AHA Scientific Statement

Update: Ambulatory Blood Pressure Monitoring in Children and Adolescents

A Scientific Statement From the American Heart Association

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Ambulatory blood pressure monitoring (ABPM) has established roles in the evaluation and management of hypertension in adults but has only been applied to children and adolescents more recently.[1] In 2008, the American Heart Association (AHA) issued the first set of consensus recommendations for performance and interpretation of ABPM in pediatrics. Since then, ABPM has found increasing use in children and adolescents, as recently summarized.[2] The present document updates the 2008 AHA statement on the use of ABPM in the pediatric population[3] with additional data published since the release of that report and also presents a revised interpretation schema. Because no outcome studies are yet available relating ABPM levels in children to outcomes such as myocardial infarction or stroke, these guidelines are largely driven by expert opinion, although they are also informed by available pediatric data on ABPM and surrogate markers of cardiovascular disease.

Cardiovascular Risk in the Pediatric Population

Epidemiology of Hypertension

High blood pressure (BP) is the leading risk factor–related cause of death throughout the world, accounting for 12.8% of all deaths, including 51% of stroke deaths and 45% of coronary heart disease deaths.[4] In the United States, 33.0% of adults >20 years of age have hypertension.[5] As our population continues to age, this will only increase, because 90% of people with normal BP at age 55 years will go on to develop hypertension in their lifetimes.[6]

The prevalence of hypertension in youths is also on the rise. US National Health and Nutrition Examination Survey (NHANES) data from 1963 to 2002 showed a 2.3% increase in prehypertension and a 1% increase in hypertension from 1988 to 1999, with higher rates in non-Hispanic blacks and Mexican Americans.[7] In fact, the entire distribution of childhood BP has shifted upward in the United States by 1.4 mm Hg for systolic BP (SBP) and 3.3 mm Hg for diastolic BP (DBP).[8] However, adjustment of the NHANES data for body mass index (BMI) attenuated the increase in SBP by 29% and DBP by 12%, which suggests that some of the increase may be related to the obesity epidemic.[8] This is supported by studies of the effect of the westernization of primitive societies, in which BMI has the most substantial effect on the age-related increase in BP compared with all other risk factors.[9] A cross-sectional pediatric study conducted in Canada found that obese adolescents had 7.6 mm Hg higher SBP than normal-weight youths, with BMI exerting the strongest effect on BP.[10] The increased prevalence of prehypertension and sustained hypertension with increasing BMI was confirmed

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in a school-based study in Texas.[11] Furthermore, longitudinal evaluation of the National High Blood Pressure Education Program childhood BP database confirmed that a higher BMI increases the rate of progression from prehypertension to hypertension.[12]

However, an obesity-related increase in BP has not been documented in all studies. In the Bogalusa Heart Study, which used the mean of 6 resting BP measurements instead of 2 or 3 measurements, there was a significant increase in the prevalence of obesity from 1974 to 1993, yet there were only small changes in BP levels.[13] Therefore, despite methodological differences that make cross-population estimates of hypertension difficult to interpret,[14] most investigators believe obesity-related hypertension is on the rise.

The rise in prevalence of hypertension in the young is especially worrisome, because autopsy studies such as the Bogalusa Heart Study and the Pathobiological Determinates of Atherosclerosis in Youth study have demonstrated increased atherosclerosis at higher BP levels in youths.[15,16] Therefore, accurate assessment of BP and treatment of hypertension in children and adolescents are essential for the prevention of future heart disease.[17] Emerging data suggest that ABPM may be superior to clinic BP in predicting cardiovascular morbidity and mortality in adults.[18] For this reason, ABPM is being increasingly used in the evaluation for hypertension and risk of end-organ damage in youths.

BP and Risk for Target-Organ Damage

Substantial data exist that link elevated BP levels measured in childhood and future target-organ damage. Pooled data from longitudinal epidemiological studies of cardiovascular risk factors in youths from the International Childhood Cardiovascular Cohort (i3C) Consortium demonstrated that higher BP measured at as young as 12 years of age predicted increased adult carotid intima-media thickness (cIMT).[19] Similarly, childhood hypertension was related to higher adult pulse-wave velocity in the Cardiovascular Risk in Young Finns Study,[20] which indicates increased arterial stiffness, and the Bogalusa Heart Study found that the cumulative burden of SBP from childhood to adulthood was a significant predictor of adult left ventricular mass (LVM).[21]

BP levels have also been related to target-organ damage measured in childhood. SBP has been demonstrated to independently determine cIMT in both children[22] and adolescents.[23] Alterations of vascular function also occur at higher levels of childhood BP, including reduced brachial artery distensibility,[24,25] higher pulse-wave velocity,[26,27] and increased augmentation index,[28] all of which indicate increasing arterial stiffness. This is relevant to future cardiovascular disease, because increased vascular thickness[29] and stiffness[30] are associated with higher LVM in adolescents, a risk factor for future adult cardiovascular disease.[31] Therefore, it is not surprising that hypertensive youths may demonstrate left ventricular hypertrophy (LVH),[32,33] but what is even more worrisome is the observation that adolescents with prehypertension already have higher LVM values than normotensive control subjects.[28,34] Furthermore, hypertension may also have neurovascular consequences, because untreated hypertensive children had lower cerebral artery reactivity than normotensive control subjects,[35] which may explain the lower scores on cognitive tests found in children with elevated BP.[36]

ABPM may be superior to casual (office) BP measurement in its ability to distinguish patients at the highest risk for target-organ damage. In adults, ABPM correlates more strongly with LVM than casual BP.[37] In children in a hypertension clinic, no correlation was found between LVM and casual BP, yet a strong relationship existed with ABPM parameters.[38] In fact, when hypertension was confirmed by 24-hour ABPM, the odds for LVH were 7.23 compared with only 4.13 when hypertension was diagnosed with casual BP levels.[39] Another study found APBM parameters were superior to both casual and home BP in predicting LVM.[40] Most other pediatric studies, with 1 notable exception,[41] have confirmed the strong relationship between hypertension diagnosed with ABPM and elevated LVM.[34,42–44] The 1 study that found no association between ABPM and LVM was missing echocardiograms on 24% of subjects (possible selection bias) and used oscillometric devices to measure casual BP (possible measurement bias).[41]

Increased cIMT, a risk factor for stroke in adults,[45] is similarly correlated with high BP on ABPM,[46,47] with the relationship independent of casual BP.[48] In hypertensive children, thicker cIMT is found with higher ABPM levels,[49–51] even when the children are matched by BMI.[52] The only study that found no relationship between ABPM levels and cIMT was a small study of children who had received a renal transplant, in whom other serious disease processes or medication use may have confounded the relationship.[53] New data are now available relating BP measured with ABPM and arterial stiffness. The ambulatory arterial stiffness index (AASI), which correlates with pulse-wave velocity, is calculated as 1 minus the regression slope of DBP plotted against SBP from ABPM. Using this technique, Simonetti et al[54] found that hypertensive children had higher AASI values than normotensive control subjects. This has been replicated in youths with type 1 diabetes mellitus and hypertension.[55] Using direct measurements, when BP was evaluated with ABPM, youths categorized as either prehypertensive or truly hypertensive had increased pulse-wave velocity compared with normotensive subjects.[56] In obese youths, higher ABPM (but not casual BP) was found to be associated with higher carotid stiffness and reduced endothelial function.[57] Similarly, decreased carotid distensibility was associated with higher daytime ambulatory SBP load in pediatric renal transplant recipients.[58]

Usefulness of ABPM to Classify BP

White Coat Hypertension

White coat hypertension (WCH) is defined as casual/office BP levels that are ≥95th percentile but normal outside of a clinical setting. It has been suggested that high BP variability, perhaps caused by transient, stress-induced elevation of BP, may contribute to clinical misclassification of hypertension.[59] However, WCH may not be entirely benign. In adults with normal ABPM, BP variability increases with increasing BP and is associated with target-organ damage and cardiovascular events.[60] In fact, WCH may represent an intermediate pathophysiological stage between normotension and

hypertension.[61] Target-organ damage, such as increased LVM,[32,51,62,63] increased cIMT,[51,63] abnormalities in BP and heart rate rhythmicity,[64] and impaired cerebral vascular reactivity,[65] may develop in youths with WCH.

A wide range of WCH prevalence has been reported in the literature. A study of 18 male adolescent athletes reported 88% had WCH,[66] whereas a study of 1071 Icelandic children 9 to 10 years of age found sustained hypertension in 2.5% and WCH in just 0.6%.[67] Other pediatric studies have reported the prevalence of WCH to be in the range of 22% to 32%.[68] Of note, Sorof et al[69] have suggested that the use of ABPM to rule out WCH should be limited to patients with borderline or mild clinical hypertension, because patients with higher office BP levels are more likely to be truly hypertensive.

Masked Hypertension

ABPM may also detect masked hypertension (MH), defined as a normal clinic BP but elevated ambulatory levels. MH is difficult to detect but may be suspected with previous reports of elevated clinical BP from other providers, or if the clinical presentation (ie, LVH) appears inconsistent with the clinic BP. Estimates of the prevalence of MH range from 7.6% in 592 unselected children[70] to 9.4% in 85 youths referred for hypertension evaluation[71] to 15% in Brazilian youths.[72] In 1 study, rates of MH did not appear to differ by age (older or younger than 15 years),[73] but MH may be more common in obese youths (19%), especially if they display a nondipper pattern (32.3%; $P \leq 0.001$).[74] A meta-analysis reported a 7% prevalence of MH in children and 19% in adults, with an overall average of 16.8%.[75] This report also found that LVM in patients with MH was higher than in normotensive people and similar to that in people with sustained hypertension, which suggests that MH imparts a similar cardiovascular risk as sustained hypertension.[75] In pediatric patients, data also suggest that MH predicts target-organ damage.[70,71] Unfortunately, determining the true prevalence of MH would require the use of ABPM in large unselected populations.

Other situations in which ABPM may be especially helpful in "unmasking" hypertension include pediatric dialysis patients, whose BP may be normal after dialysis but hypertensive at other times.[76] Similarly, after aortic coarctation repair, MH was associated with abnormal left ventricular structure and function.[77] The prevalence of MH was reported at 9.5% in youths with type 1 diabetes mellitus.[68]

Prehypertension and Progression to Sustained (Ambulatory) Hypertension

Prehypertension is now recognized as a condition that requires careful evaluation and follow-up. Pediatric patients with casual prehypertension may demonstrate abnormalities on ABPM intermediate between normotensive and truly hypertensive people,[78] and some studies have demonstrated subtle signs of target-organ damage in patients with prehypertension, including LVM values similar to youths with sustained hypertension,[34] lower glomerular filtration rate, and increased urine protein excretion,[79] as well as higher cIMT than normotensive patients.[80] Patients with prehypertension may also be at higher risk of progressing to sustained hypertension.[12] Although no longitudinal ABPM studies have been performed to evaluate the risk of progression of prehypertension, such studies could clarify the importance of prehypertension by providing more careful phenotyping of the BP patterns that produce the highest risk of progression to sustained hypertension.

Determinants of Ambulatory BP

Several determinants that influence ambulatory BP must be adjusted for in the establishment of normalized values in pediatric patients. In the pediatric population, age is independently correlated with 24-hour SBP[81] and BP variability.[82,83] Birth weight has been shown to be associated with ambulatory BP. Most but not all studies[84] find an inverse association between birth weight and daytime SBP after controlling for covariates.[85–89] Ethnicity is known to influence ambulatory BP in children and youths, an effect that may be attributable to racial differences in the relationship of body size to BP[90,91] or racial differences in the effect of psychosocial stress on BP.[92] Ambulatory BP is also affected by sex, with male youths having higher ambulatory BP than their female counterparts, irrespective of ethnicity.[93,94] Obesity, possibly through the restriction of sodium excretion,[95] is associated with increased ambulatory BP.[95,96]

Other proposed determinants of ambulatory BP include autonomic tone,[97–99] adiponectin,[100,101] and serum uric acid.[102] Lower plasma renin activity was independently associated with lower 24-hour SBP in obese adolescents.[103] However, blood aldosterone-to-renin ratio was not found to be associated with ambulatory BP in healthy children, although it did correlate with LVM.[104] Finally, elevation of several ambulatory BP parameters has been associated with stimulant use in pediatric patients, including stimulants used for attention deficit/hyperactivity disorder[105,106] and caffeine.[107]

Normative Data for ABPM

Data on normal ambulatory BP ranges in pediatric patients are required for the effective application of this assessment tool to this population. Once normal reference values are established, clinically relevant ABPM abnormalities can be differentiated and quantified as important deviations from the population-based distributions. Reference data must be derived from studies of healthy populations with sufficiently large samples that are proportionally representative of the larger pediatric population. Ideally, samples should be free of confounders that may alter BP measurement, including concurrent medication use and comorbidities such as obesity. Normative data should allow calculation of standardized values, particularly z scores and percentiles. Particularly in pediatric patients, assessment should be adjusted for various determinants of BP, such as age, sex, body size, race, and ethnicity. Established normative ambulatory BP ranges should also be validated by determination of associations with clinically relevant outcomes in the reference population, for example, end-organ damage and cardiovascular mortality/morbidity.[108] Although these associations have been determined in adults on the basis of a growing body of evidence, outcomes are largely preclinical in the pediatric population, and necessary longitudinal data are lacking; hence, the definitions are based on population-based distributions.

ABPM values differ substantially from casual measurements; therefore, comparisons to normative casual BP values such as those in the Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents[101a] or the more recent integrated pediatric cardiovascular risk reduction guidelines[17] may result in misclassification of BP category.[109,110] Reference values provided by the German Working Group on Pediatric Hypertension are currently considered the best available data for pediatric ABPM.[81,111] Of several ABPM studies in healthy control subjects, this study alone has established percentiles normalized for the nongaussian distribution of 24-hour BP in children according to age and sex, using the LMS analysis method.[81] However, as highlighted by Flynn,[112] this data set has several limitations. First, it includes only central European white children, which limits its generalizability given that normal ABPM ranges appear to vary with ethnicity.[113] Furthermore, relatively few shorter children (<140 cm in height) were included, which may limit the applicability of the results to children with certain health conditions, specifically chronic kidney disease (CKD).[112] Finally, the data set demonstrated a striking lack of variability in ambulatory DBP values (Figure); resting DBP is known to vary by age and height, whereas at least 1 study has shown that ambulatory DBP varies with age.[112,114] Thus, the normative values provided by the German Working Group on Pediatric Hypertension may not be representative of the normal ambulatory DBP in all pediatric patients.

Beyond these data, other groups have measured ABPM in healthy populations, although none have provided useful normative values. O'Sullivan et al[115] studied ambulatory BP in 1121 healthy school-aged children, reporting mean SBP and DBP during time at school, at home, and asleep. Ambulatory SBP was found to have a wide range in normal children, and no important differences were noted between school and home hours. Another study by Lurbe et al[116] assessed ABPM values in 241 healthy children aged 6 to 16 years and reported BP as systolic and diastolic means and percentiles, circadian variability, and pressure load. Some ABPM data have also been collected from very young healthy children; Varda et al[117] studied the applicability of ABPM in 97 healthy infants and toddlers, reporting mean daytime, nighttime, and 24-hour SBP and DBP. Similarly, Gellermann et al[118] reported mean daytime and nighttime SBP and DBP for healthy children aged 3 to 6 years. Still, despite this research, there is a critical need for expanded normative data for pediatric ABPM; specifically, normal values for ambulatory DBP are needed, because they may not be appropriately represented by the currently available data.

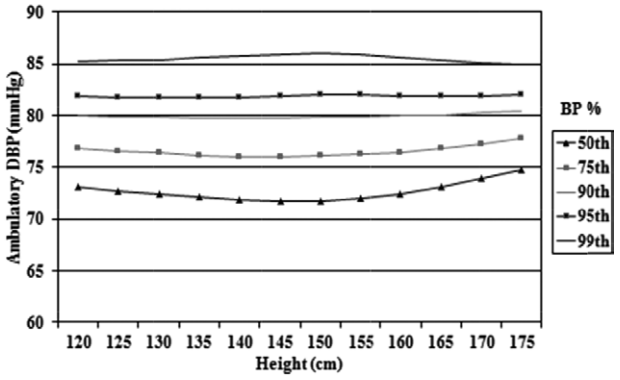

Figure. Graph of mean daytime diastolic ambulatory blood pressure (BP) for girls according to height in the Central European pediatric ambulatory blood pressure monitoring database. DBP indicates diastolic blood pressure. Modified from Wühl et al[81] with permission of the publisher. Copyright © 2002, Lippincott Williams & Wilkins, Inc.

Methods for Performance of ABPM

Nursing Implications

Nurses and other healthcare personnel involved in ABPM should follow a standardized approach to ABPM to maintain the functionality of the equipment, minimize measurement errors, and obtain valid, reliable, and reproducible BP data.[3] Care of the equipment may include yearly calibration (by either the institution's biomedical engineering department or the manufacturer), depending on the manufacturer's recommendation; cleaning the hardware with disinfecting wipes; and laundering the reusable cloth covers for the BP cuffs between patients. The nurse or other appropriately trained staff should review the patient's history for any contraindications to ABPM (severe clotting disorders or rhythm disturbances, and for some brands of equipment, latex allergy). Serious adverse events such as arm vein thrombosis have not been reported in children, although mild sleep disturbances have been documented.[119,120] Although some investigators do not believe these alterations in sleep substantially alter ABPM results,[121] 1 study did find higher 48-hour ABPM in white but not black adolescents who had shortened actigraphy-assessed sleep time.[122]

Care should be taken in selection of the appropriate size cuff according to published guidelines.[101a] Although casual BP is usually taken in the dominant arm, ABPM should be applied to the child's nondominant arm to avoid interference with school work, unless the child has arterial surgery on that side, such as repair of coarctation of the aorta or creation of an arteriovenous fistula.[101a] After application, the ambulatory BP should be measured and compared with resting, clinic BP by use of the same technique as the ABPM (auscultatory or oscillometric). If the average of 3 values is >5 mm Hg higher or lower, cuff placement should be adjusted or the device checked for calibration.

Successful ABPM is possible in most patients even during sleep,[124] and comprehensive, standardized patient/parent education will reduce the failure rate in obtaining accurate ABPM.[125] Patients and their parents need to be instructed how to stop a reading if there is excessive discomfort. This may signal kinked tubing. They should also be told to keep the arm still during readings. This is essential. Continuing with normal activities of daily living is encouraged, but monitors should not be allowed to get wet during swimming or damaged during contact sports. Removal of the monitor is not recommended, but if absolutely necessary, the device should be removed immediately after a reading to reduce the number of missed readings and reapplied as soon as possible. Finally, children should maintain a diary that indicates sleep and wake times, as well as activities that may influence BP measurements,

including stressful situations or exercise, and timing of antihypertensive medications. Symptoms such as dizziness should also be recorded, because up to 91% of children with a history of syncope demonstrate postural hypotension on ABPM.[126]

After the ABPM data have been downloaded, the readings should be scanned briefly to assess the quality of the study. If BP dipping is seen at times other than the sleep time noted in the patient log, clarification with the patient of actual sleep/wake times may be needed. Common reasons for missing data include the patient disconnecting the device at night, suspension of a reading by use of the cancellation button, turning the monitor off, dead batteries, movement artifact, or kinks in the tubing. Obtaining additional information from the patient will help determine whether missing data are patient or device related. Because ABPM studies as short as 6 hours' duration have been found to correlate with 24-hour results in 1 recent pediatric study,[127] many physicians will still interpret and accept the results of shortened monitoring periods for routine clinical care.

Equipment

For more detail on equipment used in ABPM, refer to the 2008 AHA scientific statement.[3] Briefly, both oscillometric and auscultatory monitors are available for use in pediatric ABPM.[111,115] Many monitors are available and have been evaluated with use of the Association for the Advancement of Medical Instrumentation US national standard or the British Hypertension Society standard.[128,129] A comprehensive list noting validation status is available online at www.dableducational.org. Unfortunately, monitors that have not undergone validation testing or US Food and Drug Administration clearance can be sold in the United States, and few have been formally validated in children.[130] Child-specific issues include the need for lightweight devices appropriate for smaller bodies, proper cuff sizing to ensure that the cuff width is ≈40% of the midarm circumference, and device tolerance of excessive motion.[101a] For auscultatory devices, users should ascertain whether the fourth or fifth Korotkoff sound is being used to estimate DBP and should be aware that no normative data are available for auscultatory ABPM.[131,132] Although oscillometric devices may be easier to use and have fewer erroneous readings, oscillometric BP measurement also has inherent limitations, as reflected in the generally lower ratings on British Hypertension Society protocol evaluation.[108] Nevertheless, most centers that perform ABPM in children and adolescents use oscillometric devices. These issues are summarized in Table 1.

Frequency of Measurement and Accounting for Activity

Expert opinion in pediatric ABPM recommends that at least 1 or 2 valid readings should be obtained per hour over the entire 24 hours (including during sleep) to consider an ABPM study to be adequate/interpretable. In routine clinical practice, it may be acceptable to consider as "interpretable" some ABPM studies that do not meet this high standard. Ideally, monitors should be programmed to obtain readings every 15 to 20 minutes, although some decrease in frequency during sleep is acceptable. Patient diaries are critical tools in the proper use of ABPM and should at minimum record the sleep times, nap times, and periods of physical activity.[133,134]

Table 1. Pros and Cons of Oscillometric Versus Auscultatory Ambulatory BP Devices

Oscillometric	Auscultative
Pros: • Easier to use • Fewer erroneous readings	Pros: • Diastolic BP may be defined as 4th or 5th Korotkoff sound • Systolic and diastolic pressures are measured in a similar fashion to resting, casual BP
Cons: • Systolic and diastolic pressures are calculated, not measured • Calculation formulas are proprietary	Cons: • No normative data available • More difficult to use • Fewer machines to choose • No consensus on lower age at which Korotkoff sounds are audible or accurate

BP indicates blood pressure.

Interpretation software allows for customization of diurnal patterns and exclusion of selected readings gleaned ideally from accurate diary entries. Without specific day/night notation, automatic nighttime divisions may be set that range anywhere from a 9 PM to midnight start time and from a 6 to 9 AM wake time, with some algorithms excluding the readings obtained during these "buffer" periods.[111] The use of inappropriate day/night divisions can lead to substantial misclassification.[133] Alternatively, patient-independent activity monitor–derived notation of diurnal cycles may be superior to patient notation.[135] Activity period BPs are shown to be captured reliably on ABPM in general, although some specialists recommend avoidance of contact sports or vigorous exercise during ABPM.[134,136] One study found that for each 1-unit increase in physical activity recorded by wrist actigraph, there were increases in SBP, DBP, and heart rate on ABPM of 0.02 mm Hg, 0.01 mm Hg, and 0.02 bpm, respectively.[137] Recording on a school day may also be helpful, because weekend days may produce lower ABPM results.[138]

Editing Data and Calculations

Interpretation of ABPM studies is usually based on a combination of criteria, including mean SBP or DBP and BP loads. First, outlier data are filtered out by various automated approaches to minimize the observer bias inherent in users selecting particular measurements[139,140]; however, these automated filters may not be appropriate for young children, so caution is advised. Then, mean SBP and DBP are calculated for the entire 24-hour period, as well as the wake and sleep periods, with software that allows the user to define the diurnal transitions.[141] BP load is then calculated as the proportion of readings above a threshold (usually the pediatric 95th percentile). Dipping is defined as the percentage drop from mean daytime to mean nighttime levels.

More complicated calculations of circadian BP rhythms have also been attempted in pediatric patients. One group used Fourier analysis to define circadian (24-hour) and ultradian (6-, 8- and 12-hour) BP rhythms in 938 healthy school children aged 5 to 18 years.[142] When these methods were applied to children and adolescents with stage 2 to 4 CKD, a lower amplitude of circadian and all ultradian BP and heart rate

rhythms ($P<0.01$) was found than in the healthy cohort.[143] BP variability can also be calculated. Compared with mean BP values, BP variance over long- and short-term periods may be a better reflection of consequential biological dysfunction in BP regulatory mechanisms, such as alterations in the sympathetic nervous system.[144] The standard deviation of BP during a 24-hour ABPM provides an account of short-term BP variability, whereas visit-to-visit BP variation is posited to reflect long-term variability.[145–147] More long-term variability predicts LVH and cardiovascular events such as stroke,[60,147] whereas short-term BP variability is associated with LVH in children.[148] Another parameter calculated from ABPM is the AASI (see preceding section on target-organ damage). In adults, the AASI correlates with arterial stiffness (pulse-wave velocity)[149] and predicts cardiovascular mortality.[150] In children, the AASI was found to be elevated in hypertensive children.[54,151] Although interesting, these advanced calculations remain feasible only in a research setting.

Interpretation

The standard parameters of mean BP level, load, and dipping are compared against normative pediatric values to determine normal or elevated BP. The smoothed age- and sex-specific 95th percentiles of Wühl et al,[81] which were calculated from the original data from Soergel et al,[111] are the preferred reference data (Appendix Tables A1 through A4). Differences in normative standards can lead to variability in diagnosis.[108,133,152] BP loads in excess of 25% are generally considered abnormal, with increased loads associated with LVH.[38,153] The circadian BP decline from day to night, termed *dipping*, should be ≥10%.[154]

Reproducibility

Although few studies of reproducibility of ABPM have been conducted in pediatric patients,[155–157] most experts agree there is a moderate to strong correlation seen in serial ABPM measurement.[158] Furthermore, ABPM is superior to casual BP measurement both in identifying children with target-organ damage and in determining adequate antihypertensive therapy, thus supporting the superiority of an ABPM-derived assignment of hypertension compared with casual BP in children, as in adults.[34,41,148,157,159–164] However, outcome data linking ABPM in childhood or adolescence to cardiovascular disease in adulthood are not yet available.

Recommendations for Standard Application of ABPM in Pediatrics

The preceding sections have outlined the advantages of ABPM in specific clinical situations in the evaluation and management of pediatric hypertension, as well as the rationale for modification of the prior recommendations for interpretation of ABPM studies in children and adolescents. Although there remain some uncertainties with respect to ABPM in pediatrics,[112] its benefits likely outweigh the uncertainties in most patients, particularly for initial diagnosis. Additionally, there are clearly disease states in which ABPM has been shown to be particularly useful, as summarized in Table 2 and discussed further in the online-only Data Supplement.

What follows is a synthesis of our recommendations for pediatric ABPM in list form, which we hope will prove useful to clinicians who obtain ABPM studies in children and adolescents.

- Indications for routine performance of ABPM include the following:
  - To confirm the diagnosis of hypertension in a patient with hypertension according to casual BP measurements
    - Determine whether sustained hypertension or WCH exists
  - To evaluate for the presence of MH when there is a clinical suspicion of hypertension but normal or prehypertensive casual measurements
  - To assess BP patterns in high-risk patients
    - Assess for abnormal circadian variation in BP, such as blunted dipping or isolated sleep hypertension in patients with diabetes mellitus, CKD, solid organ transplants, and severe obesity with or without sleep-disordered breathing.
    - Assess the severity and persistence of BP elevation in patients at high risk for hypertensive target-organ damage.
  - To evaluate effectiveness of drug therapy for hypertension
    - Confirm BP control in treated patients, especially those with secondary forms of hypertension.
    - Evaluate for apparent drug-resistant hypertension.
    - Determine whether symptoms can be attributed to drug-related hypotension.
- An ABPM device suitable for use in children should be selected.
  - Only devices that have been validated according to Association for the Advancement of Medical Instrumentation or British Hypertension Society standards should be used.
  - An oscillometric or auscultatory technique can be used.
  - Appropriate cuff sizes as recommended in the Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents[101a] must be available for the device selected.
- A standard approach to obtaining ABPM readings should be used.
  - ABPM should only be performed by personnel with specific training in the application of the device and interpretation of ABPM data in pediatric patients.
  - Monitors should be applied to the nondominant arm unless contraindicated (presence of a permanent dialysis access), or if a significant BP discrepancy between the extremities exists, the monitor should be placed on the arm with the higher BP.
  - Devices should be programmed to record BP every 15 to 20 minutes during waking hours and every 20 to 30 minutes during sleep.
  - After application, BP measured with the device should be compared with resting, clinic BP by the same technique used by the ambulatory device (auscultatory or oscillometric).
  - Patients should be instructed to record antihypertensive medication administration, activity, sleep, and wake times in a diary.

Table 2. Conditions in Which ABPM May Be Particularly Helpful*

Condition	Relevance of ABPM
Secondary hypertension	Elevated load, abnormal dipping and variability
Chronic kidney disease	Prevalence of hypertension, masked hypertension, association with target-organ changes and disease progression
Types 1 and 2 diabetes mellitus	Abnormal circadian variation, association with microalbuminuria and vascular changes
Obesity	Masked hypertension, correlation between BMI and hypertension severity, abnormal dipping, association with target-organ damage
Sleep apnea	Hypertension severity, abnormal circadian variation
Genetic syndromes Neurofibromatosis type 1 Turner syndrome Williams syndrome	Abnormal BP patterns indicating secondary cause of hypertension, especially renal artery stenosis and aortic coarctation
Treated patients with hypertension	Response to antihypertensive medications and/or lifestyle changes
Hypertension research	Reduction in subject number in drug trials

ABPM indicates ambulatory blood pressure monitoring; BMI, body mass index; and BP, blood pressure.

*For a detailed discussion and references, see the online-only Data Supplement.

- A sufficient number of valid BP recordings are needed for a study to be considered interpretable.
  - — Minimum of 1 reading per hour, including during sleep
  - — At least 40 to 50 readings for a full 24-hour report
  - — 65% to 75% of all possible BP readings for a partial day report (depends on frequency of recording programmed into the monitor)
- ABPM recordings should be edited for outlying values.
  - — Data should be inspected visually for gross inconsistencies that fall considerably outside the normal ranges for awake or asleep BP and heart rate for the patient's age.
  - — Values that fall outside of the following range should be discarded:
    - ○ SBP 60 to 220 mm Hg
    - ○ DBP 35 to 120 mm Hg
    - ○ Heart rate 40 to 180 bpm
    - ○ Pulse pressure 40 to 120 mm Hg
  - — Ideally, the above limits should be programmed into the ABPM software to minimize subjective editing of ABPM data.
  - — Any resting BP measurements made with the ABPM device immediately after application of the device should also be edited out.
- Standard calculations should be reported.
  - — Mean ambulatory SBP and DBP during the entire 24-hour awake and sleep periods.
  - — BP load (percentage of readings above the ambulatory 95th percentile) for both SBP and DBP during the entire 24-hour awake and sleep periods.
  - — Dipping (percent day/night difference) should be determined ([mean awake BP-mean sleep BP]/mean awake BP×100) for both SBP and DBP.
- ABPM levels should be interpreted with appropriate pediatric normative data.
  - — ABPM values should be compared with sex- and height-specific data obtained in large pediatric populations using similar techniques[3] and not with resting BP levels.
  - — A suggested schema for staging ABPM is included in Table 3. These are consensus rather than evidence-based recommendations because of a lack of pediatric cardiovascular outcome data based on ABPM.

Interpretation of ABPM Studies

Building on an earlier proposed classification scheme by Lurbe et al,[108] the 2008 AHA statement issued suggested criteria for classification of children as normotensive, white coat hypertensive, prehypertensive, masked hypertensive, and hypertensive.[3] These recommended classifications incorporated the office BP reading and the mean ambulatory SBP. Of note, this scheme is different from that used to analyze ABPM studies in adults, which uses fixed BP levels as normal/abnormal, does not include a prehypertension category, and considers a slightly higher BP load of 30% to be abnormal.[165]

Since publication of the AHA statement in 2008, the field of pediatric ABPM has continued to advance rapidly, and several issues have arisen with respect to the suggested classification scheme in that document. Some of these issues have been raised formally through peer-reviewed publications in the pediatric hypertension literature, and some have become apparent as practitioners have attempted to apply the classification scheme clinically. These issues and potential solutions will be addressed in the following sections.

Prehypertension

Several concerns have been raised regarding the definition of prehypertension in the 2008 AHA statement. First, the definition mistakenly states that the office BP cut point for prehypertension is a BP >95th percentile, but the actual definition by the National High Blood Pressure Education Program is that prehypertension is office BP ≥90th percentile and <95th percentile, or >120/80 mm Hg.[101a] Thus, we have changed the definition of prehypertension in the classification scheme to office BP ≥90th percentile or >120/80 mm Hg, mean ambulatory BP <95th percentile but elevated BP loads.

The second concern with prehypertension as defined in the 2008 AHA statement is the lack of clinical evidence as to whether this actually corresponds to prehypertension as defined by the National High Blood Pressure Education Program. Only 1 recent study has examined ambulatory BP in pediatric patients with prehypertension based on office BP.[78] Although the investigators demonstrated that prehypertensive patients had higher ambulatory BP than normotensive patients, they did not use the 2008 AHA criteria to classify the ambulatory BP studies and did not report whether the mean

ambulatory BP values of the prehypertensive patients were <95th percentile according to pediatric ambulatory BP criteria. Interestingly, some of the patients with office prehypertension were indeed hypertensive by ABPM, a finding that would actually classify them as having MH.

Finally, as noted above, there is no corresponding concept of prehypertension when it comes to ABPM in adults. This may be related to the lack of incorporation of BP load into the analysis of ambulatory BP studies in adults in the more recent AHA recommendations for BP measurement.[166] However, many pediatric hypertension experts believe that prehypertension on casual BP recordings with elevated load, despite normal means, may represent a higher-risk pattern. Therefore, we have decided to keep this category in the revised classification scheme.

Diastolic Hypertension

The classification scheme outlined in the 2008 AHA statement suggests that children undergoing ABPM should be classified on the basis of clinic and ambulatory SBP. Yet in routine clinical use of ABPM, it is apparent that some children have isolated diastolic hypertension. The frequency and significance of this are unknown; however, in at least 1 study, diastolic hypertension on ABPM has been shown to potentially signal the presence of underlying secondary causes of hypertension.[167] This would be consistent with single-center studies that used office BP measurements, which have shown that children with primary hypertension tend to have isolated SBP elevation,[168,169] and with a recent multicenter study that showed a high prevalence of DBP elevation in younger children with secondary hypertension.[170] These data suggest that diastolic hypertension is important to identify from a diagnostic standpoint and suggest that DBP elevation should also be incorporated into the classification.

However, there are some issues related to ambulatory DBP that should be considered. Many ambulatory BP devices use the oscillometric technique, which has been shown to be less accurate in measuring DBP than SBP.[171,172] Although this may not be true for all devices, it may in fact be responsible for the remarkable lack of DBP variation that was seen in the German pediatric ambulatory BP database (Figure).[112] On the other hand, all indirect methods of BP measurement have inaccuracies for both SBP and DBP compared with direct intra-arterial measurements,[173] so perhaps the widely held belief that automated devices are less accurate for DBP than SBP is erroneous.

One additional issue is that the DBP values found in the German pediatric ambulatory databases are fairly high: ≈80 to 81 mm Hg for the awake 90th percentile and 82 to 84 mm Hg for the awake 95th percentile (these are similar for boys and girls and, as noted above, are similar regardless of height).[3] For younger children especially, sustained DBP above this value would almost certainly be considered hypertensive by most clinicians, and if one believes that the actual normative values should be lower than this for younger children, one would potentially miss patients with hypertension if DBP elevation were not included in the classification scheme. Thus, we have incorporated DBP into the revised ambulatory BP classification scheme.

Nocturnal Hypertension

Nocturnal hypertension has significant prognostic implications in certain patient populations, including adults and children with CKD and diabetes mellitus.[80,174–178] It has also been cited as the most significant predictor of cardiovascular outcome in hypertensive adults.[179] Furthermore, isolated nocturnal hypertension occurs commonly in other clinical situations in which ABPM has proven useful, particularly in solid organ transplantation.[180]

It is clear from these data that nocturnal hypertension is an important variable that should be incorporated into any ambulatory BP classification scheme. Thus, we believe that even patients with isolated abnormalities of sleep BP on ABPM should be considered as having MH and that abnormalities of sleep BP should be given the same weight as abnormalities of awake BP.

Mean Arterial Pressure

The majority of devices used to perform ABPM use the oscillometric technique, which directly measures mean arterial pressure (MAP) and back-calculates SBP and DBP by use of manufacturer-specific software algorithms. The resultant calculated SBP and DBP values have been shown to vary significantly compared with SBP and DBP values obtained by auscultation.[173,181] It may be more appropriate to use MAP to classify the results of ABP studies, because this is the one BP parameter that is measured directly by most devices used to perform ABPM in children. Furthermore, treatment guided by ambulatory MAP has been shown to reduce the rate of progression of CKD in the recently published Effect of Strict Blood Pressure Control and ACE Inhibition on the Progression of CRF in Pediatric Patients (ESCAPE) trial,[182] which further highlights the importance of this ambulatory BP parameter.

However, additional evidence would likely be needed before MAP could be adopted as the standard for classifying ambulatory BP studies. Most recent publications on ABPM and outcomes have reported their results based on ambulatory SBP and DBP. We have included the full German data set, including MAP values (Appendix Tables A1 through A4). We encourage investigators to begin examining the relationship between ambulatory MAP and both intermediate and long-term outcomes so that sufficient evidence can be generated to fully evaluate the possibility of incorporating MAP into the classification scheme.

Severe Ambulatory Hypertension

This diagnosis should be evaluated in the context of the mean ambulatory BP level. For instance, a subject with a mean BP level that is mildly elevated (eg, consistently at the 96th percentile) may have an increased load of >50%, but this may not represent as high a risk as the subject with load >50% and mean BP at significantly higher than the 95th percentile (eg, in the 99th percentile) or with "spikes" of BP to extremely high levels.

Uncategorized Patients

The classification scheme in the 2008 AHA statement does not provide guidance on how to categorize patients with 2 related patterns on ABPM: (1) office BP ≥95th percentile, normal mean ambulatory BP, and elevated BP loads; and (2) normal office BP (<90th percentile), normal mean ambulatory

BP, but elevated ambulatory BP loads. Should these children be considered normotensive or masked hypertensive?

How to approach such "unclassified patients" probably depends on whether or not one agrees that the concept of BP load is a valid parameter to consider. BP load was initially adopted enthusiastically as a predictor of hypertensive target-organ damage,[183] but more recent studies have not relied on BP load, and the most recent AHA guidelines for analysis of ABPM studies in adults do not incorporate BP load.[166]

Interestingly, the investigators of the Chronic Kidney Disease in Children study have decided to classify these children as having MH,[178,184] which may be justifiable in patients with CKD, but further study is needed to validate this approach in other populations. We would recommend approaching such patients on a case-by-case basis, taking into account the presence or absence of underlying secondary causes of hypertension or specific cardiovascular risk factors.

Revised ABPM Classification

Although further study is needed to answer some of the above questions, we do believe that the classification scheme in the 2008 AHA statement can be simply modified to address some of the more obvious issues, including what to do about DBP, isolated nocturnal BP elevation, and the correct identification of children with prehypertension. We have summarized these modifications in Table 3.

Conclusions and Future Directions

Although much experience with pediatric ABPM has been gained since publication of the 2008 AHA scientific statement, much more work needs to be done. Specifically, there is an urgent need for more comprehensive normative ABPM data across sex, race, and age. Devices that can measure DBP more accurately may be useful in determining the true increase in DBP over age, because current norms indicate a flat DBP curve (Figure).[112] Better data linking ABPM patterns to target-organ damage are also needed to improve our characterization of BP, because children with abnormal load, dipping, or a circadian pattern may be at risk for cardiovascular disease despite normal ABPM mean levels. Finally, additional data evaluating the efficacy of ABPM in measuring the effect of interventions and effectiveness of ABPM-driven BP control in reversing target-organ damage are needed.

Table 3. Suggested Revised Schema for Staging of Ambulatory BP Levels in Children

Classification	Office BP*	Mean Ambulatory SBP or DBP†‡	SBP or DBP Load, %‡§
Normal BP	<90th %tile	<95th %tile	<25
White coat hypertension	≥95th %tile	<95th %tile	<25
Prehypertension	≥90th %tile or >120/80 mm Hg	<95th %tile	≥25
Masked hypertension	<95th %tile	>95th %tile	≥25
Ambulatory hypertension‖	>95th %tile	>95th %tile	25–50
Severe ambulatory hypertension (at risk for end-organ damage)	>95th %tile	>95th %tile	>50

%tile indicates percentile; BP, blood pressure; DBP, diastolic blood pressure; and SBP, systolic blood pressure.

*Based on National High Blood Pressure Education Program Task Force normative data.[101a]

†Based on normative pediatric ABPM values in Appendix Tables A1 through A4.

‡For either the wake or sleep period of the study, or both.

§For patients with elevated load but normal mean ambulatory BP and office BP that is either normal (<90th percentile) or hypertensive (≥95th percentile), no specific ambulatory BP classification can be assigned based on current evidence and expert consensus. These "unclassified" patients should be evaluated on a case-by-case basis, taking into account the presence of secondary hypertensiona or multiple cardiovascular risk factors.

‖Some clinicians may prefer the term *sustained hypertension* rather than *ambulatory hypertension*.

Appendix

Table A1. Normal Values for Ambulatory BP (mm Hg) for Healthy Boys by Height

	Height, cm													
BP Percentile	120	125	130	135	140	145	150	155	160	165	170	175	180	185
24-h SBP														
50th	104.5	105.3	106.2	107.2	108.3	109.5	110.9	112.5	114.2	116.1	118.0	119.7	121.5	123.2
75th	109.2	110.1	111.1	112.1	113.3	114.6	116.1	117.7	119.5	121.4	123.2	125.0	126.6	128.2
90th	113.8	114.8	115.9	116.9	118.2	119.5	121.0	122.6	124.4	126.3	128.1	129.8	131.3	132.8
95th	116.8	117.8	118.9	120.0	121.2	122.5	124.0	125.7	127.4	129.3	131.1	132.6	134.1	135.5
99th	122.9	123.9	125.0	126.1	127.3	128.6	130.1	131.7	133.4	135.2	136.8	138.2	139.4	140.5
Daytime SBP														
50th	110.8	111.1	111.5	112.0	112.7	113.7	115.1	116.8	118.6	120.6	122.6	124.4	126.2	128.0
75th	116.2	116.5	116.9	117.4	118.0	119.0	120.4	122.1	124.2	126.4	128.4	130.3	132.2	134.1
90th	121.7	121.9	122.2	122.5	123.0	123.9	125.3	127.1	129.4	131.9	134.1	136.1	138.0	139.9
95th	125.2	125.3	125.5	125.7	126.0	126.9	128.3	130.2	132.7	135.3	137.6	139.6	141.6	143.5
99th	132.6	132.4	132.2	132.0	132.1	132.8	134.2	136.3	139.1	142.2	144.7	146.8	148.6	150.5
Nighttime SBP														
50th	93.6	94.6	95.6	96.7	97.9	99.0	100.1	101.3	102.6	104.1	105.6	107.2	108.7	110.2
75th	98.6	99.8	101.0	102.3	103.6	104.7	105.9	107.1	108.4	109.9	111.5	113.1	114.6	116.1
90th	103.3	104.8	106.3	107.8	109.3	110.6	111.8	113.0	114.3	115.7	117.2	118.8	120.3	121.8
95th	106.3	107.9	109.7	111.4	113.0	114.4	115.7	116.8	118.1	119.4	120.9	122.4	123.9	125.3
99th	112.1	114.2	116.5	118.7	120.8	122.5	123.8	124.9	126.0	127.1	128.4	129.6	131.0	132.2
24-h DBP														
50th	65.6	65.9	66.1	66.4	66.6	66.9	67.1	67.2	67.3	67.5	67.6	67.8	68.0	68.2
75th	69.7	69.9	70.2	70.4	70.6	70.8	71.0	71.1	71.2	71.3	71.5	71.7	71.8	71.9
90th	73.9	74.1	74.2	74.4	74.5	74.7	74.8	74.8	74.9	75.1	75.3	75.4	75.5	75.6
95th	76.7	76.8	76.9	76.9	77.0	77.1	77.1	77.2	77.3	77.5	77.7	77.8	77.9	78.0
99th	82.7	82.5	82.3	82.1	81.9	81.8	81.8	81.8	81.9	82.2	82.5	82.7	82.9	83.0
Daytime DBP														
50th	72.3	72.3	72.2	72.1	72.1	72.1	72.1	72.1	72.2	72.3	72.6	72.8	73.1	73.4
75th	76.5	76.4	76.3	76.2	76.0	76.0	75.9	75.9	76.0	76.2	76.5	76.8	77.2	77.5
90th	80.2	80.1	79.9	79.7	79.5	79.4	79.3	79.3	79.4	79.7	80.0	80.5	80.9	81.3
95th	82.4	82.2	82.0	81.8	81.5	81.4	81.2	81.2	81.3	81.7	82.1	82.6	83.1	83.6
99th	86.5	86.2	85.9	85.6	85.2	85.0	84.8	84.8	85.0	85.4	86.0	86.6	87.3	87.9
Nighttime DBP														
50th	54.3	54.8	55.1	55.5	55.8	56.0	56.2	56.2	56.3	56.5	56.7	56.9	57.1	57.3
75th	57.6	58.2	58.8	59.2	59.6	59.9	60.1	60.2	60.2	60.3	60.5	60.6	60.8	60.9
90th	60.7	61.4	62.1	62.7	63.2	63.5	63.7	63.8	63.8	63.9	63.9	64.0	64.1	64.2
95th	62.6	63.4	64.2	64.8	65.4	65.8	66.0	66.0	66.0	66.0	66.1	66.1	66.1	66.2
99th	66.2	67.2	68.2	69.0	69.7	70.1	70.4	70.4	70.3	70.3	70.2	70.1	70.0	69.9
24-h MAP														
50th	77.5	78.1	78.7	79.3	79.9	80.5	81.1	81.7	82.3	83.1	83.9	84.7	85.5	86.3
75th	81.8	82.4	83.0	83.5	84.1	84.6	85.2	85.9	86.6	87.3	88.1	89.0	89.8	90.7
90th	86.3	86.7	87.2	87.6	88.0	88.5	89.1	89.7	90.3	91.1	91.9	92.7	93.5	94.3
95th	89.3	89.6	89.9	90.2	90.5	90.9	91.4	91.9	92.6	93.3	94.0	94.8	95.6	96.4
99th	95.9	95.7	95.5	95.4	95.4	95.6	95.9	96.3	96.7	97.4	98.0	98.7	99.4	100.1
Daytime MAP														
50th	83.8	84.1	84.3	84.5	84.7	85.0	85.4	85.8	86.4	87.1	88.0	89.0	90.0	91.0
75th	88.5	88.7	88.9	89.0	89.1	89.4	89.6	90.1	90.7	91.6	92.6	93.7	94.9	96.1

(*Continued*)

Table A1. Continued

	Height, cm													
BP Percentile	120	125	130	135	140	145	150	155	160	165	170	175	180	185
90th	92.9	93.0	93.1	93.1	93.1	93.2	93.4	93.8	94.5	95.4	96.5	97.7	99.0	100.3
95th	95.6	95.6	95.6	95.5	95.5	95.5	95.7	96.0	96.7	97.7	98.8	100.1	101.4	102.8
99th	101.0	100.7	100.5	100.2	99.9	99.7	99.8	100.1	100.8	101.7	102.9	104.3	105.7	107.1
Nighttime MAP														
50th	66.8	67.6	68.3	69.0	69.6	70.1	70.6	71.2	71.9	72.7	73.6	74.5	75.4	76.2
75th	71.0	71.9	72.7	73.4	73.9	74.4	74.9	75.4	76.0	76.8	77.6	78.3	79.1	79.8
90th	75.9	76.6	77.3	77.9	78.3	78.6	78.9	79.2	79.7	80.3	80.9	81.5	82.1	82.7
95th	79.5	80.0	80.5	80.9	81.2	81.3	81.4	81.5	81.9	82.3	82.8	83.3	83.8	84.3
99th	88.4	88.1	87.8	87.6	87.2	86.7	86.3	86.0	86.0	86.1	86.3	86.5	86.8	87.0

BP indicates blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; and SBP, systolic blood pressure.
Modified from Wühl et al[81] with permission of the publisher. Copyright © 2002, Lippincott Williams & Wilkins, Inc.

Table A2. Normal Values for Ambulatory BP (mm Hg) for Healthy Girls by Height

	Height, cm											
BP Percentile	120	125	130	135	140	145	150	155	160	165	170	175
24-h SBP												
50th	104.0	105.0	106.0	106.8	107.6	108.7	109.9	111.2	112.4	113.7	115.0	116.4
75th	108.2	109.3	110.3	111.2	112.1	113.2	114.6	115.9	117.0	118.0	119.2	120.4
90th	112.0	113.2	114.3	115.3	116.2	117.4	118.7	120.0	121.0	121.8	122.8	123.8
95th	114.3	115.6	116.7	117.7	118.7	119.9	121.2	122.5	123.3	124.1	124.9	125.8
99th	118.8	120.1	121.3	122.4	123.4	124.6	126.0	127.1	127.7	128.2	128.8	129.3
Daytime SBP												
50th	110.0	110.5	111.0	111.6	112.2	113.1	114.3	115.6	117.0	118.3	119.8	121.2
75th	114.4	115.0	115.7	116.3	117.0	118.1	119.4	120.7	121.9	123.1	124.2	125.3
90th	118.2	119.0	119.7	120.4	121.3	122.5	123.9	125.2	126.4	127.3	128.1	128.9
95th	120.4	121.3	122.1	122.9	123.8	125.1	126.5	127.9	129.1	129.8	130.5	131.0
99th	124.5	125.5	126.4	127.4	128.5	129.9	131.5	133.0	134.0	134.5	134.8	135.0
Nighttime SBP												
50th	95.0	95.7	96.4	96.9	97.5	98.1	98.9	100.0	101.1	102.2	103.4	104.6
75th	99.4	100.3	101.2	101.9	102.6	103.4	104.4	105.5	106.4	107.3	108.2	109.2
90th	103.3	104.4	105.5	106.5	107.5	108.5	109.5	110.5	111.2	111.8	112.4	113.1
95th	105.6	106.9	108.1	109.3	110.4	111.6	112.7	113.6	114.1	114.4	114.8	115.3
99th	109.8	111.5	113.1	114.7	116.2	117.7	118.9	119.5	119.6	119.4	119.3	119.4
24-h DBP												
50th	65.9	65.9	66.0	66.1	66.2	66.3	66.5	66.7	67.0	67.4	68.0	68.6
75th	68.6	68.9	69.2	69.5	69.8	70.1	70.4	70.6	70.7	71.0	71.3	71.6
90th	70.9	71.4	71.9	72.4	72.9	73.4	73.8	74.0	74.1	74.2	74.4	74.5
95th	72.2	72.8	73.4	74.1	74.7	75.3	75.7	76.0	76.1	76.2	76.2	76.2
99th	74.6	75.3	76.2	77.1	77.9	78.7	79.3	79.7	79.9	79.9	79.9	79.7
Daytime DBP												
50th	73.2	72.8	72.4	72.1	71.8	71.7	71.8	72.0	72.4	73.1	73.9	74.8
75th	76.9	76.6	76.4	76.2	76.1	76.1	76.1	76.2	76.4	76.8	77.3	77.8
90th	80.1	79.9	79.8	79.8	79.7	79.8	79.9	79.9	79.9	80.0	80.2	80.5
95th	81.9	81.8	81.8	81.8	81.9	82.0	82.0	82.0	82.0	81.9	82.0	82.0
99th	85.3	85.3	85.4	85.6	85.8	85.9	86.0	85.9	85.7	85.4	85.2	84.9

(*Continued*)

Table A2. Continued

	Height, cm											
BP Percentile	120	125	130	135	140	145	150	155	160	165	170	175
Nighttime DBP												
50th	55.4	55.3	55.1	54.8	54.6	54.4	54.3	54.4	54.6	54.9	55.1	55.4
75th	59.5	59.5	59.4	59.3	59.1	58.9	58.8	58.7	58.8	58.9	61.0	59.3
90th	63.1	63.3	63.4	63.4	63.3	63.1	63.0	62.9	62.9	62.9	66.9	63.1
95th	65.2	65.5	65.7	65.8	65.8	65.7	65.6	65.5	65.5	65.5	70.8	65.5
99th	69.1	69.6	70.1	70.4	70.6	70.8	70.8	70.7	70.7	70.6	79.0	70.4
24-h MAP												
50th	77.2	77.8	78.3	78.7	79.2	79.7	80.2	80.8	81.5	82.3	83.1	84.0
75th	80.6	81.2	81.8	82.4	82.9	83.5	84.1	84.7	85.3	85.9	86.6	87.4
90th	83.6	84.2	84.9	85.5	86.1	86.7	87.3	87.9	88.4	88.9	89.5	90.1
95th	85.3	86.0	86.7	87.4	88.0	88.6	89.2	89.7	90.2	90.6	91.1	91.7
99th	88.5	89.2	89.9	90.6	91.3	91.9	92.5	93.0	93.3	93.6	94.0	94.5
Daytime MAP												
50th	83.3	83.7	84.0	84.1	84.3	84.5	84.9	85.5	86.2	87.0	88.0	88.9
75th	87.4	87.9	88.2	88.5	88.7	88.9	89.3	89.8	90.3	90.9	91.6	92.2
90th	90.9	91.5	91.9	92.2	92.4	92.7	93.0	93.4	93.7	94.1	94.5	94.9
95th	92.9	93.6	94.0	94.4	94.6	94.9	95.1	95.4	95.6	95.8	96.1	96.4
99th	96.6	97.4	97.9	98.3	98.6	98.8	99.0	99.0	99.0	99.0	99.0	99.1
Nighttime MAP												
50th	68.0	68.2	68.4	68.5	68.7	69.0	69.3	69.8	70.4	71.2	72.0	72.8
75th	72.6	72.7	72.9	73.0	73.2	73.5	73.9	74.3	74.8	75.4	76.1	76.9
90th	76.8	76.9	77.0	77.2	77.4	77.7	78.0	78.3	78.6	79.1	79.6	80.3
95th	79.5	79.4	79.6	79.7	79.9	80.2	80.4	80.6	80.8	81.2	81.6	82.2
99th	84.6	84.4	84.5	84.6	84.8	85.0	85.0	85.0	85.0	85.0	85.3	85.6

BP indicates blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; and SBP, systolic blood pressure.
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Table A3. Normal Values for Ambulatory BP (mm Hg) for Healthy Boys by Age

	Age, y											
BP Percentile	5	6	7	8	9	10	11	12	13	14	15	16
24-h SBP												
50th	104.6	105.5	106.3	107.0	107.7	108.8	110.4	112.6	115.1	117.8	120.6	123.4
75th	109.0	110.0	111.0	111.9	112.8	114.1	115.9	118.2	120.9	123.7	126.5	129.4
90th	113.4	114.7	115.8	116.8	117.9	119.2	121.2	123.7	126.4	129.3	132.1	134.9
95th	116.4	117.7	118.9	120.0	121.1	122.5	124.6	127.1	129.9	132.7	135.5	138.2
99th	122.7	124.1	125.4	126.6	127.7	129.2	131.4	134.0	136.9	139.5	142.0	144.5
Daytime SBP												
50th	111.1	111.5	111.9	112.2	112.6	113.4	114.9	117.0	119.5	122.3	125.3	128.2
75th	115.7	116.3	116.8	117.3	117.9	118.8	120.5	122.9	125.6	128.5	131.5	134.6
90th	120.1	120.9	121.6	122.2	122.9	124.0	125.9	128.4	131.2	134.2	137.3	140.4
95th	122.9	123.8	124.6	125.3	126.1	127.3	129.3	131.8	134.7	137.7	140.8	143.9
99th	128.5	129.6	130.6	131.5	132.3	133.7	135.8	138.6	141.5	144.4	147.4	150.4
Nighttime SBP												
50th	95.0	95.5	96.1	96.7	97.3	98.1	99.4	101.2	103.4	105.8	108.3	110.9
75th	99.2	100.2	101.1	102.0	102.9	103.9	105.3	107.1	109.3	111.9	114.4	116.9

(*Continued*)

Table A3. Continued

	Age, y											
BP Percentile	5	6	7	8	9	10	11	12	13	14	15	16
90th	103.4	104.9	106.2	107.5	108.5	109.6	111.0	112.8	115.0	117.5	120.0	122.5
95th	106.3	108.0	109.6	111.0	112.1	113.2	114.6	116.3	118.6	121.0	123.4	125.9
99th	112.3	114.6	116.7	118.4	119.6	120.7	121.9	123.4	125.5	127.8	130.1	132.3
24-h DBP												
50th	65.3	65.7	66.1	66.3	66.5	66.6	66.9	67.2	67.4	67.7	68.1	68.6
75th	68.8	69.3	69.6	69.9	70.0	70.2	70.5	70.8	71.0	71.4	71.8	72.3
90th	72.2	72.6	73.0	73.2	73.3	73.4	73.7	74.0	74.3	74.6	75.1	75.6
95th	74.4	74.8	75.1	75.2	75.3	75.4	75.7	75.9	76.2	76.6	77.0	77.5
99th	78.9	79.0	79.1	79.1	79.1	79.1	79.3	79.6	79.9	80.2	80.7	81.3
Daytime DBP												
50th	72.2	72.4	72.5	72.5	72.3	72.1	72.0	72.0	72.2	72.5	73.0	73.5
75th	75.9	76.1	76.3	76.4	76.2	76.0	76.0	76.0	76.2	76.5	77.0	77.6
90th	79.1	79.3	79.7	79.8	79.7	79.5	79.5	79.5	79.7	80.0	80.6	81.3
95th	81.0	81.3	81.6	81.8	81.7	81.5	81.5	81.6	81.7	82.1	82.8	83.5
99th	84.5	84.8	85.2	85.5	85.4	85.3	85.3	85.4	85.6	86.1	86.8	87.7
Nighttime DBP												
50th	55.0	55.3	55.5	55.7	55.8	55.8	55.9	56.0	56.3	56.5	56.8	57.1
75th	58.5	59.1	59.5	59.8	60.0	60.0	60.0	60.1	60.3	60.5	60.7	60.9
90th	62.3	63.2	63.8	64.2	64.3	64.2	64.1	64.1	64.1	64.2	64.3	64.3
95th	65.1	66.1	66.8	67.1	67.1	66.9	66.7	66.5	66.5	66.5	66.4	66.4
99th	71.6	72.7	73.5	73.5	73.2	72.6	71.9	71.4	71.1	70.8	70.6	70.3
24-h MAP												
50th	77.4	77.9	78.7	79.3	79.7	80.2	80.8	81.7	82.7	83.8	85.1	86.4
75th	81.4	81.9	82.7	83.4	83.8	84.3	85.0	85.9	86.9	88.0	89.3	90.5
90th	85.5	86.0	86.8	87.4	87.9	88.3	88.9	89.7	90.6	91.6	92.7	93.9
95th	88.3	88.7	89.5	90.0	90.4	90.8	91.3	91.9	92.7	93.7	94.7	95.7
99th	94.3	94.6	95.1	95.4	95.6	95.7	95.8	96.2	96.7	97.3	98.1	98.9
Daytime MAP												
50th	83.5	84.1	84.5	84.8	84.9	85.0	85.3	85.9	86.8	88.0	89.4	90.8
75th	87.5	88.2	88.8	89.2	89.4	89.5	89.9	90.6	91.5	92.7	94.2	95.7
90th	91.3	92.1	92.8	93.3	93.5	93.7	94.0	94.7	95.6	96.8	98.3	99.8
95th	93.6	94.5	95.3	95.8	96.1	96.2	96.5	97.1	98.0	99.2	100.6	102.1
99th	98.2	99.2	100.1	100.7	101.0	101.0	101.2	101.6	102.4	103.4	104.7	106.1
Nighttime MAP												
50th	66.7	67.7	68.6	69.2	69.7	70.0	70.5	71.2	72.1	73.1	74.0	74.9
75th	70.5	71.7	72.8	73.5	74.1	74.5	75.0	75.6	76.4	77.2	78.0	78.6
90th	74.7	76.0	77.2	78.1	78.6	78.9	79.3	79.7	80.3	80.8	81.3	81.7
95th	77.6	79.0	80.2	81.1	81.6	81.8	82.0	82.3	82.6	82.9	83.2	83.4
99th	84.1	85.7	86.9	87.6	87.8	87.7	87.4	87.1	86.9	86.8	86.6	86.4

BP indicates blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; and SBP, systolic blood pressure.

Table A4. Normal Values for Ambulatory BP (mm Hg) for Healthy Girls by Age

	Age, y											
BP Percentile	5	6	7	8	9	10	11	12	13	14	15	16
24-h SBP												
50th	102.8	104.1	105.3	106.5	107.6	108.7	109.7	110.7	111.8	112.8	113.8	114.8
75th	107.8	109.1	110.4	111.5	112.6	113.6	114.7	115.7	116.7	117.6	118.4	119.2
90th	112.3	113.7	115.0	116.1	117.2	118.2	119.2	120.2	121.2	121.9	122.6	123.2
95th	114.9	116.4	117.7	118.9	120.0	121.1	122.1	123.0	123.9	124.5	125.0	125.6
99th	119.9	121.5	123.0	124.3	125.5	126.5	127.5	128.4	129.0	129.5	129.7	130.0
Daytime SBP												
50th	108.4	109.5	110.6	111.5	112.4	113.3	114.2	115.3	116.4	117.5	118.6	119.6
75th	113.8	114.9	115.9	116.8	117.6	118.5	119.5	120.6	121.7	122.6	123.5	124.3
90th	118.3	119.5	120.6	121.5	122.4	123.3	124.3	125.3	126.4	127.2	127.9	128.5
95th	120.9	122.2	123.3	124.3	125.2	126.2	127.2	128.2	129.2	129.9	130.4	130.9
99th	125.6	127.1	128.4	129.6	130.6	131.7	132.7	133.7	134.5	135.0	135.2	135.4
Nighttime SBP												
50th	94.8	95.6	96.2	96.8	97.5	98.2	99.0	99.7	100.5	101.3	102.0	102.9
75th	100.2	101.1	101.8	102.5	103.2	104.0	104.7	105.2	105.8	106.3	106.8	107.3
90th	105.3	106.3	107.2	108.0	108.8	109.5	110.1	110.4	110.7	110.9	111.0	111.2
95th	108.4	109.6	110.6	111.5	112.3	113.0	113.5	113.6	113.7	113.6	113.5	113.5
99th	114.5	116.0	117.3	118.4	119.3	119.9	120.1	119.8	119.4	118.8	118.2	117.8
24-h DBP												
50th	65.5	65.6	65.8	65.9	66.0	66.2	66.4	66.6	67.0	67.2	67.5	67.7
75th	68.9	69.1	69.2	69.3	69.5	69.8	70.0	70.4	70.8	71.1	71.2	71.4
90th	72.1	72.2	72.3	72.4	72.6	72.9	73.2	73.7	74.1	74.4	74.6	74.7
95th	74.0	74.1	74.2	74.2	74.4	74.7	75.1	75.6	76.1	76.4	76.6	76.7
99th	77.6	77.6	77.6	77.6	77.7	78.0	78.4	79.1	79.7	80.1	80.4	80.5
Daytime DBP												
50th	72.6	72.6	72.4	72.2	72.0	71.8	71.8	72.1	72.4	72.8	73.2	73.5
75th	76.7	76.6	76.5	76.3	76.0	75.9	75.9	76.2	76.5	76.8	77.0	77.2
90th	80.2	80.2	80.0	79.8	79.5	79.3	79.4	79.6	80.0	80.2	80.3	80.3
95th	82.3	82.2	82.1	81.8	81.5	81.3	81.4	81.6	82.0	82.2	82.2	82.1
99th	86.1	86.0	85.8	85.5	85.2	85.0	85.0	85.3	85.6	85.7	85.6	85.4
Nighttime DBP												
50th	56.4	55.9	55.5	55.1	54.8	54.6	54.3	54.2	54.3	54.5	54.9	55.3
75th	61.1	60.6	60.1	59.7	59.4	59.2	58.9	58.7	58.7	58.7	58.8	59.1
90th	65.6	65.1	64.6	64.1	63.8	63.7	63.4	63.1	62.9	62.8	62.8	62.8
95th	68.5	67.9	67.4	66.9	66.6	66.5	66.2	65.9	65.6	65.4	65.3	65.2
99th	74.2	73.6	72.9	72.4	72.2	72.0	71.8	71.4	71.1	70.7	70.3	70.0
24-h MAP												
50th	77.5	78.0	78.4	78.8	79.2	79.6	80.2	80.9	81.5	82.2	82.7	83.0
75th	81.2	81.7	82.1	82.5	82.9	83.3	84.0	84.7	85.4	86.0	86.5	86.8
90th	84.6	85.0	85.4	85.7	86.1	86.5	87.1	87.9	88.6	89.2	89.7	89.9
95th	86.6	87.0	87.3	87.6	87.9	88.3	88.9	89.7	90.5	91.0	91.5	91.7
99th	90.5	90.8	90.9	91.0	91.2	91.6	92.2	93.0	93.7	94.2	94.6	94.8
Daytime MAP												
50th	83.7	83.9	84.0	84.1	84.2	84.4	84.7	85.2	85.9	86.5	87.1	87.7
75th	88.2	88.3	88.4	88.4	88.4	88.5	88.9	89.4	90.1	90.8	91.4	91.9
90th	92.2	92.2	92.2	92.1	92.0	92.1	92.4	93.0	93.6	94.3	94.8	95.4

(*Continued*)

Table A4. Continued

	Age, y											
BP Percentile	5	6	7	8	9	10	11	12	13	14	15	16
95th	94.6	94.5	94.4	94.2	94.1	94.2	94.4	95.0	95.6	96.2	96.8	97.3
99th	99.0	98.7	98.5	98.2	97.9	97.9	98.1	98.6	99.2	99.7	100.2	100.7
Nighttime MAP												
50th	68.7	68.8	68.8	68.8	68.9	69.1	69.3	69.6	70.1	70.6	71.2	71.8
75th	73.0	73.1	73.1	73.2	73.4	73.6	73.8	74.1	74.5	74.9	75.4	75.9
90th	76.9	77.0	77.1	77.2	77.4	77.6	77.8	78.0	78.3	78.6	78.9	79.3
95th	79.2	79.4	79.6	79.7	79.8	80.1	80.2	80.3	80.5	80.7	80.9	81.2
99th	83.8	84.1	84.2	84.3	84.5	84.6	84.7	84.6	84.6	84.6	84.6	84.7

BP indicates blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; and SBP, systolic blood pressure.

Disclosures

Writing Group Disclosures

Writing Group Member	Employment	Research Grant	Other Research Support	Speakers' Bureau/Honoraria	Expert Witness	Ownership Interest	Consultant/ Advisory Board	Other
Joseph T. Flynn	Seattle Children's Hospital	None	None	None	None	None	None	None
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David M. Maahs	University of Colorado, Denver	Abbott Diabetes Care†; Eli Lilly & Co†	None	None	None	None	None	None
Brian W. McCrindle	The Hospital for Sick Children	None	None	None	None	None	None	None
Mark Mitsnefes	Cincinnati Children's Hospital	None	None	None	None	None	None	None
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Justin P. Zachariah	Boston's Children's Hospital Heart Foundation/Harvard Medical School	None	None	None	None	None	None	None

This table represents the relationships of writing group members that may be perceived as actual or reasonably perceived conflicts of interest as reported on the Disclosure Questionnaire, which all members of the writing group are required to complete and submit. A relationship is considered to be "significant" if (1) the person receives $10 000 or more during any 12-month period, or 5% or more of the person's gross income; or (2) the person owns 5% or more of the voting stock or share of the entity, or owns $10 000 or more of the fair market value of the entity. A relationship is considered to be "modest" if it is less than "significant" under the preceding definition.

†Significant.

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Joshua Samuels	University of Texas Health Science Center at Houston	None	None	None	None	None	None	None

This table represents the relationships of reviewers that may be perceived as actual or reasonably perceived conflicts of interest as reported on the Disclosure Questionnaire, which all reviewers are required to complete and submit. A relationship is considered to be "significant" if (1) the person receives $10 000 or more during any 12-month period, or 5% or more of the person's gross income; or (2) the person owns 5% or more of the voting stock or share of the entity, or owns $10 000 or more of the fair market value of the entity. A relationship is considered to be "modest" if it is less than "significant" under the preceding definition.

†Significant.

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KEY WORDS: AHA Scientific Statements ■ adolescents ■ ambulatory blood pressure monitoring ■ blood pressure, high ■ child ■ guideline ■ hypertension