and adolescents. Pediatrics 2017;140:e20171904.
2. Flynn JT, Daniels SR, Hayman LL, Maahs DM, McCrindle BW, Mitsnefes M, et al. American Heart Association Atherosclerosis, Hypertension and Obesity in Youth Committee of the Council on Cardiovascular Disease in the Young. Update: ambulatory blood pressure monitoring in children and adolescents: a scientific statement from the American Heart Association. Hypertension 2014;63:1116-35.
3. Brady TM, Stefani-Glücksberg A, Simonetti GD. Management of high blood pressure in children: similarities and differences between US and European guidelines. Pediatr Nephrol 2019;34:405-12.
4. Miyashita Y, Flynn JT, Hanevold CD. Diagnosis and management of white-coat hypertension in children and adolescents: a Midwest Pediatric Nephrology Consortium study. J Clin Hypertens (Greenwich) 2017;19:884-9.
5. Hamdani G, Flynn JT, Daniels S, Falkner B, Hanevold C, Ingelfinger J, et al. Ambulatory blood pressure monitoring tolerability and blood pressure status in adolescents: the SHIP AHOY study. Blood Press Monit 2019;24:12-7.
6. Beckett L, Godwin M. The BpTRU automated blood pressure monitor compared to 24 hour amblulatory blood pressures monitoring in the assessment of blood pressure in patients with hypertension. BMC Cardiovasc Disord 2005;5:18.
7. Roerecke M, Kaczorowski J, Myers MG. Comparing automated office blood pressures with other methods of blood pressure measurement for identifying patients with possible hypertension. A systematic review and meta-analysis. JAMA Internal Med 2019;179:351-62.
8. Myers MG, Godwin M, Dawes M, Kiss A, Tobe SW, Kaczorowski J. Conventional versus automated measurement of blood pressure in the office (CAMBO) trial. Fam Pract 2012;29:376-82.
9. Myers MG, Valdivieso M, Kiss A. Use of automated office blood pressure measurement to reduce the white coat response. J Hypertens 2009;27:280-6.
10. Myers M, Valdivieso MA. Use of an automated blood pressure recording device, the BpTRU, to reduce the "white coat effect" in routine practice. Am J Hypertens 2003;16:494-7.
11. Leung AA, Daskalopoulou SS, Dasgupta K, McBrien K, Butalia S, Zarnke KB, et al. Hypertension Canada's 2017 guidelines for diagnosis, risk assessment, prevention, and treatment of hypertension in adults. Can J Cardiol 2018;33:557-76.
12. Muntner P, Shimbo D, Carey RM, Charleston JB, Gaillard T, Misra S, et al. Measurement of Blood Pressure in Humans: a Scientific Statement From the American Heart Association. Hypertension 2019;73:e35-66.
13. Stergiou GS, Parati G, Vlachopoulos C, Achimastos A, Andreadis E, Asmar R, et al. Methodology and technology for peripheral and central blood pressure and blood pressure variability measurement: current status and future directions – position statement of the European Society of Hypertension Working Group on blood pressure monitoring and cardiovascular variability. J Hypertens 2016;34:1665-7.
14. Godwin M, Birtwhistle R, Delva D, Lam M, Casson I, MacDonald S, et al. Manual and automated office measurements in relation to awake ambulatory blood pressure monitoring. Fam Pract 2011;28:110-7.
15. Godwin M. Measuring blood pressure and diagnosing hypertension in the physician's office in the age of automated devices: time for guidelines to reflect reality. Can J Cardiol 2017;33:963-4.
16. Myers MG. A proposed algorithm for diagnosing hypertension using automated office blood pressure measurement. J Hypertens 2010;28:703-8.
17. Jegathesawaran J, Ruzicka M, Hiremath S, Edwards C. Are automated blood pressure monitors comparable to ambulatory blood pressure monitors? A systematic review and meta-analysis. Can J Cardiol 2017;33:644-50.
18. Edwards C, Hiremath S, Gupta A, McCormick BB, Ruzicka M. BpTRUth: do automated blood pressure monitors out perform mercury? J Am Soc Hypertens 2013;7:448-53.
19. Ringrose JS, Cena J, Ip S, Morales F, Hamilton P, Padwal R. Comparability of automated office blood pressure to daytime 24-hour ambulatory blood pressure. Can J Cardiol 2018;34:61-5.
20. Mattu GS, Heran BS, Wright JM. Comparison of the automated non-invasive oscillometric blood pressure monitor (BpTRU) with the auscultatory mercury sphygmomanometer in a paediatric population. Blood Press Monit 2004;9:39-45.
21. Whelton PK, Carey RM, Aronow WS, Casey DE, Collins KJ, Himmelfarb CD, et al. 2017 ACC/AHA/AAPA/ABC/ACPM/ AGS/ APhA/ASH/ASPC/ NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. J Am Coll Cardiol 2018;71:e127-248.
22. Kollias A, Stambolliu E, Kyriakoulis KG, Gravvani A, Stergiou GS. Unattended versus attended automated office blood pressure: systematic review and meta-analysis of studies using the same methodology for both methods. J Clin Hypertens (Greenwich) 2019;21:148-55.
23. Armstrong D, Matangi M, Brouillard D, Myers MG. Automated office blood pressure – being alone and not location is what matters most. Blood Press Monit 2015;20:204-8.
24. Myers M. A short history of automated blood pressure - 15 years to sprint. J Clin Hypertens 2016;18:721-4.
25. Andreadis EA, Geladari CV, Angelopoulos ET, Savva FS, Georgantoni AI, Papademetriou V. Attended and unattended automated office blood pressure measurements have better agreement with ambulatory monitoring than conventional office readings. J Am Heart Assoc 2018;7:e008994.
26. Myers MG, Campbell NRC. Unfounded concerns about the use of automated office blood pressure measurement in SPRINT. J Am Soc Hypertens 2016;10:903-5.
27. Lamarre – Cliché M, Cheong NNG, Larochelle P. Comparison of assessment of four blood pressure measurement methods in hypertensives. Can J Cardiol 2011;27:455-60.
28. Andreadis EA, Geladari CV, Angelopoulos ET. Automated office blood pressure measurements obtained with and without preceding rest are associated with awake ambulatory blood pressure. J Clin Hypertens 2019;00:1-7.
29. Rinfret F, Cloutier L, L'Archevêque H, Gauthier M, Laskine M, Larochelle P, et al. The gap between manual and automated office blood pressure measurements results at a hypertension clinic. Can J Cardiol 2017;53:653-7.
30. Myers MG, Kaczorowski J. Office blood pressure is lower than awake ambulatory blood pressure at lower targets for treatment. J Clin Hypertens 2017;19:1210-3.
31. Myers MG, Matangi M, Kaczorowski J. Comparison of awake ambulatory blood pressure and automated office blood pressure using linear regression analysis in untreated patients in routine clinical practice. J Clin Hypertens 2018;20:1696-702.
32. Bauer F, Seibert FS, Rohn B, Bauer KAR, Rolshoven E, Babel N, et al. Attended versus unattended blood pressure measurement in a real life setting. Hypertension 2018;71:243-9.
33. Johnson KC, Whelton PK, Cushman WC, Cutler JA, Evans GW, for the SPRINT Research Group, et al. Blood pressure measurement in SPRINT

(Systolic Blood Pressure Intervention Trial). Hypertension 2018;71:848-57.
34. Stergiou GS, Boubouchairopoulou N, Kollias A. Accuracy of automated blood pressure measurement in children: evidence, issues, and perspectives. Hypertension 2017;69:1000-6.
35. Rinfret F, Cloutier L, Wistaff R, Birnbaum LM, Cheong NN, Laskine M, et al. Comparison of different automated office blood pressure measurement devices: evidence of nonequivalence and clinical implications. Can J Cardiol 2017;33:1639-44.
36. Stergiou GS, Ntineri A, Kollias A, Destounis A, Nasothimiou E, Roussias L. Changing relationship among clinic, home and ambulatory blood pressure with increasing age. Am Soc Hypertens 2015;9:544-52.
37. Stergiou GS, Karpettas N, Panagiotakos DB, Vazeou A. Comparison of office, ambulatory and home blood pressure in children and adolescents on the basis of normalcy tables. J Hum Hypertens 2011;25:218-23.
38. Gidding SS, Whelton PK, Carey RM, Flynn J, Kaelber DC, Baker-Smith C. Aligning adult and pediatric blood pressure guidelines. Hypertension 2019;73:938-43.
39. Negroni-Balasquide X, Bell CS, Samuel J, Samuels JA. Is one measurement enough to evaluate blood pressure among adolescents? A blood pressure screening experience in more than 9000 children with a subset comparison of auscultatory to mercury measurements. J Am Soc Hypertens 2016;10:95-100.
40. Šuláková T, Šuláková A, Strnadel J, Pavlíček J, Obermannová B, Feber J. Can auscultatory blood pressure normative values be used for evaluation of oscillometric blood pressure in children? J Clin Hypertens (Greenwich) 2017;19:381-7.

Table I. Comparison of patient demographic data with and without a rest period

Variables	Rest period (n = 120)	No rest period (n = 67)
Age (years)	15.2 [12.8 to 16.9]	15 [12.3 to 16.6]
<13	31 (26)	21 (31)
≥13	89 (74)	46 (69)
Height (cm)	167.5 [158.6 to 174.1]	168 [150.2 to 174.2]
BMI (kg/m^2)	28.1 [23.0 to 34.2]	27.4 [22.4 to 32.8]
BMI Z-score	1.8 [1.0 to 2.4]	1.8 [0.8 to 2.2]
Male sex	84 (70)	38 (57)
Days between OV and ABPM	0 [–27 to 0]; range, −56 to 41	0 [0 to 0]; range, −57 to 20
On antihypertensive medications	8 (7)	5 (7)

OV, office visit.
Results shown in median [IQR] or number (%) unless otherwise indicated.

Table IV. Comparison of Office hypertension and ABPM hypertension results, Age <13 only*

	Patients with hypertension on ABPM (n = 10)		Patients with no hypertension on ABPM (n = 42)		Performance measures		
Comparisons with ABPM	Normal office BP (false negative)	Abnormal office BP (true positive)	Normal office BP (true negative)	Abnormal office BP (false positive)	Sensitivity	Specificity	Overall agreement (%)
AOBP	5 (50)	5 (50)	32 (76)	10 (24)	0.50	0.76	71.1
Manual office blood pressure	4 (40)	6 (60)	25 (60)	17 (40)	0.60	0.60	59.6
AOBP or manual office blood pressure†	4 (40)	6 (60)	21 (50)	21 (50)	0.60	0.50	51.9
AOBP and manual office blood pressure‡	5 (50)	5 (50)	36 (86)	6 (14)	0.50	0.86	78.8

Values are number (%). Office hypertension defined by 2017 CPG.[1] Pediatric ABPM thresholds used.[2]
*Hypertension prevalence based on elevation of daytime ABPM mean BP. Age <13 years only, hypertension prevalence of 19.2%.
†For AOBP or manual office blood pressure: a positive result is abnormal on either or both office BP, a negative result is normal on both office BP.
‡For AOBP and manual office blood pressure: a positive result is abnormal on both office BP, a negative result is normal on either or both office BP.

Table V. Comparison of Office hypertension and ABPM hypertension results, Age ≥13 only*

Comparisons with ABPM	Patients with hypertension on ABPM (n = 41)		Patients with no hypertension on ABPM (n = 94)		Performance measures		
	Normal office BP (FN)	Abnormal office BP (TP)	Normal office BP (TN)	Abnormal office BP (FP)	Sensitivity	Specificity	Overall agreement (%)
AOBP	20 (49)	21 (51)	64 (68)	30 (32)	0.51	0.68	63.0
Manual office blood pressure	13 (32)	28 (68)	50 (53)	44 (47)	0.68	0.53	57.8
AOBP or manual office blood pressure†	13 (32)	28 (68)	44 (47)	50 (53)	0.68	0.47	53.3
AOBP and manual office blood pressure‡	20 (49)	21 (51)	70 (74)	24 (26)	0.51	0.74	67.4

Values are number (%). Office hypertension defined by 2017 CPG.[1] Pediatric ABPM thresholds used.[2]
*Hypertension prevalence based on elevation of daytime ABPM mean BP. Age ≥13 years only, hypertension prevalence of 30.4%.
†For AOBP or manual office blood pressure: positive result is abnormal on either or both office BP, negative result is normal on both office BP.
‡For AOBP and manual office blood pressure: positive result is abnormal on both office BP, negative result is normal on either or both office BP.

Table VI. Comparison of Office hypertension and ABPM hypertension results by BMI Z score category, BMI Z score <2 only*

Comparisons with ABPM	Patients with hypertension on ABPM (n = 32)		Patients with no hypertension on ABPM (n = 77)		Performance measures		
	Normal office BP (false negative)	Abnormal office BP (true positive)	Normal office BP (true negative)	Abnormal office BP (false positive)	Sensitivity	Specificity	Overall agreement (%)
AOBP	18 (56)	14 (44)	61 (79)	16 (21)	0.44	0.79	68.8
Manual office blood pressure	14 (44)	18 (56)	41 (53)	36 (47)	0.56	0.53	54.1
AOBP or manual office blood pressure†	14 (44)	18 (56)	39 (51)	38 (49)	0.56	0.51	52.3
AOBP and manual office blood pressure‡	18 (56)	14 (44)	63 (82)	14 (18)	0.44	0.82	70.6

Values are number (%). Office hypertension defined by 2017 CPG.[1] Pediatric ABPM thresholds used.[2]
*Hypertension prevalence based on elevation of daytime ABPM mean BP. BMI Z-score <2 only, hypertension prevalence of 29.4%.
†For AOBP or manual office blood pressure: positive result is abnormal on either or both office BP, negative result is normal on both office BP.
‡For AOBP and manual office blood pressure: positive result is abnormal on both office BP, negative result is normal on either or both office BP.

Table VII. Comparison of Office hypertension and ABPM hypertension results by BMI Z score category, BMI Z score ≥2 only*

Comparisons with ABPM	Patients with hypertension on ABPM (n = 19)		Patients with no hypertension on ABPM (n = 59)		Performance measures		
	Normal office BP (false negative)	Abnormal office BP (true positive)	Normal office BP (true negative)	Abnormal office BP (false positive)	Sensitivity	Specificity	Overall agreement (%)
AOBP	7 (37)	12 (63)	35 (59)	24 (41)	0.63	0.59	60.3
Manual office blood pressure	3 (16)	16 (84)	34 (58)	25 (42)	0.84	0.58	64.1
AOBP or manual office blood pressure†	3 (16)	16 (84)	26 (44)	33 (56)	0.84	0.44	53.9
AOBP and manual office blood pressure‡	7 (37)	12 (63)	43 (73)	16 (27)	0.63	0.73	70.5

Values are number (%). Office hypertension defined by 2017 CPG.[1] Pediatric ABPM thresholds used.[2]
*Hypertension prevalence based on elevation of daytime ABPM mean BP. BMI Z-score ≥2 only, hypertension prevalence of 24.4%.
†For AOBP or manual office blood pressure: positive result is abnormal on either or both office BP, negative result is normal on both office BP.
‡For AOBP and manual office blood pressure: positive result is abnormal on both office BP, negative result is normal on either or both office BP.

Table VIII. Comparison of office hypertension and ABPM hypertension results, for same-day ABPM and office measurements only (129/188 of participants)*

Comparisons with ABPM	Patients with hypertension on ABPM (n = 28)		Patients with no hypertension on ABPM (n = 101)		Performance measures		
	Normal office BP (false negative)	Abnormal office BP (true positive)	Normal office BP (true negative)	Abnormal office BP (false positive)	Sensitivity	Specificity	Overall agreement (%)
AOBP	11 (39)	17 (61)	75 (74)	26 (26)	0.61	0.74	71.3
Manual office blood pressure	8 (29)	20 (71)	55 (54)	46 (46)	0.71	0.54	58.1
AOBP or manual office blood pressure†	8 (29)	20 (71)	50 (50)	51 (50)	0.71	0.50	54.3
AOBP and manual office blood pressure‡	11 (39)	17 (61)	80 (79)	21 (21)	0.61	0.79	75.2

Values are number (%). Office hypertension defined by 2017 CPG.[1] Pediatric ABPM thresholds used.[2]
*Hypertension prevalence based on elevation of daytime ABPM mean BP. hypertension prevalence of 21.7%.
†For AOBP or manual office blood pressure: positive result is abnormal on either or both office BP, negative result is normal on both office BP.
‡For AOBP and manual office blood pressure: positive result is abnormal on both office BP, negative result is normal on either or both office BP.

Table IX. Comparison of office hypertension and ABPM hypertension results in ages ≥13 years*

Comparisons with ABPM	Patients with hypertension on ABPM (n = 77)		Patients with no hypertension on ABPM (n = 58)		Performance measures		
	Normal office BP (FN)	Abnormal office BP (TP)	Normal office BP (TN)	Abnormal office BP (FP)	Sensitivity	Specificity	Overall agreement (%)
AOBP	41 (53)	36 (47)	43 (74)	15 (26)	0.47	0.74	58.5
Manual office blood pressure	27 (35)	50 (65)	36 (62)	22 (38)	0.65	0.62	63.7
AOBP or manual office blood pressure†	25 (32)	52 (68)	32 (55)	26 (45)	0.68	0.55	62.2
AOBP and manual office blood pressure‡	43 (56)	34 (44)	47 (81)	11 (19)	0.44	0.81	60

Values are number (%). Office hypertension defined by 2017 CPG.[1] ABPM threshold of ≥130/80 mm Hg.[21]

*Hypertension prevalence based on elevation of daytime ABPM mean BP. Age ≥13 years only, hypertension prevalence of 57%.

†For AOBP or manual office blood pressure: positive result is abnormal on either or both office BP, negative result is normal on both office BP.

‡For AOBP and manual office blood pressure: positive result is abnormal on both office BP, negative result is normal on either or both office BP.

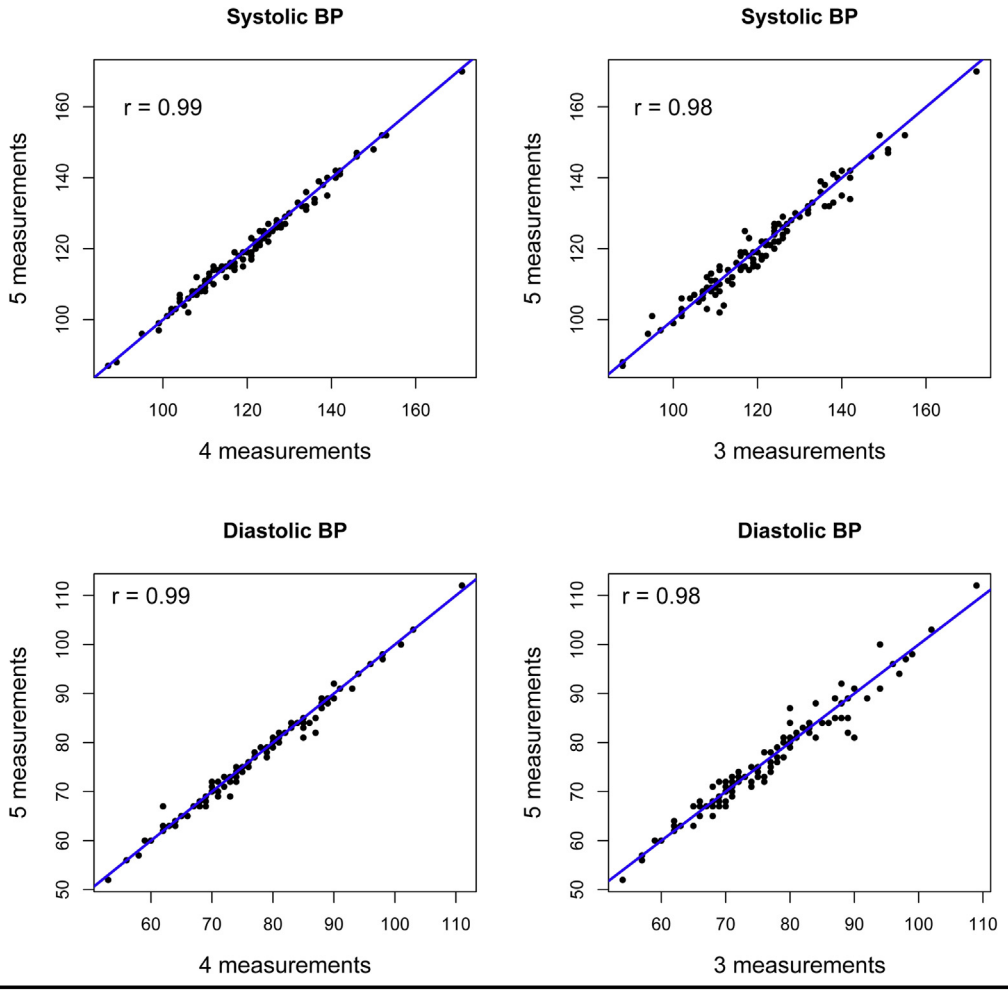

Figure 3. Scatterplots with Pearson correlation coefficient comparing AOBP average systolic and diastolic pressures for 3, 4, or 5 total measurements.

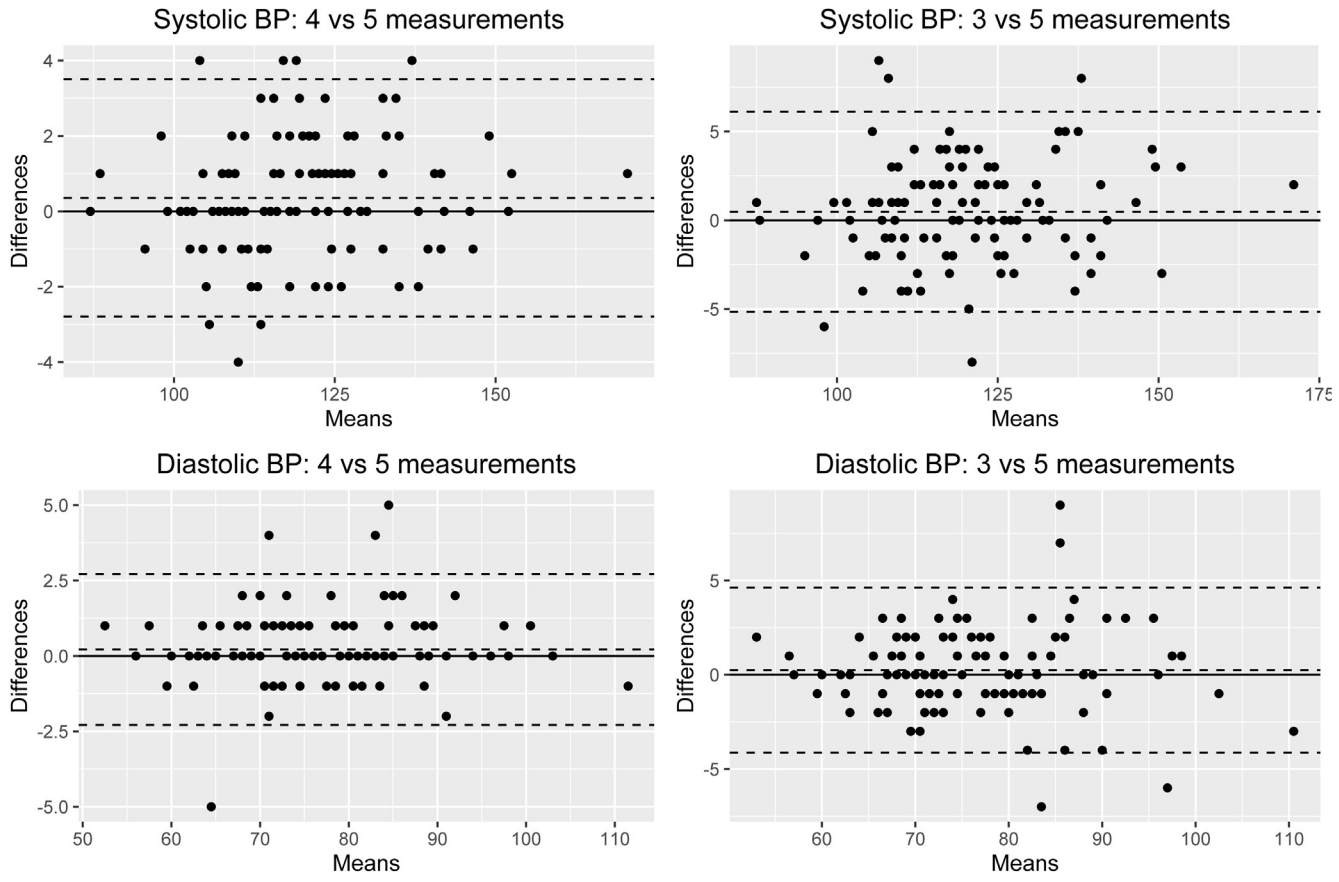

Figure 4. Bland-Altman plots demonstrating differences between means of 4 or 3 BP measurements as compared to full set of measurements. The dotted line represents 1 SD. The *y* axis is millimeters of mercury differences between means and the *x* axis is millimeters of mercury.