AHA Scientific Statement

Ambulatory Blood Pressure Monitoring in Children and Adolescents: Recommendations for Standard Assessment

A Scientific Statement From the American Heart Association Atherosclerosis, Hypertension, and Obesity in Youth Committee of the Council on Cardiovascular Disease in the Young and the Council for High Blood Pressure Research

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Introduction

Epidemiology of Hypertension

Throughout the world, 1 in every 4 adults suffers from hypertension,[1] a disease that contributes to 49% of ischemic heart disease and 62% of strokes worldwide. Inadequately controlled hypertension is currently the number one attributable risk for death across the globe.[2] Data from the Framingham Heart Study predict that 90% of people who are normotensive at age 55 years will go on to develop hypertension in their lifetime.[3] Hypertension in youth is also being diagnosed with increasing frequency.[4] The global obesity epidemic is leading to a shift in the blood pressure (BP) distribution toward increasing levels in children and adolescents.[5] This is particularly relevant because BP levels in the higher end of the distribution track into adulthood,[6] resulting in prehypertension, which marks individuals at high risk for progressing to sustained hypertension.[7]

Autopsy studies such as the Bogalusa Heart Study and the Pathobiologic Determinates of Atherosclerosis in Youth (PDAY) Study have demonstrated increased atherosclerosis at higher BP levels in youth.[8,9] Therefore, accurate assessment and management of BP is essential for the prevention of target organ damage.[10] Ambulatory BP monitoring (ABPM), which can more precisely characterize changes in BP throughout daily activities,[6] has been found to be superior to clinic BP (CBP) monitoring in predicting cardiovascular morbidity and mortality.[11] For this reason, ABPM is seeing more widespread use in evaluation for hypertension and risk of end-organ damage in adults.

In children and adolescents, ABPM is gaining acceptance as a useful modality for the evaluation of BP levels in both hypertension research and in the clinic setting.[12,13] This statement summarizes the current research and clinical applications of ABPM in children and adolescents and offers recommendations on implementation of ABPM in practice and interpretation of results. Because no outcome studies are yet available relating ABPM levels in children to hard outcomes such as myocardial infarction or stroke, these guidelines are expert opinion–driven and not evidence based.

ABPM and Risk for Target Organ Damage

In adults, ambulatory, rather than CBP, is correlated more strongly with left ventricular mass (LVM)[14] in both hypertensive and normotensive individuals.[15] Similar results have been published for children, with the relationship greatest between LVM and nighttime systolic BP (SBP)[14] and BP load.[16] A recent pediatric study using ABPM to confirm hypertension demonstrated a relationship between severity of BP elevation and odds for LVH.[17]

Similarly, increased carotid intima-media thickness (c-IMT), a risk factor for stroke,[18] is associated with ambulatory

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BP,[19] and the relationship between ABPM and c-IMT remains significant even after adjusting for CBP, suggesting that ABPM provides an independent contribution to risk stratification.[20] To the best of our knowledge, no studies in healthy children have examined the relationship between ambulatory BP levels and c-IMT, but hypertensive children do demonstrate a relationship between higher ABPM levels and thicker carotid arteries.[21,22] Furthermore, Sorof et al found that children with more significant abnormality in their ABPM pattern (increase in BP levels and the percentage of readings greater than the 95th percentile, or the BP "load") were more likely to have LVH. This may relate to an increased afterload induced by vascular abnormalities resulting in cardiac hypertrophy in hypertensive youth.[23] ABPM is also superior in identifying adults with increased arterial stiffness, whether measured in the carotid artery (ultrasound)[24] or aorta (pulse wave velocity)[25,26] and with decreased endothelial function (brachial flow–mediated dilation).[27] Few data are available in children, although one study of pediatric kidney transplant recipients found deterioration in carotid distensibility associated with higher daytime ambulatory SBP load.[28]

Ambulatory BP in adults is also more strongly correlated with renal damage (renal albumin excretion) than is CBP.[29] Albumin to creatinine ratio also relates most strongly to diastolic BP (DBP) variability, which can only be measured with ABPM.[30] Data relating ABPM to kidney damage in healthy children are less clear. One study found no relationship between ambulatory BP and either creatinine clearance or albumin excretion in hypertensive youth.[14] Another investigation found that nighttime ambulatory SBP did relate to creatinine clearance, but only in African American subjects.[31]

ABPM Is Superior to Self-Measurement of BP

Self-measurement of BP (SMBP) can be performed anywhere, not just at home, and has been suggested as an acceptable alternative in place of ABPM in adults.[32] To investigate whether SMBP values provide a feasible and reliable alternative to ABPM in differentiating true from white coat hypertension (WCH; see definition below) and in monitoring antihypertensive therapy in children, a recent study in 118 pediatric patients (age 3 to 19 years) with chronic renal failure compared ABPM, SMBP, and CBP measurements.[33] The data showed that SMBP was a valuable addition to CBP measurement, as it agreed with ABPM more closely and more consistently over the whole range of BP as compared with CBP alone. The addition of SMBP to CBP also offered a higher degree of diagnostic specificity than CBP alone. However, the diagnostic sensitivity reached by SMBP and CBP was only 81% as compared with ABPM as the reference method. Therefore, 1 of 5 children diagnosed as hypertensive by ABPM would have been missed, even when both CBP and SMBP were used in combination. In addition, the range of agreement of SMBP with ABPM, albeit narrower than that of CBP, was unacceptably wide.[33] Consequently, these data do not support the replacement of ABPM by SMBP.

Use of ABPM in Evaluation of Secondary Hypertension

Secondary hypertension is more common in children than in adults. Hypertension detected in very young children, or in children or adolescents with clinical signs that suggest systemic conditions and the diagnosis of stage 2 hypertension, are all suggestive of secondary hypertension. A number of findings on the history and physical examination may be indicative of the etiology of secondary hypertension.[34] Ambulatory BP readings may be useful in differentiating primary from secondary hypertension, as adolescents with secondary hypertension have been shown to manifest greater nocturnal SBP loads and greater daytime and nocturnal DBP loads than children with primary hypertension.[35] These patterns were highly specific for differentiating between essential (primary) and secondary types of hypertension.[35] Although confirmatory studies in this area are needed, the potential use of ABPM in differentiating between primary and secondary hypertension was also suggested in a study from the Czech Republic, which demonstrated decreased nocturnal dipping in children with secondary hypertension.[36]

White Coat Hypertension

WCH is another clinical condition in which ABPM data are critical. WCH is defined as BP levels that are the 95th percentile or higher when measured in the physician's office or clinic but are completely normal (average BP <90th percentile) outside of a clinical setting. Office measurements often fail to account for this transient, stress-induced elevation of BP. In a recent study, Stergiou et al found that office-home BP difference varied substantially by age, diminishing substantially after 12 years of age.[37] This makes diagnosis of hypertension more challenging in younger children and may explain the varied prevalence of WCH reported in the pediatric literature. In one study of 18 male adolescent athletes, 88% of those with elevated pre–sports participation BP readings had WCH after ABPM.[38] In contrast, another study of 67 otherwise healthy children referred to a hypertension clinic found that only 22% with office hypertension had WCH,[39] whereas a recent study of 212 similar hypertension clinic patients (mean age, 13.5 years) found the prevalence of WCH to be 32.6%.[40] Clearly, more data on the prevalence of this phenomena across ages in different demographic groups are needed.

There appears to be a strong, direct correlation between the presence of WCH and office BP levels, with the likelihood of WCH decreasing as office BP increases.[41,42] One group of investigators has suggested that ABPM could be limited to only those children with average office BP 1% to 10% above the Task Force 95th percentile, because those with more significant elevation of office BP (>10% above the 95th percentile) were infrequently found to have WCH, as they were more likely to be true hypertensives.[42]

Continued follow-up for patients exhibiting the WCH pattern may be necessary. Although adult studies find that patients with WCH have lower LVM than those with sustained hypertension, their cardiac mass is higher than that of normal controls.[43] Furthermore, other forms of target organ damage, such as endothelial dysfunction[44] and increased

c-IMT,[45] are associated with WCH and may account for the increase in adverse cardiovascular disease outcomes noted with this condition.[46] Data in children are sparse, but youth with WCH have been shown to have greater body mass index and a tendency toward elevated LVM index, strengthening the indications for ABPM follow-up of WCH.[47,48]

Masked Hypertension

Another condition that may be uncovered with ABPM is masked hypertension, defined as normal CBP but elevated ambulatory levels. The prevalence of this condition is not known, with estimates ranging from 5.7% in an unselected group of 592 children[49] to a high of 9.4% in a study of 85 consecutive patients referred for suspected hypertension.[47] Masked hypertension may be suspected when multiple primary care providers report hypertension, yet resting BP levels are less than the 95th percentile in the hypertension clinic or the clinical presentation (ie, LVH) seems inconsistent with CBP. In adults, masked hypertension has been associated with an increased cardiovascular (CV) risk[50] and with progression of chronic kidney disease.[51] In children, it is associated with progression to sustained clinic hypertension[49] and higher LVM.[47] Although carefully conducted home BP monitoring could possibly be used to identify masked hypertension, ABPM is a superior technique and is considered the gold standard for evaluation of both WCH and masked hypertension.

Prehypertension

ABPM may be particularly useful in children with office BP within 20% of the 95th percentile.[12] In these patients, ABPM can be very helpful in stratifying risk for target organ damage, because even with normal average ABPM values, increased BP variability is associated with target organ damage in adults.[52] This may be especially relevant if there is a strong family history of hypertension, because BP variance is under substantial genetic control. Twin and adoptive studies suggest that as much as 50% to 79% of BP variation is due to heredity,[53,54] although early perinatal events may also play a role.[55] In fact, one investigation found a relationship between impaired fetal growth and higher ambulatory SBP at 12 years of age, although the major independent determinate of ABPM was current body size.[56]

ABPM and Multiple CV Risk Factors

ABPM also offers a sensitive window to identify the burden of CV risk in youth with obesity and the metabolic syndrome. The specific link between central fat distribution in obese youth and elevated ABPM has been well described,[57,58] and total adiposity and insulin resistance have been correlated with a high prevalence of the nondipping phenomenon (inadequate decrease in BP at night) in youth.[59] Obstructive sleep apnea, which is found more often in obese children with insulin resistance, has also been associated with greater mean BP variability while awake and less nocturnal dipping, conditions that can be diagnosed only with ABPM.[60]

Children with prehypertension and adverse lifestyle habits may also benefit from evaluation with ABPM. Higher salt intake is associated with nondipper status in adolescents[61]; adult studies clearly demonstrate higher ambulatory BP levels in less active patients even after adjusting for age, body mass index, alcohol intake, and smoking.[62] Psychosocial stress may also adversely affect ABPM levels in children.[63] Similarly, use of stimulant medications, which also increase CV reactivity, result in higher heart rate (HR) and ambulatory BP values in children.[64] In a double-blind, randomized, crossover trial, a significantly higher HR×BP product or rate pressure product was found in children receiving active treatment for attention deficit hyperactivity disorder.[64] Elevated rate pressure product is an index of myocardial oxygen demand and is believed to be a proxy for silent myocardial ischemia in adults,[65] suggesting that stimulant medications may significantly increase metabolic demands on the CV systems of children being treated for attention deficit hyperactivity disorder. Caffeine is another widely consumed vasoactive drug, with more than 75% of US adults and adolescents consuming caffeine at least daily. For adolescents, the primary source of caffeine is soft drinks.[66] Caffeine consumption increases the BP of adolescents (measured by ABPM) with the greatest effect during the daytime, when sympathetic nervous system responses dominate BP control.[67] Clinicians should also probe patients for use of other substances that may affect BP, such as tobacco[68] and recreational drugs.

Methods for Collecting and Interpreting ABPM Data

Equipment

The most recent recommendations for BP measurement in adults published by the American Heart Association Council for High Blood Pressure Research include the use of ABPM and summarize findings published in previous national and international guidelines.[69] Although many of the recommendations for adults are applicable in children, substantial differences exist. First, careful selection of equipment for use in pediatric patients is essential for accurate recording. The ideal pediatric monitor is light, with the weight of available monitors ranging from 168 to 457 g. Monitors should be able to tolerate some subject movement without giving excessive error readings. Several of the devices are sold with cuffs designated for pediatric use. One device offers neonatal cuffs, but there are no validation studies available for their use. As with the measurement of BP at rest, cuff size is a critical variable in the accuracy of BP data. The width of the cuff used should be at least 40% of the mid-arm circumference.[4]

There are 2 different BP detection techniques in use, oscillometry[70] and auscultatory detection with microphone detection of Korotkoff sounds.[71] Of the 23 validated monitors currently available in the United States, 3 offer auscultatory detection in addition to oscillometry. One monitor offers ECG gating of the Korotkoff sounds to improve accuracy. There is still controversy relating to the Korotkoff sound (K4 or K5) that more accurately estimates DBP in children younger than 13 years of age,[72,73] so potential buyers/users should consult the manufacturer's specifications to determine which was used for validation. Furthermore, although published normal values for CBP[4] were obtained with an auscultatory technique, normative cut points for auscultatory ABPM

data in children are lacking. The largest cross-sectional study of ABPM in pediatrics to date used an oscillometric technique.[70] However, oscillometric devices are subject to the same potential errors as oscillometric devices used for casual BP measurement and, accordingly, have received lower ratings than auscultatory devices when evaluated according to the British Hypertension Society (BHS) protocol.[74] However, oscillometric devices usually have a lower percentage of erroneous readings than auscultatory devices and are easier to use than auscultatory devices. For these reasons, most centers performing ABPM in children and adolescents use oscillometric monitors.

The software offered with ambulatory BP monitors varies. At a minimum, monitors should be programmable to record every 15 to 20 minutes throughout the 24 hours. A report that can be customized to include pediatric reference data is ideal. Many laboratories have adapted their software to enter the 95th percentile ABPM cutoffs specified by Soergel et al[70] so that variables such as BP load can be calculated automatically for each child. Alternatively, cut points from the LMS-transformed data (based on age- and gender-specific estimates of the distribution median [M], coefficient of variation [S], and degree of skewness [L]) of Wühl et al can be used (see Appendix).[75]

Although dozens of monitors are available for purchase in the United States, few have been validated in children. A Web site (www.dableducational.org) has been created to try to provide a list of monitors that have undergone independent testing and have been shown to perform well enough to pass a national standard, such as the Association for the Advancement of Medical Instrumentation (AAMI) US National Standard[76] or the BHS Standard.[77] These standards, as well as others from Europe and Japan, are written to ensure that the monitors are accurate and durable. Currently, the International Standards Organization is developing a worldwide standard for automated BP monitors. Unfortunately, monitors that have not undergone validation testing and US Food and Drug Administration clearance can be sold in the United States.

Depending on the age of the subject, there are 2 reference standards against which device recordings may be compared, auscultation and intra-arterial catheter measurements. There is no consensus regarding the age at which Korotkoff sounds are audible and/or accurate. The AAMI Standard requires intra-arterial comparison data for children younger than 3 years of age. Either intra-arterial catheter measurement or auscultation may be used for subjects 3 years of age and older. Studies are under way to determine whether Korotkoff sounds could be reliably used in children younger than 3 years of age.

Ages Studied With ABPM

Although patients as young as 2 months have been studied using 24-hour ABPM, routine use is usually limited to children 5 to 6 years of age or older. Varda et al studied 97 healthy infants and toddlers aged 2 to 30 months using an oscillometric device and found usable recordings in 87% of subjects. One limitation noted was that the smallest available cuff was too large for some infants.[78] Gellermann et al obtained useable recordings in 77% of 101 children 3 to 6 years of age with and without renal disease and/or hypertension, with the ability to obtain useable recordings improving with age.[79] One half of the children diagnosed with high BP in the clinic setting were actually found to have normal ABPM,[80] emphasizing the use of ABPM in the diagnosis of hypertension. Children as young as 5 years of age were successfully included in a large school-based study in Germany that is widely quoted as a reference for normal oscillometric ABPM levels in children.[70] In England, O'Sullivan et al conducted a similar school study in 1121 children aged 6 to 16 years using a device that gave both oscillometric and auscultatory readings. Only 3 studies had to be excluded because fewer than 41 successful readings were obtained.[71] Finally, in a community sample of 300 healthy 10- to 18-year-olds using a similar auscultatory and oscillometric device, Harshfield et al reported that 84% of subjects had useable data.[81]

Frequency of ABPM Measurement

In published studies of ABPM, recording frequency varies from every 15 to 30 minutes for daytime or waking measures and from every 20 to 60 minutes for sleep or nighttime measures. Regardless of the frequency selected, most authorities on pediatric ABPM require at least 1 valid reading per hour, including during sleep, as a primary criterion for an interpretable study.

Accounting for Activity

An important concern in interpreting ABPM data in pediatric patients is how to divide the recording into sleep and wake times and how to account for variations in levels of physical activity. Daytime or awake time has been defined by different authors as beginning at 6 AM to 9 AM and ending at 9 PM to midnight. Sleep or nighttime has been defined as beginning at 9 PM until midnight and ending at anywhere from 6 AM to 9 AM. With this approach, readings obtained during transition times (ie, 6 AM to 8 AM and 10 PM to midnight) are discarded in the analysis.[70] Alternatively, self-reported sleep-wake times recorded in a diary have been used to divide an ABPM study into awake and asleep periods.[35,82] Finally, limited data suggest that actual sleep and wake times determined from an actigraph (a wrist device that senses motion in 3 dimensions) may be superior even to patient-initiated diary entry.[83]

Subject activity clearly influences both the success of ABPM studies and the BP readings themselves. Portman et al assessed ABPM in 99 healthy 5th graders, each of whom simultaneously recorded their activity and emotional state in a log.[84] The analysis showed that reliable and reproducible ABPM was feasible and that both ambulatory SBP and DBP varied by 10 mm Hg from lowest to highest level of activity. Jacoby et al studied 22 healthy children 4 to 17 years of age using an oscillometric ABPM unit for 24 hours of normal activity and during treadmill testing and stair-climbing activities.[85] Although all measures could be obtained at rest (19/19), only 68% of the values obtained during the treadmill testing (13/19) were valid at 300 kilopond meters and 36% (5/14) at 600 kilopond meters. Therefore, most hypertension specialists recommend that children undergoing ABPM

Table 1. American Heart Association Recommendation for the Upper Limit of Normal Ambulatory Blood Pressure in Adults

	Optimal	Normal	Abnormal
Daytime	<130/80	<135/85	>140/90
Nighttime	<115/65	<120/70	>125/75
24-Hour	<125/75	<130/80	>135/85

Reprinted from Pickering et al,[69] with permission from Lippincott Williams & Wilkins. Copyright 2005, American Heart Association.

should continue their normal activities but refrain from contact sports and vigorous exercise. Many recommend that patients hold their arm still during measurements.

Editing ABPM Data

Extreme outlier BP readings during ABPM are unlikely to be valid and are most likely artifact. However, it is sometimes difficult to decide reliably which BP values to discard, making editing a labor-intensive process that is prone to error and possibly also to observer bias. Given this, various automated approaches have been developed in an attempt to prevent these problems.[86] Winnicki et al investigated a number of automated editing methods using oscillometric ABPM in a cohort of 584 older adolescents and adults with mild hypertension.[87] Of the 6 methods studied, a modification of the Casadei method (see below) was found to have the most favorable variability, reproducibility, and validity and was, therefore, considered the method of choice.[87] Briefly, the method calls for a visual inspection for grossly inconsistent ABPM readings before interpretation. In this method, only measurements with SBP <240 and >70 mm Hg, DBP <140 and >40 mm Hg, HR <125/min, and pulse pressure >40 but <100 mm Hg with a DBP<SBP are accepted as valid. These settings can be programmed into the analysis software of most ABPM devices, thereby avoiding manual editing, which is not recommended. However, these settings may not be appropriate for younger children whose normal resting values for HR and BP may differ greatly from adults (see Adult ABPM Normals in Table 1).

Calculations Used in Interpretation

Interpretation of ABPM studies is usually based on a combination of criteria, including mean BP and BP loads. Mean SBP and DBP are calculated by the analysis software, which allows the user to define wake and sleep times, for calculation of average values for the entire 24-hour period, daytime and nighttime.[88] Mean BP levels are then compared with normative values to determine whether a subject's BP is normal or elevated. Either the seated resting BP values published in the Fourth Report on BP in Children[4] or ambulatory BP values such as those reported by the Heidelberg group (see Appendix)[70,75] theoretically can be used for this analysis. It is important to recognize that ambulatory BP measured with an oscillometric device tends to be higher than resting BP obtained with auscultation. In fact, Sorof et al found that in a population of 71 children with elevated office BP, hypertension was diagnosed in only 41% of patients using the higher ambulatory criteria, whereas the Fourth Report cut points would have led to 69% being diagnosed with hypertension ($P<0.001$).[74] Thus, although each of these criteria is useful and has its adherents, outcome studies will be necessary to resolve which is best in assessing risk or effect of treatment.[42]

BP load is defined as the percentage of valid ambulatory BP measures above a set threshold value, such as the 95th percentile of BP for age, gender, and height.[89] As for mean ABPM values, this can be assessed for the entire 24-hour period or for the awake and asleep periods separately. Loads in excess of 25% to 30% are typically considered elevated.[90] Loads in excess of 50% were demonstrated to be predictive of LVH in one pediatric study.[16] Most experts in pediatric ABPM use a combination of mean BP and BP load to categorize ABPM results as normal or abnormal. Usually this involves an elevated mean BP plus an elevated BP load. However, some patients with normal mean BP levels may have elevated BP loads. These patients may be truly hypertensive and at risk for target organ damage even if they do not fit into proposed criteria for analyzing ABPM studies (Table 2).[74] Furthermore, it is important to note that although no ABPM classification has ever been validated in outcome studies, criteria similar to the scheme presented in Table 2 are receiving increasing recognition by experts in pediatric hypertension.

Nocturnal Dipping

Abnormalities of circadian variation of BP and of BP variability have both been examined for their prognostic significance. Dipping refers to the physiological decline in SBP and DBP seen at night. Normal dipping is generally defined as a

Table 2. Suggested Schema for Staging of Ambulatory BP Levels in Children

Classification	Clinic BP*	Mean Ambulatory SBP†	SBP Load, %[70,75]
Normal BP	<95th percentile	<95th percentile	<25
WCH	>95th percentile	<95th percentile	<25
Masked hypertension	<95th percentile	>95th percentile	>25
Prehypertension	>95th percentile	<95th percentile	25–50
Ambulatory hypertension	>95th percentile	>95th percentile	25–50
Severe ambulatory hypertension (at risk for end-organ damage)	>95th percentile	>95th percentile	>50

Modified from Lurbe et al,[74] with permission.
BP indicates blood pressure; SBP, systolic blood pressure.
*Based on the National High Blood Pressure Education Program Task Force Standards.
†Based on ABPM values of Soergel et al or the smoothed values of Wühl.

≥10% decline in mean systolic and diastolic ambulatory BP levels from day to night ([mean daytime ABPM−mean nighttime ABPM]/mean day ABPM×100).[61] Blunted nocturnal dipping has been associated with nephropathy in patients with types 1[91] and 2 diabetes mellitus[82] and may be an early marker for renal deterioration. Racial differences also have been demonstrated in nocturnal dipping, with a difference in the relationship between body size and BP contributing to the elevated nighttime pressures seen in African American as compared with white youth.[92]

BP Variability

Another area where ABPM is useful is in the evaluation of BP variability. The activity of both short-term and long-term BP regulatory systems are needed to meet the changing physical and psychological demands of a normal day. ABPM provides an index of the regulation of these systems.[93,94] BP variability, which is most easily assessed by calculating the standard deviation of BP during a defined time period, may also have prognostic value. Increased BP variability has been demonstrated in obese children and is most likely related to increased sympathetic nervous system activation in obesity-related hypertension.[95] In adults, greater BP variability has been correlated with the development of hypertensive LVH.[52] Similar data are not available in children. Therefore, evaluations of BP variability in children should be conducted to determine the usefulness of this parameter in identifying patients at greater risk for target organ damage.

Reproducibility of ABPM

Like any test, the validity of ABPM is influenced by its reproducibility. Ward and Hansen[96] were among the first to demonstrate adequate correlation between mean ABPM measures in adults. Results from a later study of 45 hypertensive subjects were similar, with correlations between mean daytime, nighttime, and 24-hour ambulatory SBP and DBP ranging from 0.62 to 0.84 across 2 days recorded 2 to 3 weeks apart.[97] Several large-scale clinical studies in adults have confirmed that ABPM has greater reproducibility than casual BP. In the Hypertension and Ambulatory Recording Venetia Study, 2 monitoring sessions separated by 3 months were conducted; these demonstrated a very small difference in average daytime BP of just −0.8 mm Hg for SBP and −1.0 mm Hg for DBP.[98] Specific ABPM parameters such as nocturnal dipping also have been shown to be reproducible over time.[99]

As in adults, ABPM in children is considered to be more reproducible over time than casual BP measurements. However, one study recommended caution in using ABPM to classify children with mild BP elevation as hypertensive or normotensive as a result of markedly different results in 2 monitorings conducted 1 year apart.[100] Additionally, evaluation of diurnal variation may not be as reproducible as other ABPM parameters.[101] Similar findings have been demonstrated in pediatric renal transplant recipients.[102] On the other hand, the reproducibility of ABPM has been used to characterize the changes in BP over time in adolescents by Harshfield et al, who reported 2-year stabilities of resting and ambulatory BP in 197 youths ranging from 0.65 to 0.75.[103] Most recently, Wang et al[104] demonstrated the reliability of ambulatory BP in a longitudinal study; most clinicians experienced with the use of ABPM believe the technique, when applied consistently, demonstrates adequate reproducibility for longitudinal interpretation.

Applying the Device

Proper education of the personnel who apply ambulatory monitors is essential to maintain the functionality of the equipment, minimize measurement errors, and obtain valid, reliable, and reproducible BP data. Providers should be instructed to launder the cloth covers for the BP cuffs between patients and to clean the hardware with disinfecting wipes. Education should also include how the specific monitor functions, individual goals for the ABPM, and application of the monitor. A standardized approach should be used, including preparation of equipment, initializing and applying the monitor, providing patient teaching/instructions, and downloading the data. Points of emphasis include reviewing the patient history for any apparent contraindications to ABPM (severe clotting disorders or rhythm disturbances), selection of the appropriate size cuff, and application to the child's nondominant arm.[4]

Pediatric patients and their parents need to be educated regarding how to operate the monitor (how to stop a reading if there is excessive discomfort and what to expect when a reading is being obtained). The need to keep the arm still during BP readings should be emphasized. Often, BP is recorded every 20 minutes throughout the day and every 30 minutes during sleep. Although removal of the monitor is not recommended, 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. Safe handling of electronic equipment should be stressed, with specific instructions not to allow the monitor to get wet.

Although serious adverse events such as arm vein thrombosis have not been reported in children, mild sleep disturbances have been documented.[105] Contraindications to ABPM may include atrial fibrillation, coagulation disorders, and, for some brands of equipment, latex allergy. Patients should be instructed to report to their physician petechiae, bruises, and any apparent allergic reaction. Children should also be instructed not to turn off the device unless the cuff pumps to an extremely uncomfortable pressure. This may signal kinked tubing and would require termination of that reading. Although activities of daily living are to be encouraged, swimming and contact sports (ie, wrestling, football) are generally discouraged during ABPM. Finally, children should maintain a journal/log book indicating times and duration of activities and events that may influence BP measures, including stressful situations and light exercise. At a minimum, the log book should include the child's sleep and wake times.

Distribution of BP Values on the Basis of ABPM

Normative Data for ABPM

Knowledge of the average distribution of a parameter in a population is essential for differentiating and quantifying

abnormalities that may be associated with pathophysiological processes. As with most measurements in pediatrics, normal values for ABPM must be adjusted for body size (as a surrogate for maturational age)[92] and gender.[106] Where sufficient data are available, evaluation specific for race or ethnic differences should be performed.[107,108] Unfortunately, only limited large population-based cross-sectional studies have been performed using ABPM in healthy children, and few have truly proportional representation across age, race, body size, and gender.

Lurbe et al studied 241 healthy children aged 6 to 16 years and analyzed ABPM variables according to 3 age groups by gender.[109] Percentile-based values were reported for mean values, nocturnal decrease, day to night ratio (dipping), and pressure load. It was noted that the 95th percentile for BP load (percent of reading above the 95th percentile for casual readings) was 39% for systolic and 26% for diastolic ABPM readings. Therefore, many investigators define elevated loads as those exceeding 25% to 30%. Harshfield et al studied 200 healthy children aged 10 to 18 years and provided normal values based on ethnicity as well.[81] O'Sullivan et al studied 1121 healthy children aged 6 to 16 years.[71] Percentiles for height categories were provided. In addition, they divided the daytime period into times at school and home; no important differences were noted. Reichert et al studied 564 healthy children aged 9 to 13 years. They noted that daytime ABPM levels were higher than resting measurements, likely because of increased activity during ambulatory recordings. Therefore, they concluded that evaluation of ABPM variables with normal cut points from casual readings could result in errors in classification of ABPM levels.[110] In a similar study, ABPM was performed on 168 children and adolescents aged 6 to 20 years.[111] Presence of hypertension was determined using both the Fourth Report[4] values and pediatric ambulatory normative data.[70] The authors concluded that use of the Fourth Report criteria to classify ABPM values would lead to overdiagnosis of daytime hypertension and underdiagnosis of nighttime hypertension.[111]

Data regarding younger children are also available. Gellermann et al studied 61 healthy children younger than 6 years of age.[79] In addition to the usual nighttime decrease, a second decrease was noted during bed rest after lunch. This is in contrast to the single nighttime decrease in older children.[112] Varda and Gregoric studied 97 infants and toddlers aged 2 to 30 months.[78] They noted no differences in ABPM values in relation to gender. There was also a smaller degree of nighttime dipping.

Only one study has provided normative data in such a manner that standardized scores may be derived. Wühl et al studied 949 healthy white German schoolchildren aged 5 to 20 years.[75] The LMS method of analysis was used to account for the non-Gaussian distribution of values according to age and gender regarding the skewness (L), median (M), and coefficient of variation (S).[113] Normalized mean 24-hour SBP scores were independently related to standard deviation scores of height, body mass index, and heart rate, whereas DBP scores were only weakly related to body mass index scores. They noted that, in contrast with published reference values for casual measurements,[114-116] mean daytime SBP and DBP measurements were higher, with nighttime measurements lower across ages. Although both ABPM and casual measurements of SBP increased with age, casual measurements of DBP increased with age, whereas ABPM measurements did not (Figure). Upper-percentile values are provided in Table 3, with the full tables published in the Appendix.

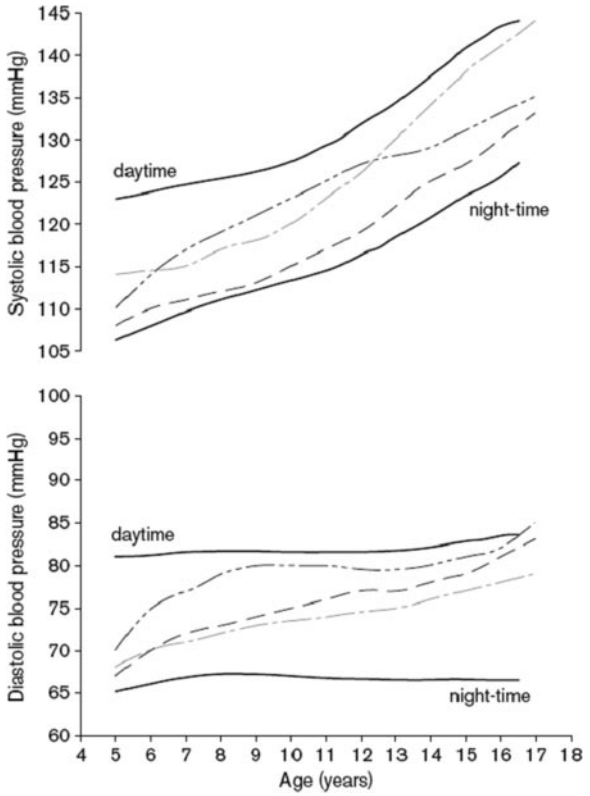

Figure. Comparison of the 90th percentile of systolic and diastolic casual blood pressure (BP) reference data with daytime and nighttime ambulatory BP monitoring data.[75] *Solid lines represent ambulatory BP data from Wühl et al[75]; – –, National Institutes of Health Third Report resting BP data,[116] European resting BP data[115]; and – · · –, Italian resting BP data.[140]

Definition of Hypertension

The definition of resting hypertension for pediatric patients is outlined in the National High Blood Pressure Education Program Working Group Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents.[4] In an effort to be consistent with adult guidelines (JNC 7),[117] a staging system was introduced. Clinicians experienced with the use of ABPM in children have recently proposed a staging schema for defining the severity of ABPM levels that includes mean ABPM levels and measures of BP load (Table 2).[74] These experts used the largest available cross-sectional study of ABPM in children[70] in their definition of ambulatory hypertension, acknowledging that it was limited to a single ethnicity. A modification of their proposed scheme that is consistent with staging of resting BP levels can be found in Table 2. Unfortunately, this system may not be helpful in categorizing all patterns of ABPM seen in children. Occasionally, a pediatric patient may demonstrate normal CBP, elevated or normal daytime ambulatory BP, but increased BP load, while maintaining sufficient nocturnal dipping to lower average ABPM values to within the normal range. Just as an exaggerated BP response to stress is

Table 3. 90th and 95th Percentiles of Mean Daytime and Nighttime Ambulatory Systolic and Diastolic BP, Stratified According to Gender and Height

	Systolic BP, mm Hg				Diastolic BP, mm Hg			
	Day		Night		Day		Night	
Height, cm	90th pct	95th pct	90th pct	95th pct	90th pct	95th pct	90th pct	95th pct
Boys								
120	120.6	123.5	103.7	106.4	79.1	81.2	61.9	64.1
125	121.0	124.0	104.9	107.8	79.8	81.3	62.2	64.3
130	121.6	124.6	106.3	109.5	79.3	81.4	62.4	64.5
135	122.2	125.2	107.7	111.3	79.3	81.3	62.7	64.8
140	123.0	126.0	109.3	113.1	79.2	81.2	62.9	65.0
145	124.0	127.0	110.7	114.7	79.1	81.1	63.1	65.2
150	125.4	128.5	111.9	115.9	79.1	81.0	63.3	65.4
155	127.2	130.2	113.1	117.0	79.2	81.1	63.4	65.6
160	122.2	132.3	114.3	118.0	79.3	81.3	63.6	65.7
165	131.3	134.5	115.5	119.1	79.7	81.7	63.7	65.8
170	133.5	136.7	116.8	120.2	80.1	82.2	63.8	65.9
175	135.6	138.8	119.1	121.2	80.6	82.8	63.8	65.9
180	137.7	140.9	119.2	122.1	81.1	83.4	63.8	65.8
185	139.8	143.0	120.3	123.0	81.7	84.1	63.8	65.8
Girls								
120	118.5	121.1	105.7	109.0	79.7	81.8	64.0	66.4
125	119.5	122.1	106.4	109.8	79.7	81.8	63.8	66.2
130	120.4	123.1	107.2	110.6	79.7	81.8	63.3	66.0
135	121.4	124.1	107.9	111.3	79.7	81.8	63.4	65.8
140	122.3	125.1	108.4	111.9	79.8	81.8	63.2	65.7
145	123.4	126.3	109.1	112.5	79.8	81.9	63.0	65.6
150	124.6	127.5	109.9	113.1	79.9	81.9	63.0	65.5
155	125.7	128.5	110.6	113.8	79.9	81.9	62.9	65.5
160	126.6	129.3	111.1	114.0	79.9	81.9	92.8	65.4
165	127.2	129.8	111.2	114.0	79.9	81.9	62.7	65.2
170	127.5	130.0	111.2	114.0	79.9	81.8	62.5	65.0
175	127.6	129.9	111.2	114.0	79.8	81.7	62.3	64.7

BP indicates blood pressure; pct, percentile.
Adapted from Wühl et al,[75] with permission from Lippincott Williams & Wilkins.

associated with progression to sustained hypertension,[118] many clinicians believe that this ABPM pattern marks an individual who should undergo periodic review of BP levels.

Recommendations for Standard Assessment of ABPM in Children

- Indications where ABPM may prove useful include:
  - Confirming the diagnosis of hypertension
    - To determine whether true hypertension or WCH exists
    - To evaluate for the presence of masked hypertension when there is clinical suspicion of hypertension but normal casual measurements
  - Assessing BP variability
    - To determine dipping status in patients at high risk for end-organ damage
    - To assess the severity and persistence of BP elevation (see Table 3)
  - Evaluating the effectiveness of drug therapy for hypertension
    - To evaluate for apparent drug-resistant hypertension
    - To determine whether symptoms can be attributed to drug-related hypotension
  - Evaluating BP levels more accurately in chronic pediatric diseases associated with hypertension (Table 4)
- An ABPM device suitable for use in children should be selected.
  - Only devices that have been validated according to AAMI or BHS standards should be used.
  - An oscillometric or auscultatory technique can be used.
  - Appropriate cuff sizes as recommended in the Fourth Report[4] 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 an arteriovenous fistula).
  - Devices should be programmed to record BP every 20 to

Table 4. Pediatric Indications for Use of ABPM

Condition	Benefit
Diabetes	Tighter control to reduce renal albumin excretion[127,128]
Coarctation of the aorta	Rule out masked hypertension[129–131]
Liver or heart transplant recipient	Rule out masked hypertension[132,133]
Renal transplant recipient	Evaluate for nocturnal hypertension[134]
Polycystic ovary disease gene carriers	Identification of sustained hypertension early[135]
William syndrome	Alterations in large arteries increase risk for hypertension[136,137]
Turner syndrome	Tight control of BP to reduce aortic root dilation with bicuspid aortic valve[138]
Neurofibromatosis 1	Identify subjects needing further study to rule out renal artery stenosis[139]

ABPM indicates ambulatory blood pressure monitoring; BP, blood pressure.

30 minutes during waking hours and every 30 to 60 minutes during sleep hours.
  - After application, BP measured with the device should be compared with resting, clinic BP using the same technique as used by the ambulatory device (auscultatory or oscillometric).
    - Agreement of an average of 3 clinic and 3 ambulatory BP levels within 5 mm Hg will be considered adequate calibration. Cuff placement and proper device function should be verified for values falling outside of this range.
    - Wide disagreement between resting and ambulatory device measurements of DBP may occur with the use of auscultatory ABPM devices that lack pediatric settings that adjust for the often larger K4–K5 differences seen in younger children. If this occurs, an oscillometric device may be preferred or interpretation may be restricted only to the values for SBP.
  - Patients should be instructed to record antihypertensive medication administration, activity, sleep, and wake times in a diary.
- 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 HR for the patient's age.
  - Values falling outside of the following range should be discarded:
    - SBP 60 to 220 mm Hg
    - DBP 35 to 120 mm Hg
    - HR 40 to 180 beats per minute
    - 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.
- Standard calculations should be reported.
  - Mean ambulatory SBP and DBP during the 24-hour period, daytime, and nighttime periods
  - BP load (percentage of readings above the ambulatory 95th percentile of Soergel[70] or the smoothed data of Wühl, see Appendix)[75] should be calculated.
  - Dipping (percent day-night difference) should be determined ([mean daytime SBP−mean nighttime SBP]/mean daytime SBP×100); repeat for DBP.
- ABPM levels should be interpreted using appropriate pediatric normative data.
  - ABPM values should be compared with gender- and height-specific data obtained in large pediatric populations using similar techniques (see Appendix)[70,75] and not to resting BP levels.[4]
  - A suggested schema for staging ABPM is included in Table 2. It should be noted that these are consensus rather than evidence-based recommendations because there is a lack of pediatric outcomes data.
  - The diagnosis of hypertension can be made with significant abnormalities in ambulatory BP levels and loads occurring during the daytime, nighttime, or the entire 24-hour period.

Conclusions

Usefulness of ABPM in Measuring Effect of Interventions

There is convincing evidence in adults that adverse health habits, such as sedentary lifestyle, high-salt diet, and psychosocial stress, increase risk for developing hypertension. For this reason, pediatric guidelines advocate adoption of a healthy pattern of exercise favoring ideal body weight and a diet that is low in sodium and rich in potassium, calcium, and magnesium.[4] No diet, exercise, or combined interventions in hypertensive children have been evaluated to date with ABPM. However, in healthy youth, ABPM has been used to demonstrate significantly improved daytime SBP and DBP, along with lower HR, as a result of a simple breathing meditation intervention.[119]

Pharmacological Interventions

ABPM is often used in randomized clinical trials of BP-lowering drugs in adults to compare antihypertensive efficacy between therapeutic agents and to assess 24-hour BP control,[120] including improvement in nocturnal dipping with treatment.[121] Use of ABPM, therefore, provides additional information on circadian BP control that may alter selection and dosage of an antihypertensive medication. Furthermore, ABPM aids in correct classification of true hypertensives and controls and can be useful in ruling out a placebo effect as the explanation for therapeutic efficacy of a medication. Increasing numbers of randomized clinical trials of antihypertensive medications in children have been completed since passage of the Food and Drug Modernization Act of 1997.[122] However, ABPM has not yet been applied successfully to large-scale pharmacological trials in children. Although 2 Food and Drug

Modernization Act–related trials did incorporate ABPM into the trial designs, in both cases, investigators were unable to convince most study participants to undergo ABPM as part of the trials (Joseph T. Flynn, MD, MS, written communication, April 5, 2007).

Some experience with ABPM in assessing drug treatment in children has come from single-center case series. In one study, ABPM showed that some children thought to have well-controlled hypertension were actually persistently hypertensive, prompting increases in antihypertensive therapy.[13] In a small study of 14 children with renal hypertension, ABPM readings proved that treatment with ramipril was effective in lowering 24-hour average BP while also improving nocturnal dipping.[123] In a separate trial of 21 adolescents, ABPM was used to demonstrate the efficacy of amlodipine, a calcium channel blocker, as an effective once-daily antihypertensive agent.[124] Despite the paucity of data on the use of ABPM in monitoring hypertensive treatment in children, a recent survey of 438 North American pediatric nephrologists found that the majority favor use of ABPM for this purpose.[125] The increasing clinical use of ABPM is likely to spur further interest in the use of ABPM in pediatric antihypertensive trials.

Future Directions

It is clear that ABPM is useful in the evaluation of BP levels in youth. However, there is a need for larger data sets, including normative data in healthy nonwhite populations. Information relating ABPM to well-defined or intermediate end points in youth with sustained hypertension is also lacking. Additional data will also be important in evaluating the efficacy of ABPM in measuring effects of interventions and reversal of target organ damage. Further research is also needed in the development of standardized protocols appropriate for validation of monitors used in pediatric patients. Finally, although adult studies suggest that significant cost savings can result from the use of ABPM versus conventional CBP measurement to classify and monitor hypertensive patients,[126] similar cost-effectiveness analyses have not yet been performed in children.

Appendixes

Ambulatory Blood Pressure Values for Healthy White Children. Adapted from Wühl et al,[75] with permission from Lippincott Williams & Wilkins.

Appendix A. Normal Values for Ambulatory Blood Pressure (mm Hg) for Boys by Height

	Height (cm)													
BP Percentile	120	125	130	135	140	145	150	155	160	165	170	175	180	185
24-hour 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-hour 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-hour 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
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	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	71.9	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	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	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	88.1	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; SBP, systolic blood pressure; DBP, diastolic blood pressure; and MAP, mean arterial pressure.

Appendix B. Normal Values for Ambulatory Blood Pressure (mm Hg) for Girls by Height

	Height (cm)											
BP Percentile	120	125	130	135	140	145	150	155	160	165	170	175
24-hour 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-hour 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
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-hour 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; SBP, systolic blood pressure; DBP, diastolic blood pressure; and MAP, mean arterial pressure.

Appendix C. Normal Values for Ambulatory Blood Pressure (mm Hg) for Boys by Age

	Age, years											
BP Percentile	5	6	7	8	9	10	11	12	13	14	15	16
24-hour 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
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-hour 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-hour 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; SBP, systolic blood pressure; DBP, diastolic blood pressure; and MAP, mean arterial pressure.

Appendix D. Normal Values for Ambulatory Blood Pressure (mm Hg) for Girls by Age

	Age, years											
BP Percentile	5	6	7	8	9	10	11	12	13	14	15	16
24-hour 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-hour 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-hour 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
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; SBP, systolic blood pressure; DBP, diastolic blood pressure; and MAP, mean arterial pressure.

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*Modest.

†Significant.

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*Modest.

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KEY WORDS: AHA Scientific Statements ■ children ■ hypertension ■ blood pressure ■ pediatrics

Ambulatory Blood Pressure Monitoring in Children and Adolescents: Recommendations for Standard Assessment: A Scientific Statement From the American Heart Association Atherosclerosis, Hypertension, and Obesity in Youth Committee of the Council on Cardiovascular Disease in the Young and the Council for High Blood Pressure Research

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